DOE/RW-0477

Nuclear Waste Policy Act
(Section 113)

Site Characterization Progress Report: Yucca Mountain, Nevada

October 1, 1994 - March 31, 1995

Number 12

August 1995

U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Washington, DC 20585

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Department of Energy
Washington, DC 20585

August 31, 1995

NOTE TO READERS:

A great deal was accomplished during the reporting period that directly advanced understanding and characterization of the proposed site. Implementation of the Program Plan has allowed the Office of Civilian Radioactive Waste Management to make measurable and significant progress toward determining whether Yucca Mountain, Nevada is a technically suitable site for a geologic repository. The first technical basis report supporting the assessment of three 10 CFR 960 siting guidelines was submitted to the National Academy of Sciences for peer review, representing an important step toward a 1998 assessment of technical site suitability.

Another important milestone during this period was the submission of the U.S. Department of Energy's License Application Annotated Outline to the U.S. Nuclear Regulatory Commission. This outline presents the framework and identifies the specific information needed to develop the license application for a geologic repository at Yucca Mountain.

Excavation of the Exploratory Studies Facility progressed to about 545 meters (1802 feet) during this reporting period. Progress was slow during initial testing of the machine and excavation through the Bow Ridge Fault. Modifications to both operating procedures and the tunnel boring machine have since resulted in improved excavation rates and the tunnel was at 1421 meters (4660 feet) and ahead of schedule at the time of publication.

Directly responsible for progress during this reporting period was the level of funding for the program. Most of the additional funding received for fiscal year 1995 was allocated to the Yucca Mountain Site Characterization Project. This funding level allowed significant progress toward key objectives that were defined in the Program Plan.

Sincerely,

Daniel A. Dreyfus, Director
Office of Civilian Radioactive
Waste Management

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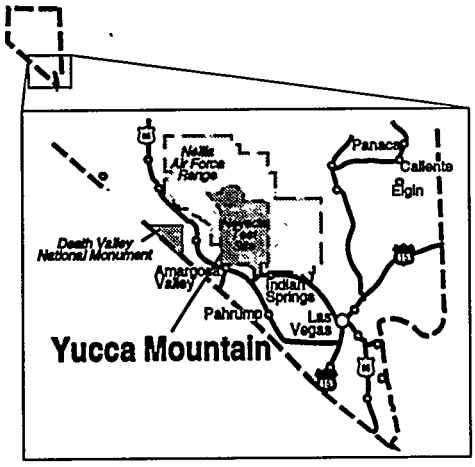
Executive Summary

Site characterization activities at Yucca Mountain, Nevada, from October 1, 1994, through March 31, 1995. Twelfth in a series reported in accordance with the requirements of Section 113(b)(3) of the Nuclear Waste Policy Act of 1982, as amended, and 10 CFR 60.18(g).

During the first half of fiscal year 1995, most activities at the Yucca Mountain Site Characterization Project were directed at implementing the Program Plan developed by the Office of Civilian Radioactive Waste Management. The Plan is designed to enable the Office to make measurable and significant progress toward key objectives over the next five years within the financial resources that can be realistically expected.

Activities this period focused on the immediate goal of determining by 1998 whether Yucca Mountain, Nevada, is technically suitable as a possible site for a geologic repository for the permanent disposal of spent nuclear fuel and high-level radioactive waste. Work on the Project advanced in several critical areas, including programmatic activities such as issuing the Program Plan, completing the first technical basis report to support the assessment of three 10 CFR 960 guidelines, developing the Notice of Intent for the Environmental Impact Statement, submitting the License Application Annotated Outline, and beginning a rebaselining effort to conform with the goals of the Program Plan. Scientific investigation and analysis of the site and design and construction activities to support the evaluation of the technical suitability of the site also advanced. The following sections highlight accomplishments in each major area. Specific details relating to all Project activities and reports generated are presented in the main body of the report.



Location of Yucca Mountain Site

Programmatic Activities

To support the implementation of the Program Plan, the Yucca Mountain Site Characterization Office refocused project planning and licensing activities to ensure efficient, measurable

progress toward determining whether Yucca Mountain is suitable for a permanent geologic repository.

Program Plan Goals

FY 1998-

- Evaluate technical suitability of Yucca Mountain
- Draft Environmental Impact Statement

FY 2000-

- Determine overall suitability of Yucca Mountain
- Final Environmental Impact Statement
- Site Recommendation Report

FY 2001-

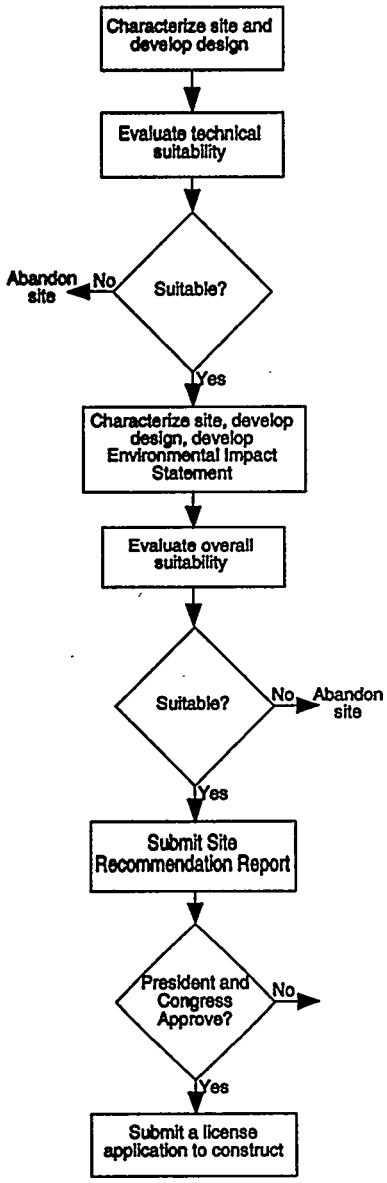
- License Application

Project Planning

On December 19, 1994, the Office of Civilian Radioactive Waste Management issued its Program Plan to the U.S. Nuclear Regulatory Commission, other stakeholders, and the public. The three-volume Program Plan describes the goals, activities, and schedule milestones in the major product areas of the Program. Volume I presents an overview of the integrated waste management system. Volume II outlines the strategies established in the Program Plan for site suitability, the National Environmental Policy Act process, and repository licensing. The primary basis for Volume II of the plan is the draft Five-Year Plan for the Yucca Mountain Site Characterization Office, developed during the last reporting period. In the new Program Plan, site characterization activities are tied to these three major Project elements. Volume III addresses Civilian Radioactive Waste Management System storage and transportation activities.

By implementing the Program Plan, the Office of Civilian Radioactive Waste Management will evaluate the technical suitability of the Yucca Mountain site by the end of fiscal year 1998, using a step-wise assessment of compliance with each 10 CFR Part 960 siting guideline, or group of guidelines. In this evaluation, the Office will ascertain whether the postclosure guidelines of 10 CFR Part 960 and those preclosure guidelines related to radiological safety and technical feasibility are satisfied. The 1998 evaluation will be supported by a Total System Performance Assessment. The Department's determination of overall site suitability is scheduled for the end of fiscal year 2000. The evaluation will use information

developed to support the National Environmental Policy Act process and the Draft Environmental Impact Statement to be released for public comment in 1998, as well as the preclosure guidelines related to Environmental Quality, Socioeconomic Impacts, and Transportation. Also in 2000, the U.S. Department of Energy expects to deliver a Final Environmental Impact Statement and, if the site is found suitable, a Site Recommendation Report to the President. In the following year, if the President and Congress approve the site recommendation, the Department will submit a License Application to the Commission to construct the repository.



Decision process flowchart

Because of the changes reflected in the Program Plan and increasing site knowledge, some portions of the detailed program outlined in the Site Characterization Plan have changed or are changing. To report these changes, the Project developed two matrixes that (a) map the Site Characterization Plan sections to the Annotated Outline of the License Application and (b) identify the requirements or planning document for each item. These matrixes have been included in Appendix A of this Progress Report.

During this reporting period, the Office of Civilian Radioactive Waste Management completed the fiscal year 1995 technical implementation plans for most of the Project Work Breakdown Structure elements. Activities in these plans implement the Program Plan. In addition, the Fiscal Year 1995 Project Implementation Plan was completed and submitted to the Commission. This plan is an integrated presentation of the year's activities and describes how they support Project goals.

The Project began a rebaselining effort during this reporting period that will make existing schedules, milestones, and activities consistent with those outlined in the Program Plan.

As part of this effort, a preliminary integrated Project Summary Schedule was developed that enhanced the schedules provided in the Program Plan. This schedule also incorporates the results of more detailed planning and discussions held during the Yucca Mountain Technical Program Review in February 1995.

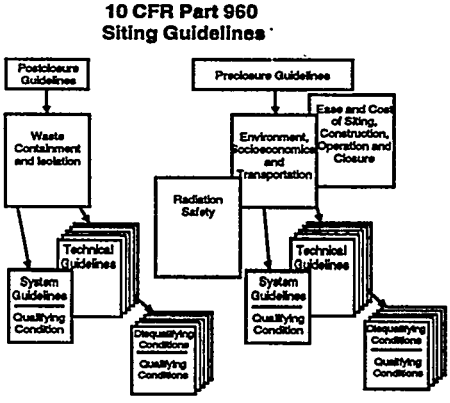
Regulatory Activities

The first technical basis report supporting the Program Plan approach to site suitability was issued. This report supports the assessment of compliance with the guidelines on Surface Characteristics, Preclosure Hydrology, and Erosion.

During this reporting period, the Office of Civilian Radioactive Waste Management established its process for evaluating site suitability. The Office held several public workshops on the process in 1994. A final explanation for this process was distributed in December 1994 and is documented in the "Process for Evaluating the Suitability of the Yucca Mountain Site for Development as a Repository for High-Level Radioactive Waste and Spent Nuclear Fuel."

The first technical basis report supporting the Office's evaluation of suitability was completed by the Project. The report for surface processes summarizes the data and analyses to support assessment of compliance with the guidelines for Surface Characteristics, Preclosure Hydrology, and Erosion.

In addition, the Office of Civilian Radioactive Waste Management revised elements of its technical site suitability process, mainly to advance the schedule presented in the Program Plan for preparing the technical basis reports. To that end, two previously scheduled reports for Preclosure Rock Characteristics and Geochemistry/Postclosure Rock Characteristics were combined into one report: the Geochemistry/Rock Characteristics Technical Basis Report, which will also include the Human Interference guideline. This combination plus rescheduling allows time for incorporating additional data from the Exploratory Studies Facility. Because



Structure of the U.S. Department of Energy Siting Guidelines

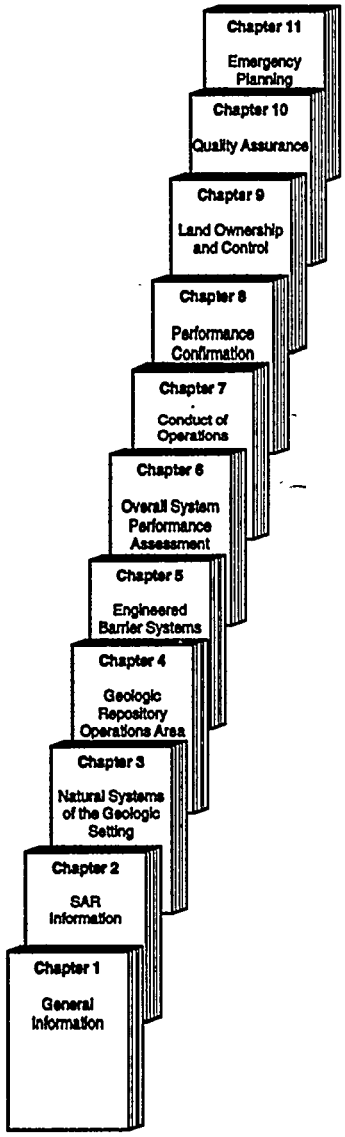
much of the information supporting the technical basis report for Preclosure Radiological Safety can be made available earlier, the Project is examining the possibility of issuing this report ahead of the schedule presented in the Program Plan.

A draft Notice of Intent for the Environmental Impact Statement was completed and is in review.

Environmental compliance activities during the reporting period focused on the Environmental Impact Statement for the Yucca Mountain repository. A draft Notice of Intent was completed and is currently under review. In addition, several planning documents were drafted, including a scoping plan, a management plan, and a public involvement plan.

Also during this reporting period, Revision 0 of the License Application Annotated Outline was submitted to the Commission. This revision marks the transition from a Management and Operating Contractor document to a Department of Energy document. This revision of the outline incorporates a licensing strategy consistent with the Program Plan and the multi-purpose canister concept. The outline is consistent with the systems-based approach provided in the Commission's Draft Regulatory Guide. Future revisions of the Annotated Outline will incorporate guidance provided in the Commission's License Application Review Plan, which was not received in time to be factored into Revision 0.

Interactions with the Commission and other organizations continued through meetings, presentations, and technical exchanges. The Commission provided comments on the Five-Year Plan and the Project responded to Commission concerns on Exploratory Studies Facility design control and quality assurance. Several Nuclear Regulatory Commission interactions involved issue resolution activities.



License application

The issues of seismic hazards, substantially complete containment, absence of extreme erosion, volcanism, and ground-water travel time were key during this reporting period. The Project and the Commission resolved questions on the first seismic topical report (on assessment methodology) so that Commission review can proceed. Through discussion, an annotated outline for the second seismic topical report (on design methodology) was agreed upon. Several outstanding Site Characterization Analysis open items were resolved with the Commission related to the requirement for substantially complete containment. The Commission reaffirmed its statement that satisfying the Project's waste package performance goal (mean waste package lifetime well in excess of 1,000 years) is an acceptable means of demonstrating compliance with the requirement.

The Project revised its approach for calculating ground-water travel time to include two travel time calculations from the repository to the accessible environment—one under pre-waste and one under post-waste-emplacement conditions.

Several interactions involved the Project's approach for calculating ground-water travel time. In a November 29-December 1, 1994, exchange with the Commission, the Department presented its approach for calculating pre-waste-emplacement ground-water travel time. At this exchange, Commission staff suggested an alternative approach. This alternative approach includes two travel time calculations from the repository to the accessible environment: one under pre-waste-emplacement conditions and one under post-waste-emplacement conditions. The post-waste-emplacement calculation would be performed as a function of time and thermal loading to include the effects of the thermal pulse. If the travel time was not significantly degraded under post-waste-emplacement conditions, the pre-waste emplacement calculation would be used to evaluate compliance. Technical discussions are continuing to develop a methodology for calculating ground-water travel time that is mutually acceptable.

In other interactions, the Project agreed to provide supplemental information in its topical report to further evaluate the case for the absence of extreme erosion at Yucca Mountain. The Office of Civilian Radioactive Waste Management also started an expert elicitation process on the probability of volcanism at Yucca Mountain.

Resolution of open items from the Site Characterization Analysis continued. One of the most noteworthy was comment 80 on substantially complete containment. Resolution of this open item was crucial to the related issue resolution initiative. At the end of this reporting period, 94 open items have been resolved (including two objections) and 104 remain open. Most of the remaining open items need data from site characterization activities to be resolved.

Quality Assurance

During this reporting period, the Office of Quality Assurance began implementing a performance-based audit program. Performance-based audits review processes that impact product adequacy, and evaluate processes, tasks, or end products on the basis of expected results. By the end of this reporting period, all but one affected organization had transitioned to the new Quality Assurance Requirements and Description document. During audits and surveillance of the design process and independent design reviews of two Exploratory Studies Facility design packages, the Office of Quality Assurance identified deficiencies in the Management and Operating Contractor's Quality Assurance Program. The Management and Operating Contractor identified corrective actions in a response to these concerns.

Implementation began on a performance-based audit program, which reviews processes, tasks, or end products on the basis of expected results

The processes associated with identifying and controlling quality-affecting activities were significantly changed. The

Management and Operating Contractor separated the functions for classification and grading from the functions of identification and control of potentially site-disturbing activities. This separation eliminates the potential confusion between requirements that derive from quality assurance classification and limiting site impacts.

In an October 13, 1994, letter, the Commission expressed various concerns with the design control process as implemented by the Management and Operating Contractor and about the Quality Assurance Program for the Office of Civilian Radioactive Waste Management. In its response, the Office described formal evaluations and other considerations that provide confidence that activities are sufficiently controlled to ensure that the site is not compromised. The Office did, however, recognize that it was difficult to extract the information from existing documents and to trace 10 CFR Part 60 requirements through its document hierarchy to design drawings and specifications. Thus, the office committed to compiling the information into a single document that would also describe how the 10 CFR Part 60 requirements have been incorporated into the current design. This report was delivered in March 1995.

Report developed to address:

a) overall implementation of 10 CFR 60 requirements in the current design and

b) potential site impacts during construction

In a March 9, 1995, letter, the Commission provided the results of its initial staff review of the response to their quality assurance concerns and outlined a plan for a three-phase verification. This verification plan includes two in-field verifications of corrective actions, the first of which is scheduled for April 3-6, 1995.

Program Outreach

Staff coordinated and attended the National Stakeholders' Meetings, focusing on the site suitability evaluation process, held in Las Vegas, Nevada, and in Washington, D.C., in December 1994. Public outreach activities continued, including tours, informational materials, and meetings to provide current information on site characterization progress. Tours of special interest included those for members of Congress, the British Broadcasting Corporation, Department staff, and guests from a conference of National Science Teachers. The Project also produced several videos emphasizing current work and the tunnel boring machine. Staff coordinated and attended two Affected Units of Local Government meetings. These meetings dealt with the Multi-purpose Canister Environmental Impact Statement, for which the Notice of Intent was published in the October 14, 1994, *Federal Register.*

Staff coordinated and attended the National Stakeholders' Meetings, focusing on the site suitability evaluation process, held in Las Vegas, Nevada, and in Washington, D.C., in December 1994.

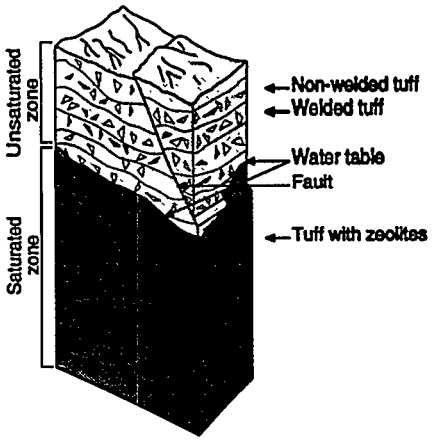
Site Investigations and Analyses

In accordance with the Program Plan, the Office of Civilian Radioactive Waste Management refocused site investigations activities at Yucca Mountain to support an evaluation of Technical Site Suitability in fiscal year 1998. Many of these investigations will continue beyond 1998 in support of licensing and confirmatory assessment activities.

The first phase of the Project's thermal test strategy was completed. This phase focuses on the information and data needed to support the 1998 technical site suitability evaluation.

In December 1994, the Department directed that a multi-participant team review the current in situ thermal testing program and provide a new consolidated Exploratory Studies Facility thermal test strategy consistent with the Program Plan. The first phase of this effort was completed during this reporting period and documented in a draft report submitted January 31, 1995, for Departmental review. This first phase focused on the early time period (1995 through 2001) and developed a set of

information and data needs that must be met by the thermal test program to support the 1998 evaluation of Technical Site Suitability and the 2001 License Application. Any changes to the current test plan will be described in future revisions of this report.



Cutaway of geology at Yucca Mountain

The Project's overall study characterizing infiltration in the unsaturated zone has been reconfigured and accelerated, with the primary goal of defining the upper boundary condition for infiltration. This condition will be developed as a conceptual and numerical model based on arid-land watershed processes and field data. The model is intended to link infiltration flux and past climatic variations, possible future climate scenarios, potential changes in the surface environment (such as loss of vegetation), and sporadic but extreme atmospheric events, ranging from thunderstorm downbursts to changing annual precipitation rates. Precipitation measurements indicate that the winter season of 1994-1995 was the wettest since 1984. These data will be incorporated into the conceptual model of infiltration. In addition, maps of net-infiltration and potential fast-pathways are being developed.

During this reporting period, hydrologists found that all USW UZ-16 samples from the Calico Hills nonwelded unit had slightly elevated chlorine-36 signals. This could indicate the source is global atmospheric weapons testing fallout, which is supported by the high tritium concentrations that have also been found in the unit. There is some evidence in the literature that the high concentration of chlorine-36 might also result from the higher atmospheric production of chlorine-36 in the past. The chlorine-36 results are being used by hydrologic modelers to evaluate the validity of site-scale flow and transport models. In related investigations, hydrologists are continuing to determine how the chlorine-36 and chloride distributions relate to the

Hydrologists investigated the source of elevated chlorine-36 concentrations and how chlorine-36 and chloride distributions relate to the origin and stability of perched water underlying Yucca Mountain.

origin and stability of perched water underlying Yucca Mountain. A report that assembles and interprets all current chlorine-36 data is being developed. The report provides preliminary information on infiltration rates, identifies fast-transport paths, and estimates water residence times. Hydrologists will continue to investigate the implications of the data and collect more data.

Final preparations for drilling USW UZ-7a were completed during this reporting period. This borehole is located to penetrate the main trace of the Ghost Dance fault. In addition, two boreholes (USW NRG-6 and USW NRG-7A), located along the northern boundary of the repository block and immediately south of Drill Hole Wash, were instrumented with pressure transducers. The instruments will be used to study gaseous phase movement in the unsaturated zone and to evaluate the effects of the North Ramp tunneling operations on in situ rock-gas pressures. Surface-based air-permeability testing was completed in three additional boreholes that were drilled using three different drilling methods. The results have been incorporated into numerical flow models of Yucca Mountain.

Scientists continued to collect data from a large number of boreholes to support the characterization of the gaseous phase movement in the unsaturated zone. The current emphasis is on collecting baseline, ambient data so that the effects of Exploratory Studies Facility construction on the gas-circulation system can be evaluated. Unsaturated-zone modeling efforts included work on a conceptual and numerical model of the gas-flow system of Yucca Mountain, and progress on developing the three-dimensional site scale model.

Alcove 2 is located to support the activity investigating the hydrologic properties of major faults in the Main Test Level of the Exploratory Studies Facility.

The tunnel boring machine reached the Bow Ridge fault at 199 meters (653 feet). Project staff inspected the fault and

agreed on a location and configuration of Alcove 2 that will ensure that test boreholes are properly located to support the activity on hydrologic properties of major faults in the Main Test Level of the Exploratory Studies Facility.

Perched water was encountering during the drilling of USW SD-7 in the upper part of the Calico Hills formation.

Several activities in the Exploratory Studies Facility designed to characterize the unsaturated zone were conducted. Monitoring for perched water in the Exploratory Studies Facility and in the first alcove continued without detecting any perched water. Perched water was encountered, however, during the drilling of surface borehole USW SD-7. Drilling began October 3, 1994, on this borehole, which is located approximately where the Main Test Level drift and the South Ramp meet. The perched water was encountered below the repository level in the upper part of the Calico Hills formation at a depth of about 485 meters (1,590 feet). Shut-in pressure monitoring in the radial boreholes in Alcove 1 of the Exploratory Studies Facility was conducted. Results indicate that the high permeability of the Tiva Canyon Member of the Paintbrush Tuff, coupled with the proximity of Alcove 1 to the surface, allows free gaseous exchange between Alcove 1 and the atmosphere. Radial borehole monitoring in Alcove 2 will be another source of information on the unsaturated zone.

C-hole tests, in part, will demonstrate the applicability of laboratory sorption measurements to the prediction of field transport behavior.

Preparations continued for the long-term hydrologic testing in the C-hole complex, including laboratory sorption measurements. The C-hole tests will provide information that will be used to characterize flow paths, and the results will increase Project understanding of fracture matrix interactions in the saturated zone. Information from these tests will also be used to determine bulk estimates of aquifer properties and to predict movement of radionuclides in the saturated zone. They will demonstrate the applicability of laboratory measures for predicting field transport behavior.

Studies on sorption, transport, and solubility continued under the geochemistry site program. Scientists evaluated which ground-water compositional parameters have the greatest impact on the sorption of each radionuclide of concern to the Project and recommended ground-water compositions to be used in future sorption experiments. Field studies supporting biological sorption and transport studies began this reporting period. Samples were collected from Alcove 1 and the Bow Ridge fault for microbial analysis in the laboratory. The results of these studies will be used to predict (on a laboratory scale) the effects of microorganisms on the transport of radionuclides. In support of solubility investigations on important waste elements, scientists began collecting data on selenium to investigate its solubility. Because laboratory experiments indicate minimum selenium sorption on tuffs, this element is important in performance assessment calculations.

Mineralogy investigations are currently emphasizing the distribution of erionite, which is a natural mineral that occurs in the Topopah Spring and Calico Hills unit and is a known carcinogen. The Project must determine adequate but cost-effective procedures for dealing with this hazardous mineral and also address this mineral in the preclosure portion of the site suitability evaluation. In other mineralogy work, data on fracture mineralogy from UE-25 UZ#16 added significantly to the database needed to evaluate transport in fractures.

P-Tunnel at the Nevada Test Site was chosen to help in the characterization of Calico Hills, especially related to radionuclide transport.

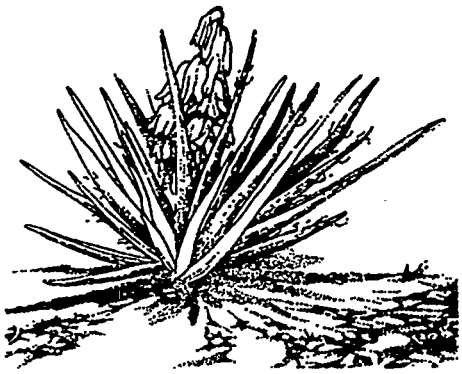
In support of the Technical Site Suitability evaluation, scientists chose a test site within P-Tunnel at the Nevada Test Site to help in the characterization of Calico Hills, especially related to radionuclide transport. The rocks in P-Tunnel share many characteristics with the Calico Hills unit, making it a valuable site for studying processes important in Calico Hills. Tests here allow the Project to further probe in the field the

understandings of flow, sorption, and transport reached in the laboratory. Tests in this tunnel, coupled with scheduled Calico Hills tests, should substantially decrease the existing uncertainty associated with repository performance. Scientists also evaluated the need for testing and early entry into the Calico Hills unit.

Project geologists continue to map features at the surface of Yucca Mountain as a part of the continuing process to verify the accuracy of the preliminary geologic map of Yucca Mountain published in 1984. Geologic mapping continued behind the tunnel boring machine, with mapping of the North Ramp beginning at the end of January.

A final technical report was published in March on the status of volcanic hazards investigated at the potential repository. Project volcanologists also presented information at the first meeting of the Expert Judgment Panel on Volcanism. This panel will independently estimate the recurrence and intersection probabilities for volcanism published by the Project.

As the first phase in the ground-motion modeling activity, a workshop was conducted to select approximately five scenarios for earthquakes and to specify geologic constraints and associated uncertainties. A panel of ground-motion experts was selected to evaluate ground-motion attenuation.



Yucca baccata

Two quarterly Ambient Air Monitoring Reports were submitted to the State of Nevada in fulfillment of the State air quality permit requirements. The permit covers surface-disturbing activities associated with site characterization. Because of control measures on drill rigs and dust suppression measures, no significant increase in the concentrations of

particulate matter that can be inhaled has been noted, despite increased surface-disturbing activities at the site.

Design, Construction, and Performance Assessment Activities

During this reporting period, design and construction activities associated with the repository, waste package, and Exploratory Studies Facility were focused on implementing the Program Plan. Performance Assessment activities centered on the goal of providing a Total System Performance Assessment to support the 1998 Technical Site Suitability evaluation.

Repository

The Project has identified a thermal load strategy that allows the design process to proceed in spite of uncertainties about the thermal effects on the performance of engineered and natural barriers. Design activities will focus on a reference design thermal loading, which will allow up to 70,000 metric tons of uranium equivalent to be placed in less than the primary repository area of 1,200 acres. The Project will, however, maintain flexibility to accommodate alternative thermal loadings and pursue a vigorous performance confirmation program. This strategy will be used in the evaluation of Technical Site Suitability in 1998 and in the License Application scheduled for 2001.

Design activities are focusing on the reference design thermal loading that will allow the maximum 70,000 metric tons of uranium equivalent to be emplaced.

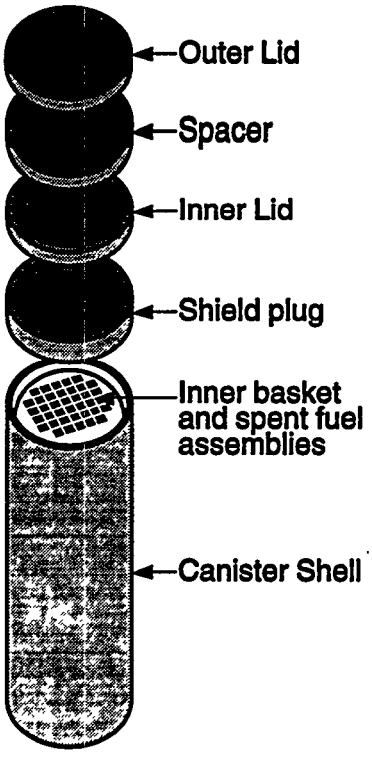
Several efforts will support the Project's strategy of selecting a reference design thermal loading and alternative thermal loading options. Design efforts will identify features where flexibility is needed and develop a range of waste package designs, including a robust waste package capable of withstanding warm, humid conditions. Thermal management studies will examine various options, including waste selection,

emplacement configurations, and ventilation. In addition, a program of long-term testing and monitoring will be designed to increase the confidence in performance predictions.

Five design analyses are evaluating the integration between the multi-purpose canister and the mined geologic disposal system.

Waste Package

Design efforts for the multi-purpose canister and its disposal container are being integrated. Five design analyses have been developed or are being prepared to determine how the requirements of the Mined Geologic Disposal System will affect the design of the multi-purpose canister. The subjects of the analyses are weight, dimension envelope, and configuration; dryness of the multi-purpose canister cavity and composition of fill gas; access for addition of filler materials; criticality control; and materials. Design basis boiling water reactor and pressurized-water reactor fuels have been identified. Sections of the Waste Package Conceptual Design Report are currently being drafted.



Example Multi-purpose Canister

Waste package design evaluations during this reporting period included thermal, structural (including drop analyses), criticality (especially burnup credit), and cost estimates. Waste package performance evaluations focused on container oxidation, cladding oxidation, and corrosion.

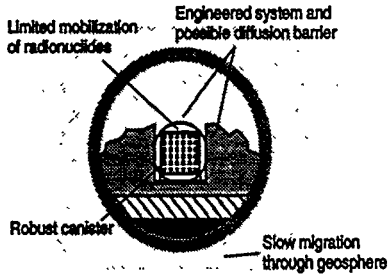
Current waste package container designs focus on a multiple barrier approach for both spent nuclear fuel packages and for vitrified high-level waste packages. The multiple barrier design is being pursued under the bimetallic/single metal alternative identified in the 1988 Site Characterization Plan. In December 1994, existing data were assembled into a three-volume Engineered Materials Characterization Report, which will be continually updated as new data become available from testing and modeling activities. The Project also revised and

issued the Metallic Barrier Scientific Investigation Plan as a controlled document. This plan will be the main document guiding the materials evaluation effort for the next several years.

Titanium Grades 12 and 16 have been recommended as candidate materials for one of the barriers in the multiple barrier design for the waste packages because of their favorable performance characteristics, determined by a degradation mode survey. Laboratory testing for bimetallic/single metal material systems was planned, including long-term corrosion studies, thermogravimetric analysis studies, microbiologically influenced corrosion studies, and crack growth tests.

A stochastic model for pitting initiation and growth has been developed and is being used to simulate the permanent cessation of growth for macroscopic pits. This model is the prototype for modeling other degradation processes, which will begin as experimental information becomes available.

Although technically an out-year activity, considerable progress has been made during the reporting period on radionuclide transport modeling in the near-field waste package environment through the international program. Simple, semianalytic bounding models have been developed for estimating the effect of heterogeneity on the transport of radionuclides from a nuclear waste repository to the accessible environment.



Strategy for waste containment and isolation

Performance Assessment

An enhanced strategy for waste isolation and containment was formulated during this reporting period. The strategy relies on the entire system working together: the natural setting would provide a favorable hydrologic environment that would limit the amount of water contacting the waste package, thus extending

the life of the engineered materials. The natural setting would also provide the traditional barrier in limiting the transport of radionuclides released from the engineered barriers to the accessible environment.

During the period, analysts performed sensitivity analyses and prepared for the third iteration of total system performance assessment, called TSPA-1995. The sensitivity analyses were performed to evaluate the potential effect of various assumptions regarding the relative importance of the Calico Hills hydrostratigraphic unit in limiting transport to the accessible environment. The three general objectives of TSPA-1995 are (1) to incorporate representative results and corresponding uncertainty from process models, (2) to test the significance of a range of conservative assumptions used in previous iterations, and (3) to evaluate a range of potential system and subsystem postclosure performance measures.

Analysts developed a short list of scenarios describing the expected behavior of flow and transport in Yucca Mountain. These scenarios will be used as a baseline for initial performance calculations and later comparisons with other scenarios.

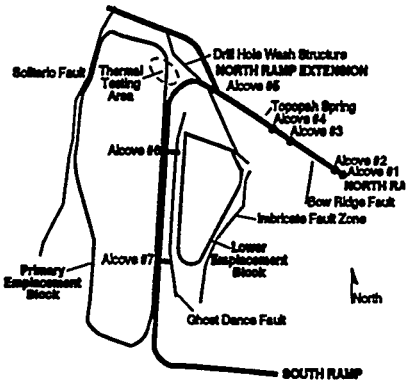
The design and construction process is being streamlined and the remaining design packages have been aligned with the Exploratory Studies Facility configuration in the Program Plan.

Exploratory Studies Facility

Designers developed and implemented initiatives to streamline the design and construction process and align the remaining design packages with the Exploratory Studies Facility configuration in the Program Plan. Because most of the design for the underground portion of the Exploratory Studies Facility was completed as part of the North Ramp design, the 50 and 90 percent design reviews do not have to be repeated on

major parts of the design. Thus, designs for the rest of the facility can be released sooner without sacrificing quality.

A technical assessment team, tasked since 1993 to examine the seismic design basis for the Exploratory Studies Facility, recommended seismic design inputs appropriate for design of the facility. As part of the process to develop these inputs, a probabilistic assessment of vibratory ground-motion hazard at Yucca Mountain was performed. Building on the recommendation by the technical assessment team, the Exploratory Studies Facility design group developed a graded approach for seismic design of temporary and permanent items.



Repository Layout

Temporary structures were designed to a mean horizontal acceleration of 0.3g consistent with the Uniform Building Code Zone 3 in which the Nevada Test Site is located. This is conservative because site-specific analyses indicate a value of 0.19g for the mean horizontal acceleration. Pending development of a methodology for seismic design of a repository, the design of permanent items, such as openings, ground support, and linings, for the Exploratory Studies Facility has been conservatively analyzed using ground-motion values corresponding to maximum horizontal and vertical accelerations of 0.4g.

Excavation using the tunnel-boring machine continued on the Exploratory Studies Facility. Initial test excavation (Phase I) and shakedown (Phase II) were completed during this period and limited operations (Phase III) began in December 1994. Progress slowed in January and early February 1995 during excavation through the Bow Ridge Fault. The slow down was caused by loose, blocky ground and the need to use special construction methods to fill voids to ensure safety. In spite of this slow progress, the tunnel-boring machine was 34 meters (112 feet)

ahead of schedule by the end of March at about 545 meters (1802) feet. The construction of the planned testing Alcove 2, however, was deferred.

Excavation on the North Ramp progressed through Bow Ridge Fault and was ahead of schedule by the end of March.

Construction of surface facilities continued, with progress on roads, and power, water, and security facilities. Construction also began on the surface conveyor.

Epilogue

The earlier portion of this Executive Summary discusses major decisions, accomplishments, activities, and issues of interest that occurred during the reporting period. To acknowledge continuing progress, however, this Epilogue summarizes key events that have occurred since the close of the reporting period on March 31, 1995, but before this Progress Report was printed.

On April 3-6, Commission staff conducted in-field verifications to determine if acceptable corrective actions regarding the Commission's concerns on design control had been effectively implemented. They cited the Department's Design Guidelines Document for the Mined Geologic Disposal System as good practice and provided recommendations related to Exploratory Studies Facility design activities and administrative procedures. The Department immediately began addressing the recommendations.

Consistent with the milestone in the Program Plan, the Topical Report on burnup credit for actinides was submitted to the Commission on May 31, 1995. This Topical Report provides the basis for acceptance of the use of partial burnup credit. The Commission has also formally accepted for review the first topical report on seismic hazard methodology.

Partly because of the slow down of the tunnel boring machine that occurred during the excavation through the Bow Ridge Fault, the Department instituted an aggressive management strategy that consolidates outages and minimizes tunnel-boring machine downtime. The approach will be continued beyond FY 1995 to ensure that the underground excavation continues at a rate consistent with the schedule for the decision on technical site suitability.

On June 9, 1995, Dr. Daniel A. Dreyfus briefed the Nuclear Regulatory Commission on the status of the Civilian Radioactive Waste Management Program. Among the many points in this briefing, he stated the Department's intention to focus on a reference design thermal loading earlier in the design process which will also help the Commission in its review of the License Application. He also re-emphasized the Department's continuing commitment to carefully evaluating the risks of potential criticality associated with any material being considered for disposal. Criticality-related risks associated with the disposal of weapons-grade plutonium in a geologic repository were highlighted by the news media several months ago. Possible applicability of such concerns to geologic disposal of spent nuclear fuel is included in the Program's consideration of nuclear criticality.

Tunnel Boring Machine at Yucca Mountain

CHAPTER 1 - INTRODUCTION

This Site Characterization Progress Report summarizes the progress on site characterization activities at Yucca Mountain, Nevada, for the period October 1, 1994, through March 31, 1995. The report is the twelfth in a series issued approximately every six months during site characterization activities undertaken to evaluate Yucca Mountain as a possible geologic repository for the permanent isolation of spent nuclear fuel and high-level radioactive waste. This progress report is prepared in accordance with Section 113(b)(3) of the Nuclear Waste Policy Act of 1982 (NWPA, 1983), as amended (NWPAA, 1987), and 10 CFR 60.18(g).

The report highlights work started, in progress, and completed during the reporting period. In addition, this report documents and discusses changes to the Office of Civilian Radioactive Waste Management (OCRWM) Site Characterization Program resulting from the ongoing collection and evaluation of site information, systems analyses, the development of repository and waste package designs, and the results of performance assessment activities. Details on the activities summarized can be found in the numerous technical reports cited throughout the report.

During this period, OCRWM began implementing the Program Plan (DOE, 1994), which embodies the new program approach developed and refined during the previous reporting period. This implementation stimulated and directed most of the activities of the Yucca Mountain Site Characterization Project (YMP) during the reporting period. Thus, the chapters after this introduction describe these activities and relate them to the Program Plan.

To put the current site characterization activities in perspective, however, the rest of this chapter describes the historical evolution of the Project and key features and main goals of the approach to site characterization outlined in the Program Plan. It also discusses current U.S. Department of Energy (DOE) strategies for meeting these goals in the three major elements of the repository program: site suitability, the National Environmental Policy Act (NEPA, 1969) process, and licensing.

1.1 HISTORICAL PERSPECTIVE

The YMP started in 1977 when DOE began evaluating the possibility of disposing of radioactive waste in a geologic repository at the Nevada Test Site. Over the next two years, DOE investigated a number of sites near the Nevada Test Site and decided to concentrate exploration efforts on the tuffs of Yucca Mountain. In 1980, DOE began a structured, formal analysis to evaluate whether Yucca Mountain was indeed appropriate for further evaluation. This analysis was conducted to be compatible with the area-to-location phase of site screening described in the national siting plan used before the passage of the Nuclear Waste Policy Act of 1982. As a result of this formal evaluation, DOE identified Yucca Mountain as a potentially acceptable site in February 1983.

The Nuclear Waste Policy Act of 1982 established a national policy for the disposal of highly radioactive waste, specifically commercial reactor spent nuclear fuel and defense high-level waste. The Act also created OCRWM within DOE and assigned that office the responsibility for developing a waste management system.

In response to the requirements of the Act, DOE issued the 10 CFR Part 960 guidelines in 1984 for evaluating the suitability of sites for repositories and started the site screening process. The Environmental Assessment for Yucca Mountain (DOE, 1986), also required by the Act, was issued in 1986. Surface-based studies at Yucca Mountain have been ongoing since May 1986. Initially, these studies consisted of non-surface-disturbing testing in existing exploratory boreholes and wells; analyses of, and experiments with rock and water samples; geophysical surveys; meteorological, hydrologic, and seismic monitoring; geologic mapping, and sampling of surficial materials.

With the 1987 Amendments to the Nuclear Waste Policy Act, Congress designated Yucca Mountain as the only site to be characterized to determine its suitability as a geologic repository. During the following year, OCRWM issued a Site Characterization Plan (SCP) (DOE, 1988) in accordance with the Act and began conducting a program of detailed site-specific investigations and evaluations to assess the suitability of Yucca Mountain. The U.S. Nuclear Regulatory Commission (NRC) review of the document, the Site Characterization Analysis (NRC, 1989), was issued in July 1989. This document identified points requiring clarification and NRC concerns in the form of comments, questions, and objections.

New surface-disturbing work began in July 1991 when the State of Nevada granted necessary permits, with expanded surface-based activities started in November 1992, to support construction of the Exploratory Studies Facility (ESF) North Portal.

During the first half of fiscal year (FY) 1994, DOE conducted preliminary evaluations of various options for restructuring the repository program to meet changing needs and expectations. The 1988 SCP presented a comprehensive testing, design, and performance assessment program. External and internal pressures since 1988 have tended to broaden, rather than focus the Program, with rising expectations of high degrees of certainty in understanding natural geologic systems. Congress had begun to express concern about the continuing growth in the estimated cost of site characterization. In addition, because the site characterization schedule did not require definitive results until the license application was completed in 2001, progress was difficult to demonstrate and to measure. Thus, over the last half of FY 1994, DOE developed and refined a new approach designed to show early observable progress within the financial resources likely to be available. The new approach was designed to ensure the scientific integrity of the evaluation of site suitability, to match the funding that could be expected, and to define measurable progress.

1.2 KEY FEATURES OF THE PROGRAM PLAN

The following discussion identifies key features and major goals of the Program Plan and DOE strategies in the key areas of site suitability, National Environmental Policy Act process, and licensing.

1.2.1 Program Plan Goals

The approach to site characterization documented in the SCP specified extensive testing, data collection, and analysis to produce a comprehensive understanding of the Yucca Mountain site. The strategy envisioned simultaneous decisions on site suitability, licensing, and repository design issues. The re-evaluation that resulted in the Program Plan asked if the program outlined in the SCP could be broken into phases and if a logical set of products based on a data set smaller than originally envisioned in the SCP could be delivered earlier than outlined in the SCP. The re-evaluation distinguished between data required to evaluate site suitability, data required to support licensing and to define a cost-effective design, and data required to confirm the safety of the repository before closure. This distinction allows the Project to phase products and use smaller data sets so that an earlier evaluation of site suitability can be made while preserving the schedule for licensing, constructing, and operating the repository if the site is found suitable.

The sequence established by the Program Plan allows suitability and licensing decisions to be made on the basis of an increasing knowledge base and increasing confidence. The DOE must develop those data and analyses necessary to enable NRC to make findings with reasonable assurance regarding the performance of the site at each step in the licensing process. This process is manifested by a maturing understanding of the performance of the natural and engineered components of the system, as well as the sensitivities of the system to the performance of its individual components. Iterative performance assessments will serve to drive and document the maturation of this understanding.

Because of the changes reflected in the Program Plan and because of increasing site knowledge, some portions of the detailed program outlined in the SCP have changed. In Chapters 1 through 7, the SCP described the site and summarized repository and waste package design. Chapter 8 described the information needed from site tests, approaches to meeting performance requirements, and the programs for repository, seals, and waste package. Appendix A of this Progress Report provides two tables that document changes from the SCP that are completed or in progress. Table 1 provides a high-level summary for the design and performance assessment program, while Table 2 summarizes the changes and modifications to site program activities since the SCP. As indicated in Table 2, most of the changes are related to the consolidation of studies or to activities being deleted because of the design change from shafts to ramps.

Currently, the site characterization activities emphasize those scientific investigations and engineering activities needed to support an evaluation of Technical Site Suitability in 1998. In this evaluation, OCRWM will ascertain whether the postclosure guidelines of

10 CFR Part 960 and those preclosure guidelines related to radiological safety and technical feasibility are satisfied. The 1998 evaluation will be supported by a Total System Performance Assessment that will include subsystem interactions.

If the 1998 decision on site suitability is positive, the focus of the program will shift to determining overall site suitability and supporting the development of the license application. The preclosure guidelines related to environmental quality, socioeconomic impact, and transportation will be evaluated as a part of the determination of overall site suitability expected by the end of FY 2000. Other activities will be directed to developing more cost-effective repository and waste package designs. Results will be used in the environmental impact statement scheduled for 2000, in the license application scheduled for 2001 (if the President and Congress approve the site recommendation), in interactions with the NRC during the licensing process, and in the amended license application to receive and possess waste scheduled for 2008. Confirmatory testing resulting in a larger data set–including tests in selected drifts of the expanding underground facility–will continue through the construction and operation of the repository to ensure that the repository performs as predicted. Testing to confirm the performance of the repository will continue until closure–a period of at least 50 yr and possibly up to 100 yr.

One of the other major goals of the Program Plan is to clearly define progress using interim milestones in the areas of suitability, the National Environmental Policy Act process, and licensing. The following sections outline current strategy in each of these areas.

1.2.2 Repository Site Suitability Evaluation and Site Recommendation

The Program Plan defines additional measures of progress and also accelerates key evaluations compared with those scheduled in the 1988 SCP. The major change from the strategy outlined in the SCP is to phase the program to provide for an early determination of technical suitability by OCRWM in 1998 and an overall site recommendation by the Secretary in 2000.

The Program will evaluate site suitability on the basis of the DOE siting guidelines set forth in 10 CFR Part 960. Compliance with the guidelines will be sequential with individual guidelines or groups of guidelines being evaluated as sufficient data and analyses become available during site characterization. Section 2.1.3 of Chapter 2 of this Progress Report discusses the schedule and includes a figure showing how evaluations of guidelines relate to other Project activities. Appendix C expands on the interim evaluations in the site suitability process.

Technical basis reports are planned between 1995 and 1997 to support higher-level findings required by the guidelines. These reports document the data and analytical results from site characterization activities that support the evaluation of the relevant qualifying and disqualifying conditions in the technical and system guidelines. Each report will describe the Program's current understanding of the subject area, including evaluations of uncertainties, alternative models or interpretations permitted by the data, and bounds on conditions and

processes that are consistent with reasonable models of the site. Technical basis reports for which DOE believes sufficient data are now available to support higher-level findings will be developed first. Those requiring more comprehensive data will follow. Each technical basis report will be submitted for review by outside experts, and the National Academy of Sciences will select qualified reviewers and manage the review process.

The pre-1998 surface-based site testing program uses existing boreholes, together with a limited number of strategically placed new boreholes, to obtain adequate data to improve hydrologic models. This will be helpful for predicting movement of moisture through Yucca Mountain under both existing conditions and conditions that would exist if a repository were developed. The geophysics program is being emphasized to improve predictive capabilities, particularly for subsurface areas where excavations are not planned before 1998. This will provide important information about the potential for previously unrecognized fracture zones that could serve as pathways for rapid flow. Boreholes to investigate the steep hydraulic gradient to the northwest of the site are also a high priority because of the need to incorporate this feature into hydrologic models of the site. These studies will reduce uncertainty in calculations of ground-water travel time that provide a basis for evaluating the 10 CFR Part 960 Disqualifying Condition for Geohydrology, as well as for improving confidence in predictions of total system performance.

The ESF excavation sequence has been streamlined by deferring some testing alcoves to allow access to the Ghost Dance fault zone at the earliest possible opportunity. In situ observation of this feature is important to establish whether it could serve as a preferential flow path from the repository to the water table, again contributing to the understanding that serves as a basis for evaluating the Geohydrology Disqualifying Condition. Testing alcoves are prioritized to allow observation of key contacts and fault zones as early as possible, and tests in the alcoves are focused on geology and hydrology for the pre-1998 period.

1.2.3 National Environmental Policy Act Process for Repository Development

The Nuclear Waste Policy Act of 1982, as amended, specifies the overall approach to evaluating the potential environmental impact of the proposed repository. If the Yucca Mountain site is found suitable, the Secretary may then recommend that the President approve the site for development as a repository. Any such recommendation must be accompanied by an environmental impact statement prepared pursuant to the National Environmental Policy Act. Under the planned schedule for completing the environmental impact statement, the process will begin with a notice of intent to prepare the statement, scheduled to be issued by DOE in 1995, and will end with a final statement and record of decision being issued by DOE in 2000. Thus, the statement will be available to the Commission to use as a basis for issuing a repository construction authorization in 2004. If necessary, after the record of decision is issued, DOE will develop and issue a mitigation action plan, pursuant to its own National Environmental Policy Act implementing regulations (10 CFR 1021.331)

The environmental impact statement will address the potential impacts associated with constructing, operating, and eventually closing a repository at the Yucca Mountain site. The

impacts of postclosure performance of the repository and waste transport will be examined to the extent that they are known at the time the statement is prepared. The statement will also examine, as appropriate and feasible, various repository operational scenarios that may affect design features. The Nuclear Waste Policy Act of 1982, as amended, provides that the statement need not consider the need for a repository, alternatives to geologic disposal, or alternative sites to Yucca Mountain.

The statement will incorporate the methodologies and analyses from the national transportation impact assessments, including both highway and rail analyses, conducted for the multi-purpose canister environmental impact statement and other relevant DOE environmental impact statements. Assessments will be updated, as needed and appropriate, in the repository environmental impact statement. In addition, the repository environmental impact statement will identify alternative transportation corridors in Nevada for eventual construction of a rail spur to Yucca Mountain.

1.2.4 Repository Licensing Process

The repository licensing process builds on, and adds to, the information, analyses, and designs that are required for the determination of site suitability. Although most site investigations needed to evaluate suitability must continue to support the licensing process, several will be completed, or nearly so, when the Technical Site Suitability evaluation is made in 1998. If the site is found suitable, the results of these investigations will be incorporated into the license application and data collection, designs, and analyses conducted after the 1998 evaluation will focus on the primary objective of the licensing program: submitting a successful license application to NRC in 2001.

The licensing strategy being implemented includes the timely acquisition of information needed to support each step in the licensing process and early resolution of regulatory issues. This strategy is implemented by (a) identifying licensing information needed during site characterization, and (b) developing and periodically updating an annotated outline for a license application and providing it to the NRC staff for review so that NRC may comment, if necessary, on the sufficiency of information collected before the application is submitted.

To demonstrate progress in developing a viable license application, DOE established major milestones for submitting an annotated outline of the repository license application to NRC. The annotated outline will incorporate the specific information needed for licensing from the various Project technical efforts in site characterization, design, and performance assessment, as well as from quality assurance (QA). The outline will be updated at least annually. The outline allows NRC to review and comment on DOE's increasingly detailed understanding of the proposed repository system, as well as the DOE interpretation of NRC guidance on expected format and content of the license application. The NRC comments are expected in the form of preliminary safety evaluation reports. This commenting process will help DOE assess when it has sufficient information to present to NRC to resolve issues or to decide that site characterization in a specific technical area is complete. Thus, the annotated

outline process will facilitate the finalization and submittal of the license application in 2001, if the site is found suitable for development as a repository.

The Program Plan departs from the strategy outlined in the SCP with the recognition that not all of the activities previously envisioned will be conducted prior to submitting the initial license application. The licensing strategy envisioned in the Program Plan relies on a focused program to provide necessary and sufficient information to support findings by the Commission consistent with its reasonable assurance standard. This strategy recognizes that additional information will be obtained through continued surveillance, measurement, and testing during the construction and operation of the repository. This information would be reflected in subsequent license application updates and amendments.

Predictions about the long-term ability of the repository's engineered and natural barriers to contain and isolate spent nuclear fuel and high-level waste, based upon the available data and supported by bounding analyses and models, would be included in the initial license application. These predictions, together with the other evidence to be presented, should be sufficient to allow NRC to determine whether a finding of "reasonable assurance" can be made and to support a decision as to whether or not their objectives for the long-term performance of the repository system will be met. This determination will be made consistent with NRC requirements: "The application . . . shall be as complete as possible in the light of information that is reasonably available at the time of docketing." (10 CFR 60.24(a)) and ". . . the demonstration of compliance may take uncertainties and gaps in knowledge into account . . . ." (10 CFR 60.101(b)).

If the site is found suitable, the license application for construction authorization would be based on Title I (preliminary) repository design and Title II (final pre-fabrication) waste package design, results of surface and subsurface testing to support design; results of modeling; laboratory and field data from site characterization; scientific investigations; and limited results from long-duration, in situ coupled process (thermohydrologic and thermomechanical) testing. A safety analysis report will support the application. A principal focus will be on ensuring the safety of repository operations and providing high confidence in waste package containment for at least 1,000 yr.

Under construction authorization, the Project would begin constructing the surface facilities and first few panels for underground emplacement. Beyond 2001, the Project would place high priority on those tests designed to improve confidence about long-term performance as part of the performance confirmation program required under 10 CFR Part 60, Subpart F. During this time, the long-duration in situ tests that measure moisture redistribution and changes in rock properties in response to thermal loading would be key information sources. The Project would give high priority to confirming the behavior of engineered materials within the range of expected repository conditions.

After NRC has issued the license to receive and possess spent nuclear fuel and high-level waste, the scientific work would focus on obtaining data on changes to the site caused by repository construction and waste emplacement. The objective would be to confirm, in accordance with 10 CFR 60.140(a), the basis for earlier predictions about containment and

isolation, to confirm that natural and engineered systems are functioning as expected, and to test the models that will be relied upon for confirming the long-term predictions required to support a decision by NRC to permit closure of the repository. The license application for an amendment to close the repository would not be submitted until sufficient confirmatory test information is available to provide adequate confidence to support a decision to close the repository. The SCP envisioned 50 yr of retrievability before closure; the Program Plan allows for up to 100 yr of retrievability before closure or until sufficient confidence is attained for postclosure performance.

1.2.5 Progress Report Content

As shown in the box on this page, the main chapters of the progress report deal with programmatic, site, design and construction, and performance assessment activities. Various appendixes support the main text, including several newly added this reporting period. Appendix A provides a matrix correlating activities in the SCP with those in the annotated outline. This appendix provides the details of changes that have occurred at the specific study and activity level. Appendix J was added this reporting period to provide an update on references that were identified as in preparation in the previous progress report.

In addition for more-general readers, the report begins with a Note to Readers that summarizes major achievements during the reporting period. The Executive Summary is a high-level summary of major decisions, accomplishments, and issues of interest during the reporting period. The Executive Summary also includes an Epilogue that identifies key events that occurred after the reporting period ended but before this report was printed.

Progress Report

Chapter 1	Introduction
Chapter 2	Programmatic Activities
Chapter 3	Site Programs
Chapter 4	Repository Design
Chapter 5	Waste Package
Chapter 6	Performance Assessment
Chapter 7	Exploratory Studies Facility Design and Construction
Appendix A	Matrix of Annotated Outline with SCP
Appendix B	Site Characterization Program Baseline History
Appendix C	Interim Evaluations in Site Suitability
Appendix D	Interactions with Nuclear Regulatory Commission and Others
Appendix E	Status of NRC Site Characterization Analysis Open Items
Appendix F	Change Control Board Actions
Appendix G	Study Plan Status
Appendix H	Glossary
Appendix I	References
Appendix J	Status of Progress Report #11 In-Preparation References
Appendix K	Acronyms, Abbreviations, and Symbols

CHAPTER 2 - PROGRAMMATIC ACTIVITIES

This chapter reports the results of Program Plan implementation on Project planning and regulatory activities, including site suitability, environmental compliance, and licensing activities. Other programmatic activities reported include those in QA and public outreach. Programmatic activities focus, evaluate, plan, control, and ensure the quality of site characterization, design, and performance assessment activities.

2.1 PROJECT PLANNING AND BASELINE CONTROL

As the Project began implementing the Program Plan, needed changes in planning documents were identified and revisions started. In particular, the activities required to change the cost, schedule, and technical baselines to reflect the Program Plan were initiated. Specific changes in the baseline will be reflected in the appropriate supporting documents and reported in future Site Characterization Progress Reports.

2.1.1 Program Plan

The DOE developed a Program Plan for the Civilian Radioactive Waste Management System (DOE, 1994a) and provided it to NRC, other stakeholders, and the public on December 19, 1994. This plan consists of three volumes:

- Volume I: Overview of the integrated waste management system
- Volume II: Yucca Mountain Site Characterization Project activities. The draft Five-Year Plan for the Project, developed during the last reporting period, was the primary basis for this volume
- Volume III: Civilian Radioactive Waste Management System (CRWMS) storage and transportation activities.

The Program Plan describes the goals, activities, and schedule milestones for the major products of the Project for FY 1995-2000. The plan also implements the strategies established in the Program Plan and discussed in Chapter 1 for site suitability, the National Environmental Policy Act, as amended (NEPA, 1969) process, and repository licensing.

The changes reflected in the Program Plan dramatically affect Project planning and baseline control. Responding to the changes, the Project began a rebaselining effort to modify existing schedules, milestones, and activities to make them consistent with those outlined in the Program Plan.

Also partly because of the changes reflected in the Program Plan, some portions of the detailed program outlined in the SCP (DOE, 1988) have changed or are changing. To report these changes, DOE has developed two matrixes (presented in Appendix A) that document

changes from the SCP that are complete or in progress. Table 1 provides a high-level summary for the design and performance assessment program, while Table 2 summarizes the changes and modifications to site program activities since the SCP. As indicated in Table 2, most of the changes are related to consolidating studies or deleting activities due to the change from shafts to ramps.

Forecast: The scope and schedule information in the Program Plan will be used during the next reporting period to support Project activities required to baseline the Program.

2.1.2 Technical Implementation Plans

The Project completed the FY 1995 Technical Implementation Plans (CRWMS M&O, 1994a) for most Project Work Breakdown Structure elements. Activities discussed in these plans implement the OCRWM Program Plan. In addition, the Project Technical Implementation Plan Fiscal Year 1995 Revision 0 (DOE, 1994b) was completed, which provides an integrated presentation of the year's activities and how they support the Project goals. These plans were provided to the NRC and other stakeholders on December 19, 1994.

The FY 1995 Technical Implementation Plans include the strategy for the implementation of Project priorities, mapping of proposed budget to those priorities, detailed work scope statements, and proposed milestones and deliverables including comprehensive completion criteria. Logic for planned work was checked against the OCRWM Program Plan master schedule to ensure consistency and was evaluated for appropriate predecessor and successor activities.

Work also began on the draft FY 1996 Technical Implementation Plans (CRWMS M&O, in prep.[a]), reflecting the results of the Yucca Mountain Technical Program Review that was conducted in February 1995.

Forecast: The draft FY 1996 Technical Implementation Plans are expected to be completed by April 1995, and detailed planning for FY 1996 will begin in April. In previous years, DOE completed the detailed annual planning and provided the plans to the CRWMS Management and Operating Contractor (M&O) and other Project participants for implementation. This fiscal year, however, DOE has adopted a new management approach in order to consolidate the planning effort and help ensure clear lines of responsibility. Under the new approach, the M&O will do the detailed planning, with DOE providing upper-level guidance. DOE will then approve the plan before implementation.

2.1.3 Schedule

The DOE began to rebaseline the Project schedule to be consistent with the Program Plan. As part of this effort, an integrated Project Summary Schedule was developed, which is an enhancement of the schedules provided in the Program Plan. This summary schedule incorporates the results of more detailed planning and the discussions that occurred during the

Yucca Mountain Technical Program Review in February 1995. Table 2-1 presents the key milestones for the Project, consistent with this Project Summary Schedule, and Figure 2-1 shows how the summary milestones relate to other key Project activities. Appendix C summarizes interim evaluations in the site suitability evaluation process.

At this time, the Project Summary Schedule is only a preliminary schedule developed by the Project, and has not yet been approved for baselining. The schedule baseline for the Project presented in Progress Report #10 (DOE, 1994c) has not yet been officially changed.

Forecast: Schedule rebaselining will continue.

2.1.4 Document Hierarchy and Program Baseline

The document hierarchy for OCRWM includes both Program and Project documents and both regulatory and management documents are indicated. In general, lower-level documents derive their requirements from parent documents above in the hierarchy and requirements in higher-level documents "flow down" to the documents below. Both Program and Project-level documents are under configuration change control.

The following discusses changes in Project-level documents that control both regulatory and management activities.

2.1.4.1 Regulatory Controls

The regulatory hierarchy includes documents (a) for the YMP and (b) for the Waste Acceptance, Storage, and Transportation Project, which are the two major centers for OCRWM under the Program Plan. This Progress Report only addresses those documents related to the SCP.

In general, requirements in Program-level documents capture overall system and top-level system functions and elements. Design requirements and specifications and designs for system elements are found in the Project-level documents. For regulatory control, the CRWMS Requirements Document (DOE, 1995a) establishes the technical requirements for the entire program (including waste acceptance, storage, and transportation). The Mined Geologic Disposal System Requirements Document (DOE, 1994d) is the controlling document for the YMP. It defines the Program-level requirements for designing the repository, the Engineered Barrier System, the ESF, and surface-based testing facilities.

Table 2-1. Preliminary Summary Schedule

Milestone	Date
Site Suitability Interim Evaluations	
Surface Processes	9/95
Tectonics	1/97
Preclosure Radiological Safety	2/97
Reasonably Available Technology	7/97
Geochemistry/Rock Characteristics	7/97
Geohydrology/Transport	4/98
Total System Performance/Remaining Postclosure Qualifying Conditions	9/98
Technical Site Suitability Evaluation[a]	9/98
Site Recommendation Report[a]	9/00
National Environmental Policy Act Process	
Environmental Impact Statement (EIS) Notice of Intent	5/95
EIS Implementation Plan	12/95
Draft EIS[a]	9/98
Final EIS[a]	8/00
Record of Decision	9/00
Licensing	
License Application Annotated Outline, Rev. 0	3/95
License Application Annotated Outline, Rev. 1	1/96
License Application Annotated Outline, Rev. 2	1/97
License Application Annotated Outline, Rev. 3	1/98
License Application Annotated Outline, Rev. 4	1/99
License Application Annotated Outline, Rev. 5	1/00
License Application[a]	6/01
Exploratory Studies Facility Construction/Testing	
Complete North Ramp	3/96
Complete Excavation of first Ghost Dance fault Drift	7/96
Complete Excavation of second Ghost Dance fault Drift	11/96
Complete Excavation for Short-Term Heater Tests	12/96
Complete South Ramp/Daylight	5/97
Complete North Ramp Extension	9/98
Waste Package/Repository Design	
Complete Repository/Waste Package Advanced Conceptual Design	3/97
Complete Repository/Waste Package License Application Design	9/00

[a] Major milestone in Program Plan.

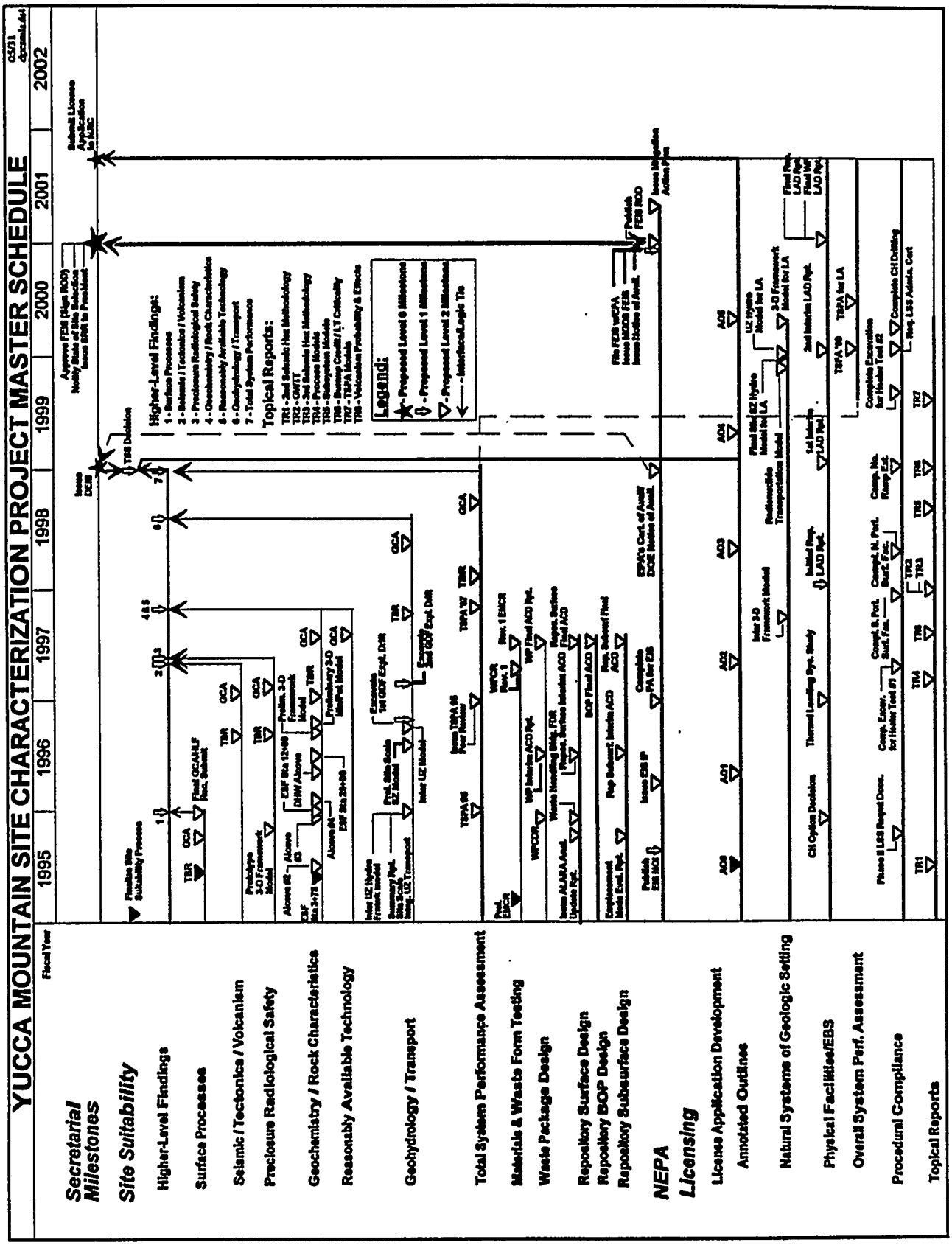


Figure 2-1. Yucca Mountain Site Characterization Schedule

The next level is Project documentation, which establishes site-specific design requirements and specifications for the repository, for the facilities at the site to support site characterization, and for the Engineered Barrier System. These design requirements documents are the Repository Design Requirements Document (DOE, 1993a), the Site Design and Test Requirements Document (DOE, 1995b), and the Engineered Barrier Design Requirements Document (DOE, 1994e).

Under the Site Design and Test Requirements Document are more specific documents for controlling the elements currently taking place under site characterization. These documents address the ESF and the facilities supporting surface-based testing. The Exploratory Studies Facility Design Requirements (DOE, 1995c) document describes the functions to be performed by and the design requirements for facilities, underground openings, utilities, and services of the ESF. The Surface-Based Testing Facilities Requirements Document (DOE, 1994f) identifies requirements for facilities needed to support sampling and testing to be carried out from the ground surface. The scope and contents of the Test Requirements Document (also under the Site Design and Test Requirements Document) are yet to be determined.

During this reporting period, NRC expressed concerns with various aspects of the OCRWM Quality Assurance Program (see discussion in Section 2.3.4). Among those concerns was the potential impact of activities in the ESF on site characterization testing and the site's waste isolation capabilities. As a part of their basis for the comment, NRC expressed concern with the difficulty in demonstrating the flowdown of 10 CFR Part 60 requirements through the document hierarchy. The DOE developed the Regulatory Compliance Review Report (DOE, 1995d), issued in March 1995, to address both issues. The evaluation that resulted in that report concluded that the design process has appropriately considered 10 CFR Part 60 requirements in Design Package 2C for the ESF. (Design Package 2C addresses North Ramp excavation layouts, ground support, utilities, electrical power, site lighting, site grounding, and alcoves.)

In addressing the flowdown difficulty, the report selected a sample of 10 CFR Part 60 requirements and documented the implementation of those requirements through the Exploratory Studies Facility Design Requirements and into specific design products. The DOE is also completing the documentation for the remaining 10 CFR Part 60 requirements applicable to Design Package 2C. This work will be reflected in major revisions in both the Site Design and Test Requirements Document and the Explortory Studies Facility Design Requirements.

Specific changes during this reporting period and forecasted changes are summarized in Table 2-2.

Table 2-2. Regulatory and Management Document Progress

Document	Progress or Change	Forecast
Regulatory Documents		
Mined Geologic Disposal System Requirements Document	Incorporate the multi-purpose canister concept into the technical baseline	Revise to incorporate the Program Plan as defined in the OCRWM Baseline Change Proposal BCP-00-94-0005 (DOE, 1995e).
Repository Design Requirements Document	No change	Revise to incorporate the multi-purpose canister changes from revised Mined Geologic Disposal System Document, to incorporate Program Plan and corresponding baseline change, and to allocate requirements to repository configuration items
Engineered Barrier Design Requirements Document	No change	Revise to incorporate multi-purpose canister changes from revised Mined Geologic Disposal System Document and to allocate requirements to engineered barrier configuration items
Site Design and Test Requirements Document	Interim change notice prepared to reflect changes to the test objectives removed from the Site Characterization Program Baseline	Complete revision to allocate requirements to configuration items, establish external and internal interfaces and review 10 CFR Part 60 requirement applicability and allocation
Exploratory Studies Facility Design Requirements	Interim change notice issued to address changes to support ongoing ESF design activities.	Revise to provide detailed interpretation of the applicable 10 CFR Part 60 requirements for the design of the ESF, to provide the allocation of each ESF design requirement to each configuration item, and to address changes in the Site Design and Test Requirements Document

Table 2-2. Regulatory and Management Document Progress

Document	Progress or Change	Forecast
Surface-Based Testing Facilities Requirements Document	No change	Revise to address changes in the Site Design and Test Requirements Document, to reorganize the requirements to allocate specific requirements to configuration items, to emphasize requirements that respond to regulatory requirements (10 CFR Part 60), and to evaluate and make necessary changes to reflect current field practices
Controlled Design Assumptions	Completely revised, including concept of operations, functional analysis, design assumptions, and design assumption tracking process	Revise to capture recent thermal strategy and conceptual design process
Management Documents		
Project Management Plan	No change	Revise to capture current Project organizations and relationships, include changes in DOE Order 4700.1 (Project Management System), reflect new Program Plan, and incorporate new project management process model
Advance Acquisition Plan	No change	Eliminate plan and develop individual Advance Acquisition Plans for procurements that exceed the federal acquisition thresholds
Configuration Management Plan	No change	Revise to capture current Project organizations and relationships,
Environmental, Safety and Health Protection Implementation Plan	No change	Revise Safety and Health Plan and Environmental Management Plan
Test and Evaluation Plan	No change	Revise to include all testing activities across the Project to respond to changes in Program-level Test and Evaluation Master Plan

Table 2-2. Regulatory and Management Document Progress

Document	Progress or Change	Forecast
Project Work Breakdown Structure		
Systems Engineering Management Plan	No change	Revise to incorporate Program Plan, using working group consisting of representatives from the following areas: repository design, waste package design and development, ESF, systems engineering, specialty engineering, project engineering integration, regulatory and licensing, scientific programs, field engineering, environmental safety and health, quality assurance, and performance assessment
Regulatory Compliance Plan		Major revision to capture results of the Program Plan and to present a revised, focused strategy for accomplishing regulatory compliance with siting guidelines (10 CFR Part 960) and licensing requirements (10 CFR Part 60)
Site Characterization Program Baseline	Revision 12, issued February 3, 1995. Revised Study 8.3.1.5.1.6, "Characterization of the Future Regional Climate and Environments," and Study 8.3.1.15.1.5, "Excavation Investigations." Editorial changes to Section 8.4 in response to NRC comments. Revised ESF/ Repository interface drawings to reflect design changes. Revision 13, issued for review, comments being resolved. Removed testing objectives (now baselined in the Site Design and Test Requirements document) and changed ESF/Repository interface drawings to reflect design changes (most significant changes were in ramp length and slope)	Revision 14: (a) remove performance allocation tables (moved to the Site Characterization Parameters Tables document (DOE, 1995) and controlled by the Change Control Board); (b) describe the repository and engineered barrier design via general arrangement drawings; (c) describe the natural barriers using maps, cross-sections, and text; (d) discuss Project interfaces (physical, functional, and operational) both internal (ESF to repository) and external (repository to multi-purpose canister); (e) discuss Project waste isolation strategy, the ESF, and the repository concepts of operations. (See Appendix B for a history of changes to the Site Characterization Program Baseline.)

2.1.4.2 Management Controls

The Project management requirements and constraints are contained in documents identified as Management Control. These documents identify the approach for management of the Project activities in accordance with applicable management requirements. Specific changes during this reporting period and forecasted changes are summarized in Table 2-2.

2.1.4.3 Change Control Board Actions

The Project Change Control Board evaluates proposed changes to the Project technical baseline. If the proposed change is approved, a Change Directive is issued and the change is implemented by affected organizations in accordance with directions listed in the directive.

Appendix F presents a table summarizing the key Project Change Control Board actions completed during this reporting period. These actions affected baseline documents or activities regarding deliverable reports, surface-based testing, and the ESF. The most noteworthy changes were those that streamlined the Project technical baseline, restructured the Site Characterization Program Baseline (DOE, 1995f) document, and reduced the estimated cost for surface preparations efforts for the ESF.

2.2 REGULATORY ACTIVITIES

During this period, the Project refocused regulatory activities to support the implementation of the Program Plan. Regulatory activities, including the development of product outlines and interactions with oversight organizations, identify the information needed from site characterization, design, and performance assessment activities to achieve the objectives of the Program Plan. Progress in the regulatory activities associated with site suitability, environmental compliance, and licensing activities to prepare for Program Plan implementation is reported in this section.

2.2.1 Site Suitability Activities

In November 1994, OCRWM completed and published for comment a document entitled "Process for Evaluating the Suitability of the Yucca Mountain Site for Development as a Repository for High-Level Radioactive Waste and Spent Nuclear Fuel." Public workshops to discuss the final process for evaluating site suitability and the effectiveness of the OCRWM public involvement process in developing the site suitability evaluation process were held in December 1994 in Las Vegas, Nevada, and Washington, D.C. The workshops also discussed the OCRWM "Draft Work Statement for the National Academy of Sciences Board on Radioactive Waste Management for Peer Review of the Technical Bases for the Suitability Evaluation Process."

The OCRWM revised its schedule for Technical Site Suitability to address issues raised during the DOE February 1995 Technical Program Review. The issues focused on improving the schedule presented in the Program Plan for preparing technical basis reports with respect to the data acquisition and synthesis activities that support them. The revised plan combines the Preclosure Rock Characteristics and Geochemistry/Postclosure Rock Characteristics technical basis reports into one technical basis report for Geochemistry/Rock Characteristics. This allows for a single, logically defined technical basis report and peer review addressing rock properties and processes. In addition, the technical basis report for Geochemistry/Rock Characteristics has been rescheduled to allow time for additional data collection from the ESF. According to the current schedule for advance of the tunnel boring machine, empirical data on the Topopah Spring Tuff in the primary block will be available to support interpretations presented in the Geochemistry/Rock Characteristics technical basis report in March 1996. The Yucca Mountain Site Characterization Office (YMSCO) plans to begin writing the report in late June 1996.

Information from the technical basis report for Geochemistry/Rock Characteristics is required to support the guideline compliance assessment for the preclosure system guideline for reasonably available technology. Consequently, this guideline compliance assessment has been rescheduled to coincide with development of the guideline compliance assessment for Geochemistry/Rock Characteristics. With the revised schedule, additional design information will also be available for this guideline compliance assessment.

Discussions during the Technical Program Review, and followup meetings with Principal Investigators, indicated that much of the information supporting the technical basis report for Preclosure Radiological Safety will be available sooner than expected. Therefore, this technical basis report will be ahead of the schedule documented in the Program Plan.

The revised schedule for Technical Site Suitability introduces a new National Academy of Sciences peer review of the Total System Performance Assessment - 1995 (CRWMS M&O, in prep.[b]) in FY 1996. Thus, the Academy will be able to review a Project Total System Performance Assessment before addressing the technical basis report for Total System Performance Assessment in 1998. The early peer review is expected to provide additional guidance for planning YMSCO data acquisition activities.

A draft of the technical basis report for surface processes was issued (DOE, 1995g). This report includes technical data and analyses that may be used to support guideline compliance assessments for three guidelines: Surface Characteristics, Preclosure Hydrology, and Erosion.

Forecast: Work will continue on the technical basis report for Preclosure Radiological Safety (DOE, in prep.[a]).

2.2.2 Environmental Compliance Activities

Environmental compliance activities during the reporting period focused on the environmental impact statement for the potential Yucca Mountain repository. The environmental impact statement must accompany the site recommendation report that will be submitted to the President should Yucca Mountain be determined to be a suitable site for a repository. In addition, numerous environmental surveys and permitting actions were completed for new and planned site characterization activities at Yucca Mountain during the period. Progress in these areas is reported in this section.

2.2.2.1 National Environmental Policy Act

As currently planned, scoping for the repository environmental impact statement will begin in mid 1995. A draft notice of intent to prepare an environmental impact statement and to solicit public comments on its scope was completed in late 1994 and is currently in review. Preliminary drafts of a scoping plan, management plan, and the public involvement plan supporting the preparation of the environmental impact statement were also completed.

In addition, preliminary work on the following documents began:

- Request for proposal to obtain the services of an independent contractor to prepare the environmental impact statement
- Annotated table of contents to help focus DOE planning with regard to the likely content of the environmental impact statement. (A final annotated table of contents will be completed *after* public scoping and will be included in an implementation plan.)
- Environmental impact statement style guide
- Technical guidelines for each resource area specifying the types and extent of analyses that the environmental impact statement contractor will be expected to conduct.

The status of activities and plans related to the environmental impact statement was presented at the following public meetings:

- Nuclear Waste Technical Review Board, January 1995
- DOE Technical Program Review, February 1995
- Nevada Conference on Nuclear Waste Transportation, February 1995
- State/Tribal/Local Government Coordination Group Meeting, February 1995.

Forecast: The Notice of Intent to prepare the environmental impact statement is expected to be approved and published in the *Federal Register* by mid-summer. Scoping meetings will begin shortly thereafter.

2.2.2.2 Permits

Permits are required for some land use activities having potential environmental impacts. This section discusses the progress or activity on these permits.

Water Quality

A request for approval to use a portable bathroom/holding tank facility was submitted to the State. The Nevada Department of Health approved the facility in February with several conditions. The system is expected to be on line in April 1995.

As required by the Stormwater Discharge Permit, the Stormwater Pollution Prevention Plan was sent to the State on October 12, 1994.

A temporary water appropriation permit changing the place of use for trenching activities was filed in July and approval was received in October 1994.

Three extensions of time were filed with the State Engineer for water permits 58827, 58828 and 58829 (C-hole complex).

A Groundwater Discharge Permit Application for the mine evaporation pond was submitted to the State on March 3, 1995. A Permit to Construct for an individual sewage disposal system was submitted to the State on March 20, 1995.

Air Quality

The Bureau of Air Quality changed the due date for the Annual Usage Report for Air Quality Permits from April 15, 1995, to February 15, 1995, and the report was filed with the State on February 14, 1995. In this report, the following permits were dropped:

1. Permit #3650 (Conveyor System) - ESF design changes required extensive modifications of the system.

2. Permit #3690 (Cone Plant) - Change in construction activities eliminated the need for the facility.

3. Permit #3694 (Radial Stacker conveyor) - The need for an extra conveyor at the batch plant did not materialize.

A request for an Air Quality Operating Permit for a new conveyor system for the ESF was submitted on February 7, 1995. A request for an Air Quality Operating Permit for two diesel standby generators was submitted on March 2, 1995.

The Bureau of Air Quality modified permit #3733 (Concrete Batch Plant) from 18 tons to 125 tons on October 4, 1994.

Drilling and Tracers

A Waiver to Drill was requested for USW WT-24 in December 1994 and approval is expected in April 1995. A request for tracer use in USW WT-24 was requested on December 23, 1994, and approval was received on December 29, 1994. A request for tracer use in USW UZ-6 and USW UZ-6s was requested and approved in February 1995.

Forecast: The Project permit applications and modifications, projected to be submitted during the remainder of FY 1995 include the following: air quality permits for four additional drill rigs; modification of the Underground Injection Control Permit to increase the number of boreholes for tracer injection and to request the use of additional tracers, four tracer injection approvals under the Underground Injection Control Permit, and air and water permits for a hydrocarbon bio-remediation project.

2.2.2.3 Environmental, Safety, and Health Audits

Environmental, Safety, and Health audits are performed on a continuing basis by the CRWMS M&O Environmental, Safety, and Health Compliance Department to ensure that Project activities and support functions comply with federal and state statutory requirements, DOE Orders, and Project plans and procedures. Environmental, Safety, and Health Compliance Department oversight activities during this period consisted of both comprehensive Environmental, Safety, and Health audits and focused, special-issue audits.

A comprehensive Environmental, Safety, and Health audit assesses all aspects of an organization's Environmental, Safety, and Health activities and programs. During this reporting period, a comprehensive Environmental, Safety, and Health audit was performed on the Project-related activities of the Los Alamos National Laboratory (Los Alamos). The conduct of the audit was monitored by a DOE Headquarters Self-Assessment Team observer.

Focused, special-issue audits provide a quick response capability for assessments of high priority Environmental, Safety, and Health concerns or areas of interest. The following four focused, special-issue audits were conducted this reporting period:

- Analytical Services Capabilities of Environmental Technologies, Inc.
- Nevada Test Site Area 6 Hydrocarbon-Contaminated Soil Disposal Site
- Matrix Training of Project Safety and Health Professionals
- Reynolds Electrical & Engineering Co., Inc. Hydrocarbon Spill Response and Reporting Procedures.

Forecast: Three comprehensive Environmental, Safety, and Health audits and four focused, special-issue audits are planned for the remainder of FY 1995. Sandia National Laboratories (SNL) is the next Project organization scheduled for a comprehensive audit.

2.2.2.4 Environmental Surveillance

Approximately 309 environmental surveillances were conducted at the Yucca Mountain site to ensure compliance with environmental, programmatic, and permit requirements. Corrective action and follow-up work was required on 25 percent (76) of the surveillances, and 59 percent (45) of those follow-up activities were completed.

Forecast: Three hundred surveillances are projected for the remainder of FY 1995.

2.2.2.5 Preactivity Surveys

Seventeen land access and environmental compliance activity reviews were completed. This effort involved the acquisition of required land access approvals and right-of-way reservations and the completion of environmental preactivity surveys (which include radiological, archaeological, and biological surveys) before each Project site activity starts. An additional 11 requests to initiate preactivity surveys were received. There are currently 19 "open/active" field activities for which land access and environmental preactivity surveys are being or will be conducted.

Forecast: Approximately 15 land access and environmental compliance activity reviews are expected to be completed during the remainder of FY 1995. This effort will involve land access approvals and right-of-way reservations, as well as separate radiological, archaeological, and biological preactivity surveys.

2.2.2.6 Land Acquisition and Site Access

A participant request to initiate site activity is a prerequisite requirement for the activity, and 15 such requests were received during this reporting period. Ten of these requests have been completed and access authorization granted. Those completed are percolation and standard penetration tests for the ESF leach field; Lawrence Berkeley Laboratory (LBL) geophysics experiment; Borehole USW WT-24 road, pad construction, and drilling; power line for ESF booster pump station; Ghost Dance fault trench; gauge stations on eastern slope of Yucca Mountain; foundation for ESF conveyor; Borehole USW UZ-5 workover, instrumentation and testing; Borehole USW UZ-4 workover, instrumentation and testing; study pits 0.5 km north of Lathrop Wells cinder cone; and trenching for Crater Flat Fault Study. The remaining five requests are in process.

Three requests from the last reporting period, volcanism studies at Sleeping Butte, volcanism studies at Crater Flat, and Quaternary faulting studies in Crater Flat, are awaiting right-of-way reservation grants. One request from last period, trenching in the Amargosa Valley, is awaiting the finalization of an agreement with a private land owner, and another, digital seismic stations for the Southern Great Basin Seismic Network, requires an Operations Permit from the Nevada Operations Office of DOE.

One environmental assessment for the Bureau of Land Management was prepared during this period and two more are in process. The YMP provided the services of one person to work with the Bureau of Land Management to provide an interface and to expedite processing of right-of-way reservation applications.

2.2.3 Licensing Activities

Licensing activities include the management of and participation in interactions with NRC and other oversight organizations to clarify regulatory and technical issues and reach a common understanding of regulatory requirements. The DOE has continued the Issue Resolution process of identifying, clarifying, and resolving technical and regulatory issues during site characterization. The Mined Geologic Disposal System License Application Annotated Outline (DOE, 1995h) was prepared as a DOE document and submitted to NRC for the first time in that form.

2.2.3.1 Interactions with the U.S. Nuclear Regulatory Commission and Other Organizations

This section reviews and discusses significant actions, agreements, and accomplishments that resulted from 17 interactions between DOE and NRC, 7 meetings of the Advisory Committee on Nuclear Waste, and 3 meetings of the Nuclear Waste Technical Review Board. Appendix D lists the interactions with each of the following agencies.

U.S. Nuclear Regulatory Commission

Several interactions with NRC centered on how the Program Plan is modifying DOE site characterization activities. At a December 2, 1994, Management Meeting, NRC provided comments on the DOE Five-Year Plan, which is the basis for Volume II of the Program Plan. At a January 17, 1995, Management Meeting, DOE discussed the waste isolation and containment strategy. Topics related to the Program Plan were also covered at the bimonthly Management Meetings between DOE and NRC.

Several interactions were focused on issue resolution activities. Topical reports on seismic hazard assessment (DOE, 1994g) and seismic design methodology (CRWMS M&O, in prep.[c]) were discussed at the October 7, 1994, Technical Meeting and January 26, 1995, Technical Exchange. The NRC concerns on the approach for addressing the potentially adverse condition of erosion and the absence of deterministic hazard analyses in the overall design process were resolved sufficiently to allow work on those reports to progress. The NRC concerns with the Extreme Erosion Topical Report (DOE, 1993b) were also discussed at the October 7, 1994, Technical Meeting, and NRC agreed that available information should address most, if not all, of their concerns in this area. The DOE and NRC discussed various approaches for demonstrating compliance with the ground-water travel time subsystem requirement at November 30, 1994, and March 29, 1995, Technical Exchanges. At the December 7, 1994, Technical Exchange, NRC confirmed that the DOE waste package

performance goal should provide an acceptable means of demonstrating compliance with the substantially complete containment subsystem requirement. Section 2.2.3.2 provides more discussion on Issue Resolution topics.

At a Management Meeting on November 1, 1994, DOE responded to NRC concerns on ESF design control and QA. The DOE described planned and ongoing actions to address these concerns, and reaffirmed that ESF activities are in compliance with applicable regulations. The design control and QA concerns were also discussed at three bimonthly ESF Technical Meetings during the review period. The NRC has scheduled an in-field verification April 3-6, 1995, to assess DOE corrective actions in this area. Section 2.3 provides more discussion on QA and design control concerns.

Advisory Committee on Nuclear Waste

Like the NRC, the Advisory Committee on Nuclear Waste expressed significant interest in how the Program Plan would be implemented and how it would impact DOE site characterization activities. The Committee noted that Technical Site Suitability and licensing decisions would be based on less data than originally planned, and expressed the concern that an increased use of bounding assumptions and expert judgment to compensate for the fewer data may not be sufficient.

The Advisory Committee on Nuclear Waste focused on hydrology and related issues at several meetings during the reporting period. The DOE presented the impacts of the Program Plan on saturated and unsaturated zone activities at the 68th Advisory Committee Nuclear Waste meeting. The Committee toured the Yucca Mountain site on October 20, 1994, to learn more about hydrology-related activities. In addition, the Committee held a working group meeting on Uses and Limitations of Ground-Water Dating Methods in Las Vegas on October 21, 1994. The 70th Advisory Committee on Nuclear Waste meeting January 18-19, 1995, included a presentation on the history of the ground-water travel time subsystem requirement. At the 71st Advisory Committee on Nuclear Waste meeting February 21-22, 1995, the Director of the NRC Division of Waste Management discussed the implementation of the ground-water travel time requirement. The NRC staff, the State of Nevada, and Advisory Committee on Nuclear Waste consultants made presentations on ground-water travel time at the 72nd Advisory Committee on Nuclear Waste meeting March 15-16, 1995. The Advisory Committee on Nuclear Waste expressed the concern that ground-water travel time may not be an appropriate measure of geologic repository performance, and the Committee noted that the limited latitude provided in 10 CFR 60.113(b) may not be sufficient to address this concern. The latitude specified in 10 CFR 60.113(b) allows NRC to approve or specify another radionuclide release rate, ground-water travel time, or designed containment period, as long as the overall system performance objective is met.

Nuclear Waste Technical Review Board

The Nuclear Waste Technical Review Board Fall Full Board meeting on October 12, 1994, focused on three main areas related to site suitability: (1) the process by which DOE will assess site suitability; (2) the main Technical Site Suitability issues at Yucca Mountain

and the DOE priorities regarding exploration, testing, and data collection; and (3) the roles assigned to natural and engineered barriers and the extent to which engineered barriers should be considered in evaluating site suitability. The Board noted that the schedule for making a site suitability evaluation in 1998 appears optimistic. In addition, the Nuclear Waste Technical Review Board expressed concern that the National Academy of Sciences peer review of the DOE technical basis reports does not include an integrated review of all the reports. The Nuclear Waste Technical Review Board also noted that the Academy is composed of volunteers and academics, and it may not follow the DOE process, complete the DOE stated work scope, or comply with the DOE schedule.

The Nuclear Waste Technical Review Board meeting of the combined panels on Hydrogeology and Geochemistry and Structural Geology and Geoengineering held November 17-18, 1994, focused on thermal management for a high-level waste repository. The discussions included alternative thermal management strategies, in situ thermal testing needs, performance analysis, and the DOE process for making a thermal management decision. The Nuclear Waste Technical Review Board expressed the concern that it will be difficult to determine which specific thermal issues can be addressed and answered with the current ESF tests.

The Winter Full Board Meeting January 10-11, 1995, covered a number of environmental topics, including the DOE environmental monitoring program at Yucca Mountain; the DOE strategy for National Environmental Policy Act compliance for the multi-purpose canister and for a Yucca Mountain repository; integration of the repository environmental impact statement with Yucca Mountain site characterization studies; and the DOE socio-economic program. The DOE also presented the waste isolation strategy for a Yucca Mountain repository and explained how surface-based and ESF testing would provide the data required to support site suitability and licensing evaluations related to system performance.

National Academy of Sciences

Pursuant to the Energy Policy Act of 1992 (U.S. Congress, 1992), the National Academy of Sciences Committee on Technical Bases for Yucca Mountain Standards is preparing recommendations to the U.S. Environmental Protection Agency (EPA) on public health and safety standards for Yucca Mountain. The committee held no public meetings during the reporting period. The recommendations of the National Academy of Sciences to the EPA is expected to be issued during the next reporting period. The DOE is incorporating an independent peer review by the National Academy of Sciences into its site suitability process (see Section 2.2.1 for a further discussion).

2.2.3.2 Issue Resolution

The OCRWM Issue Resolution process helps identify, clarify, and resolve technical and regulatory issues during site characterization. This process was developed based upon "The Issues-Based Approach to Planning Site Characterization" contained in the SCP (p. 8.1-1 of DOE, 1988). Issue Resolution is directed toward determining the definition and interpretation

of regulatory terms, acceptability of site characterization methodologies, and adequacy of site characterization planning and acquired data and analyses, as required by 10 CFR Part 60. Although an issue is not considered "closed" during the prelicensing period and any issue can be revisited based on new information, it is important for DOE to seek clarification and early resolution with NRC staff on as many areas of uncertainty as possible. This clarification is accomplished by frequent interactions and communications with NRC and its staff. These interactions may include reports sent to NRC staff for review and comment (e.g., topical or technical reports), letters, submittals of the Mined Geologic Disposal System License Application Annotated Outline (see Section 2.2.3.3), or meetings between DOE and NRC.

Resolution of the Site Characterization Analysis (NRC, 1989) open items is being coordinated within the Issue Resolution process. Resolving NRC open items is a bilateral process that consists of (a) OCRWM providing documentation or other basis to NRC to resolve specific items, and (b) NRC accepting (or not accepting) the basis for resolution, and informing OCRWM. Both steps are needed to remove open items from further consideration.

Issue Resolution activities during the reporting period are summarized in the following sections.

Seismic Hazards

Seismic hazards Issue Resolution activities are focused on three DOE topical reports that describe the proposed seismic hazard assessment and seismic design methodologies for Yucca Mountain. Seismic Topical Report I (DOE, 1994g) describes the probabilistic seismic hazard assessment methodology for the potential repository. Seismic Topical Report II (CRWMS M&O, in prep.[c]) will describe the seismic design methodology for systems, structures, and components at Yucca Mountain. Seismic Topical Report III will provide the seismic design inputs (seismic response spectra, time histories, and fault displacement level, etc.) for the appropriate seismic hazard levels.

The DOE transmitted Seismic Topical Report I to NRC on June 30, 1994. The NRC responded by letter dated September 7, 1994 (NRC, 1994a), stating that the report did not meet the criteria of their Topical Report Review Plan (NRC, 1994b), and therefore they would not initiate a review. The primary NRC concern was the absence of deterministic hazard analysis in the overall seismic design process. The NRC concerns were discussed at a DOE-NRC Technical Meeting on October 7, 1994, and addressed by a DOE letter to NRC dated November 9, 1994 (DOE, 1994h). The NRC responded by letter of January 12, 1995 (NRC, 1995a), and indicated that they are willing to review the topical report, based on certain understandings with DOE. These understandings related to Seismic Topical Report I were discussed further at the January 26, 1995, Technical Exchange between DOE and NRC, and DOE provided written confirmation and clarification of those understandings in a letter to NRC dated March 16, 1995 (DOE, 1995i). The DOE believes the report contains sufficient information to allow NRC to review the topical report and document the basis of their technical and regulatory concerns as a part of the topical report review process. On the basis of these interactions and correspondence, DOE has provided information requested by NRC to allow their review to begin.

Concurrently with the work on Seismic Topical Report I, DOE has been preparing Seismic Topical Report II and discussing related issues with the NRC. The DOE developed and submitted to NRC an annotated outline for Seismic Topical Report II on August 22, 1994 (DOE, 1994i). By letter of November 3, 1994 (NRC, 1994c), NRC expressed concerns with the proposed technical approach and requested a revised annotated outline, which DOE provided by letter of January 26, 1995 (DOE, 1995j). The issues of concern were discussed at the January 26, 1995, Technical Exchange between DOE and NRC. The NRC responded by letter of February 14, 1995 (NRC, 1995b), stating that the subject matter qualifies as a topical report, but they noted remaining concerns related to (a) the use of performance goal-based design and (b) the separation of preclosure and postclosure design.

Substantially Complete Containment

Issue resolution activities related to the NRC substantially complete containment subsystem requirement were successfully concluded during the reporting period. At the December 7, 1994, DOE-NRC Technical Exchange, DOE and NRC discussed the substantially complete containment issue and related Site Characterization Analysis open items. The DOE discussed ongoing and planned activities related to waste package material research and waste package design, and the NRC reaffirmed its statement that satisfying the DOE waste package performance goal (mean waste package lifetime well in excess of 1,000 yr) is an acceptable means of demonstrating compliance with the substantially complete containment requirement. By letter dated March 7, 1995 (NRC, 1995c), NRC stated that it considers a number of related Site Characterization Analysis open items (Comment 80 and Questions 35, 37, 47, and 53) to be resolved.

Absence of Extreme Erosion

The DOE and NRC discussed NRC comments on the Extreme Erosion Topical Report (DOE, 1993b) at the October 7, 1994, DOE-NRC Technical Meeting. The NRC indicated that they had no significant technical concern related to extreme erosion at Yucca Mountain but stated that the DOE topical report had not provided a convincing case for the absence of the potentially adverse condition. The DOE agreed to provide supplemental responses to the NRC comments and concerns, drawing upon multiple lines of evidence to substantiate the case. In addition, DOE intends to provide corroborating evidence for the varnish cation ratio dating method. The DOE and NRC discussed the draft supplemental DOE responses by telephone on January 13, 1995. The supplemental responses will be provided to the NRC in April 1995, and the corroborating dating evidence will be provided when available, in late 1995. For more discussion on extreme erosion, see Chapter 3, Section 3.5 of this Progress Report.

Volcanism

The DOE provided the NRC onsite representative informational advance copies of the final technical report on the status of volcanic hazards investigations at the potential Yucca Mountain repository (Crowe et al., 1995). In addition, DOE initiated an expert elicitation process on the probability of volcanism at Yucca Mountain. Geomatrix, Incorporated, is

coordinating the expert elicitation process, which will include four workshops. The first workshop was held in Phoenix, Arizona, February 22-23, 1995, and the second workshop was held in Las Vegas, Nevada, March 29-30, 1995. In conjunction with the second workshop, Geomatrix led a field trip to the Crater Flat area on March 28, 1995. The expert elicitation process should be completed during the next reporting period. Section 3.6 provides more discussion on volcanism.

Ground-Water Travel Time

The DOE presented its approach for calculating pre-waste-emplacement ground-water travel time to NRC at the DOE-NRC Technical Exchange held November 29-December 1, 1994. In summary, this approach would first define the boundary of the disturbed zone as a near-field zone of permanent changes to flow and transport parameters caused by the thermal effects of the repository. The ground-water travel time would then be calculated under pre-waste-emplacement conditions from the boundary of the disturbed zone through the unsaturated and saturated zones to the accessible environment. The significance of travel times of 1,000 yr or less in terms of radionuclide release would also be evaluated.

At the same Technical Exchange, NRC staff suggested an alternative conceptual approach for taking into account the effects of disturbances and for determining the fastest path of likely radionuclide travel. The suggestion for taking disturbances into account would involve conducting two calculations, one under pre-waste-emplacement conditions and the other under post-waste-emplacement conditions. If the post-waste-emplacement travel time was not significantly less than the pre-waste-emplacement time, the pre-waste-emplacement ground-water travel time would be used as the basis for evaluating compliance with the rule. The staff's suggestion for determining the "fastest path" of radionuclide travel involved constructing a distribution of the fastest travel time from each travel-time realization and defining the "fastest path" as the mean or median of that distribution.

The DOE revised its approach consistent with the NRC suggestion for taking the disturbed zone into account. This revised approach includes conducting the two travel-time calculations suggested by the staff from the repository to the accessible environment, one under pre-waste-emplacement conditions and the other under post-waste-emplacement conditions. The post-waste-emplacement calculation would be performed as a function of time and thermal loading to include the effects of the thermal pulse. If the travel time was not significantly degraded under post-waste-emplacement conditions the pre-waste-emplacement calculation from the repository to the accessible environment would be used to evaluate compliance with the rule. If the post-waste-emplacement travel time was significantly degraded, then the boundary for the calculation would have to be moved outward from the repository in increments until the pre- and post-waste-emplacement results were similar. In this instance, the evaluation of compliance would be based on calculation of pre-waste-emplacement travel time from that location, taking into account both the likelihood of occurrence of travel times less than 1,000 yr and the significance of radionuclide transport through such pathways. This revised approach was presented at the DOE Technical Program Review in February 1995 and at the DOE-NRC Technical Exchange on March 29, 1995.

In its discussions with the staff on March 29, DOE described how the likelihood of travel times less than 1,000 yr would be evaluated and explained why it believes that the mean or median of a distribution of fastest paths would be unlikely to represent the fastest path of likely radionuclide travel. The DOE also stated that taking into account the significance of radionuclide transport through pathways in which travel time might be less than 1,000 yr would contribute to an evaluation of compliance that would be reasonable. The staff further clarified its suggestion on how the disturbed zone should be taken into account.

For more discussion of the calculational aspect of ground-water travel time, see Chapter 6, Section 6.5 of this Progress Report.

Resolution of Site Characterization Analysis Open Items

The Project continues to work toward resolving open items from the Site Characterization Analysis (NRC, 1989). During the reporting period, OCRWM provided supplemental responses to Comment 80, on October 7, 1994 (DOE, 1994j), Comment 101, on October 11, 1994 (DOE, 1994k), Question 53, on October 7, 1994 (DOE, 1994j), Question 37, on November 23, 1994 (DOE, 1994m), and Question 35, on December 2, 1994 (DOE, 1994n). In addition, NRC staff agreed that OCRWM provided the technical basis to resolve Question 43 in a letter dated February 17, 1995 (NRC, 1995d), and Comment 80, Question 35, Question 37, Question 47, and Question 53 in a letter dated March 7, 1995 (NRC, 1995c).

As of the end of this reporting period, 94 open items have been closed by NRC (including 2 objections) and 104 remain open. The majority of the remaining open items await data to be acquired through site characterization activities for their resolution. Of the 104 remaining open items, 26 were being reviewed by the NRC staff after DOE submitted supplemental responses.

Appendix E presents the status of Site Characterization Analysis comment resolution. For each open item, actions that need to be performed to close the item are identified. Open items will continue to be resolved as site characterization and other programmatic activities provide pertinent information.

Resolution of Progress Report Comments and Questions

During this reporting period the Project received no new comments or questions from NRC staff on Progress Reports.

As of the end of this reporting period, 19 observations, two comments, and three questions have been closed; two comments and five questions remain open. The DOE thinks that the remaining open items [one from Progress Report #6 (DOE, 1992a), one from Progress Report #7 (DOE, 1992b), and five from Progress Report #8 (DOE, 1993c)] have been addressed in subsequent Progress Reports, but NRC staff verification of responses has not been received.

Forecast: During the second half of FY 1995, DOE intends to accomplish the following through the Issue Resolution process: (a) respond to NRC questions that arise during the review of Seismic Topical Report I; (b) submit Seismic Topical Report II to NRC for review; (c) provide supplemental responses to NRC comments on the Erosion Topical Report, and provide additional corroborating dating information; (d) present its revised approach to calculating ground-water travel time to the Advisory Committee on Nuclear Waste at its 73rd Meeting in April 1995; (e) work with NRC to develop a methodology for calculating ground-water travel time that is mutually acceptable; (f) complete an expert elicitation on the probability of volcanism at the potential repository site; (g) respond to NRC comments on two study plans related to volcanism and volcanic hazards (Study Plans 8.3.1.8.1.1, "Probability of Magmatic Disruption of the Repository," and 8.3.1.8.5.1, "Characterization of Volcanic Features"); (h) initiate discussions with NRC on long-term repository criticality control; and (i) continue to pursue resolution of remaining Site Characterization Analysis open items.

2.2.3.3 License Application Annotated Outline

Revision 0 of the Mined Geologic Disposal System License Application Annotated Outline was transmitted to NRC on March 31, 1995. Though Revision 0 marks the transition from an M&O contractor document to a DOE document, it continues to directly build on and enhance the information presented in the previous revisions. Chapters 3, 4, 5, 6, and 7 were significantly revised in this revision. The practice of including both skeleton text and planning package materials has been eliminated by removing the planning package materials from all sections to eliminate the perceived duplication of information. In addition, editorial and consistency changes were made throughout the document. Over 1,100 information needs were identified during the development of Revision 0. These information needs will be incorporated into the annual and long-range planning process to help focus site characterization, design, and performance assessment activities on the acquisition of information needed to demonstrate regulatory compliance.

Revision 0 was developed using the format and content guidance provided in NRC Draft Regulatory Guide DG-3003 "Format And Content For The License Application For The High-Level Waste Repository" (NRC, 1990). Future revisions will not only implement the systems-based approach in the Format and Content Regulatory Guide but will also follow the guidance provided in NUREG-1323 "License Application Review Plan for a Geologic Repository for Spent Nuclear Fuel and High-Level Radioactive Waste" (NRC, 1994d). The License Application Review Plan was not received early enough to be factored into the preparation of Revision 0.

Forecast: Revision 1 of the License Application Annotated Outline is planned to be issued to the NRC in January 1996. Revision 1 will include significant revisions and additions to most chapters. The major information scheduled to be incorporated into Revision 1 is included in Volume II of the Civilian Radioactive Waste Management Program Plan, presented to NRC in December 1994.

2.3 QUALITY ASSURANCE

During this reporting period, the Office of Quality Assurance enhanced the audit program to include performance based audits. These audits will provide OCRWM with an overview of product adequacy. The Office of Quality Assurance has continued to focus on transition to the new Quality Assurance Requirements and Description (DOE, 1992c) as a priority task with all but one affected organization now accepted to the new document.

2.3.1 Program Activity

The Quality Assurance Requirements and Description document is the principal QA document for the Civilian Radioactive Waste Management Program. The Quality Assurance Requirements and Description contains regulatory requirements and program commitments necessary for the development of an effective QA. Significant progress has been made in the transition to the new Quality Assurance Requirements and Description. By the end of this reporting period, the following organizations had transitioned to the new Quality Assurance Requirements and Description: U.S. Geological Survey (USGS), Technical & Management Support Services, SNL, Lawrence Livermore National Laboratories (LLNL), Los Alamos, CRWMS M&O, and OCRWM.

During this reporting period, significant changes have been made in the processes associated with identifying and controlling quality-affecting activities. As described below, the procedures for QA classification and implementing QA controls to limit adverse impacts to the site during site characterization have been enhanced.

The Office of Quality Assurance helped DOE management develop a response to an October 13, 1994, letter from the NRC (NRC, 1994e). This letter expressed concerns regarding the design control process. For further details, see Section 2.3.4 of this report.

The Office of Quality Assurance began implementing a performance-based audit program. While audits have focused on programmatic adequacy through review of requirement flowdown to procedural implementation, performance-based audits provide a review of processes which impact product adequacy. Performance-based audits evaluate processes, tasks, or end products on the basis of expected results. This auditing method increases line management involvement by allowing management to assist in the development of auditing criteria. Conclusions can be drawn about the effectiveness of the process and/or the adequacy of the product.

The Office of Quality Assurance, Yucca Mountain Quality Assurance Division, conducted seven audits during this reporting period. Audits are verification activities that are planned and documented to evaluate compliance with requirements and determine effectiveness of implementation through a review of objective evidence. The following organizations were subject to audit: Los Alamos, LLNL, CRWMS M&O, Reynolds Electrical & Engineering Co., Inc., Technical & Management Support Services, SNL, and USGS.

Audit results indicate that all organizations, with the exception of the M&O, are satisfactorily implementing the Quality Assurance Requirements and Description. The audit of the M&O determined that the Corrective Action Program was not effectively implemented. The deficiency in the M&O Corrective Action process has been documented by the Office of Quality Assurance. The Office of Quality Assurance will monitor and verify resolution of this issue.

In addition to audit activities, the Yucca Mountain Quality Assurance Division conducted fifteen surveillances during the reporting period. Surveillances are observations of real-time quality-affecting activities and/or the review of documentation to verify conformance with specified requirements. The surveillances evaluated specific site characterization activities including the adequacy and effectiveness of corrective actions taken to resolve previously reported conditions.

Quality Assurance Divisions for the organizations supporting DOE conducted many verification activities during this reporting period. The affected organizations performed 28 audits and 89 surveillances on internal and external organizations.

Forecast: The Office of Quality Assurance is revising the corrective action process. OCRWM procedures are being established to address identification of deficient conditions, trending and root cause analysis. Integration of the corrective action process will provide the standardization needed for the establishment of a program that can accommodate trending for both OCRWM and individual affected organizations.

2.3.2 Determination of Importance Evaluations

A Determination of Importance Evaluation remains as the mechanism established by the Project for the identification and control of potentially site-disturbing activities. Determination of Importance Evaluations are still performed to identify and provide controls on activities with the potential to impact site characterization testing or the natural barrier's capability to isolate waste. As discussed in Section 2.3.2, the Determination of Importance process evolved during this reporting period to a revision to M&O Nevada Line Procedure-2-0, Determination of Importance Evaluations (Revision 1). General application of Total Quality Management concepts identified the need for process changes, which were subsequently supported by various QA findings. As a result, the Determination of Importance process has undergone some fundamental enhancements. Changes to the process include the following:

- Requiring reviews by affected organizations (i.e., those with input to the Determination of Importance Evaluation and those expected to use the document as input to a design or test package) to ensure requirements are effectively developed and communicated

- Determination of Importance Evaluation staff review of the subsequent implementing documents to ensure Determination of Importance Evaluation requirements are properly interpreted

- Combining the Waste Isolation, Test Interference, and Determination of Importance Evaluations into a single document to improve efficiency and ensure consistency in scope and format

- Separating the QA Classification and Determination of Importance Evaluation process into distinct products to formalize QA classification earlier in the design process and eliminate confusion between QA classification site-impact-related QA requirements

- Determination of Importance Evaluation staff participation in the field change control process to ensure Determination of Importance Evaluation requirements are not compromised through the change process.

Through these changes and an increased emphasis on more effective communications, Determination of Importance Evaluations have been revised to clarify requirements (e.g., in the North Portal Pad Determination of Importance Evaluation, to clarify ambiguous wording in the requirements). Determination of Importance Evaluations have also been combined for efficiency (e.g., the 69kV Power Supply System Determination of Importance Evaluation was incorporated into the North Portal Pad Determination of Importance Evaluation), and revised to ensure critical site characterization activities occur when required [e.g., the North Ramp (Package 2C) Determination of Importance Evaluation requires Test Coordination Office concurrence on the timing of test alcove construction where timing is critical to test interference impact].

The new process also provides for increased flexibility in evaluating site impacts, through the recognition of Category I, II, and III Determination of Importance Evaluations. Category I Determination of Importance Evaluations allow efficient, formal documentation of the decision-making process for field activities that are limited in scope or sufficiently remote that no reasonable scenario would result in potential impact to waste isolation or site characterization (e.g., for limited excavation activities, or activities involving insignificant use of materials such that no impact will occur). Category II Determination of Importance Evaluations permit limited evaluations for activities that are bounded by existing evaluations with respect to potential impact and resulting QA controls (e.g., for activities sufficiently similar in scope to a previously-evaluated activity such that the existing controls are adequate). A Category III Determination of Importance Evaluation is performed when an activity has not been evaluated before, and has the potential to impact the site such that QA controls may be warranted.

Activities, which include site characterization activities involving the use of temporary items, are evaluated with respect to their potential adverse impacts on permanent, important items (i.e., items on the Q-List (DOE, 1990), including the natural barrier). Based on these potential impacts, appropriate controls are established for the associated activities. As part of

the planning process for testing and construction activity, Determination of Importance Evaluations consider the potential of site characterization activities to interfere with ongoing or planned tests, and to affect the ability of the site to isolate waste. Potential test interference or waste isolation concerns are addressed through imposition of controls on testing, design, construction, or operations activities. Waste Isolation Evaluations and Test Interference Evaluations have historically been inputs into job packages or test planning packages, or inputs to Determination of Importance Evaluations, which are in turn inputs to design packages, job packages, or test planning packages.

Under the revised M&O Nevada Line Procedure-2-0, the Determination of Importance Evaluation compiles the considerations for test interference and waste isolation impacts into a single document, thereby ensuring that the scope of evaluation is consistent. Conclusions of the impact assessment result in QA requirements for conducting the activity. The M&O Determination of Importance Evaluation organization receives requests for evaluations of site-disturbing activities from all participants. On the basis of potential site impacts of an activity, a Determination of Importance Evaluation is prepared which establishes the minimum controls on the activities, including on the use of associated tracers, fluids, and materials. This information is transmitted to the job package or test planning package coordinator (for surface-based testing) or to the design organization (for ESF) for incorporation into appropriate packages, specifications, or drawings. The information is also transmitted to EG&G for updating the tracers, fluids, and materials data base. As-built information on the actual use of tracers, fluids, and materials is provided by the constructor or tester to EG&G. A YMSCO procedure, YMP Administrative Procedure-2.8Q, is in review and will provide specific guidance to participants in requesting and reporting tracers, fluids, and materials.

During this reporting period, the following Determination of Importance Evaluations were produced. Some of these Determination of Importance Evaluations were prepared prior to the revision of M&O Nevada Line Procedure-2-0, and corresponding input Waste Isolation Evaluations and Test Interference Evaluations exist for each.

ESF Determination of Importance Evaluation

Determination of Importance Evaluation for Muck Storage Area

Determination of Importance Evaluation for North Portal Pad

Determination of Importance Evaluation for North Ramp (ESF Package 2C)

Determination of Importance Evaluation for Subsurface Wastewater and Sanitary Sewer System

Determination of Importance Evaluation for Integrated Data and Control System

Determination of Importance Evaluation for Diesel Exhaust Emissions Study

Surface-Based Testing Determination of Importance Evaluation

Determination of Importance Evaluation for Instrumentation of USW NRG-7A and USW NRG-6

Determination of Importance Evaluation for UE-25 ONC#1 and NRG#4 (Nye County Oversight Boreholes)

Determination of Importance Evaluation for UE-25 UZ-16 Instrumentation

Determination of Importance Evaluation for Workover, Instrumentation, and Testing of Miscellaneous Boreholes

Determination of Importance Evaluation for Drilling USW UZ-7A

Determination of Importance Evaluation for Magnetotelluric Surveys

Determination of Importance Evaluation for Solitario Canyon Trench SCF-E1 Excavation

Determination of Importance Evaluation for Ghost Dance fault Trench GDF-T5 Excavation

Forecast: The project level tracers, fluids, and materials procedure is expected to be implemented. Generic, global-scope surface and subsurface Determination of Importance Evaluations are planned to eliminate package dependence and improve turnaround time on preparation of Determination of Importance Evaluations.

2.3.3 Q-List and Management Control List

The Yucca Mountain Project Q-List (DOE, 1990) and Management Control List (DOE, 1993d) are used to tabulate permanent items (i.e., items which may become part of a licensed pre- or postclosure repository). The Q-List describes those permanent items determined to be important to radiological safety, important to waste isolation, or otherwise subject to the requirements of the Quality Assurance Requirements and Description as specified in Section 2.2.3A. The Management Control List describes those permanent items determined not to be subject to these Quality Assurance Requirements and Description requirements, and are subject to conventional quality management and design controls.

Both documents reflect conclusions of classification analyses; the Q-List also contains items originally placed thereon by direct inclusion using a conservative assumed basis. Items on the Q-List by direct inclusion require documented analysis to warrant their removal.

Previously, a Determination of Importance Evaluation was the mechanism established by the Project for classification, grading, and the identification and control of potentially site-

disturbing activities. During this reporting period, the M&O has separated these functions into separate procedures. Determination of Importance Evaluations are still performed to identify and provide controls on activities with the potential to impact site characterization testing or the natural barrier's capability to isolate waste (Determination of Importance Evaluations are discussed further in Section 2.3.3). Classification Analyses of potential repository items, however, is now performed apart from the Determination of Importance Evaluation.

Classification Analyses are performed in accordance with M&O Quality Administrative Procedure-2-3, "Classification of Permanent Items," which was revised during this reporting period to address the creation of a Waste Acceptance, Storage, and Transportation Q-List, and changes to the Waste Acceptance, Storage, and Transportation and Mined Geologic Disposal System Q-Lists. The revised procedure also addresses the interface between Waste Acceptance, Storage, and Transportation and Mined Geologic Disposal System, in recognition that analyses under one project may impact the Q-List of another. For example, the Waste Acceptance, Storage, and Transportation Classification Analysis for the multi-purpose canister may result in changes to the Mined Geologic Disposal System Q-List. As discussed briefly above, the separation of Classification Analyses and Determination of Importance Evaluations eliminates potential confusion with respect to requirements that derive from QA classification (M&O Quality Administrative Procedure-2-3) vs. limiting site impacts (M&O Nevada Line Procedure-2-0; see Section 2.3.3).

The M&O Quality Administrative Procedure-2-3 establishes the evaluation criteria for the classification of permanent items (i.e., items which are assumed to have a function in an operating repository) in accordance with the requirements of Quality Assurance Requirements and Description Section 2.2.3 A. The Classification analysis (prepared in accordance with the format and content requirements of M&O Quality Administrative Procedure-3-9, "Design Analysis," is the supporting analysis for the Quality Assurance Procedure-2-3 classification, which identifies whether a permanent item has a function which falls within one or more of seven categories:

QA-1 Important to Radiological Safety

QA-2 Important to Waste Isolation

QA-3 Important to Radioactive Waste Control

QA-4 Important to Fire Protection (i.e., of QA-1 or -2 items)

QA-5 Important to Potential Interaction (i.e., function not required, but failure could impact QA-1 or -2 items)

QA-6 Important to Physical Protection of Facility and Materials

QA-7 Important to Occupational Radiological Exposure.

Note that the classification numbers do not imply an order of importance. When a classification analysis results in a change to the Mined Geologic Disposal System Q-List, the M&O prepares a draft revision to the Q-List and proposes that change to YMSCO.

Also during this reporting period, "QA Classification and Implementation Plan," (DOE, 1995k) and YMP Administrative Procedure-2.7Q, Item Classification and Maintenance of the Q-List, were approved. These two documents provide overall guidance on the classification of repository items; the latter of these documents, which is the governing procedure for changes to the Mined Geologic Disposal System Q-List, is designed to interface with M&O Quality Administrative Procedure-2-3. As discussed above, M&O Quality Administrative Procedure-2-3 directs the M&O to propose changes to the Q-List based on the results of classification analyses. YMP Administrative Procedure-2.7Q provides the process and criteria that YMSCO uses to review those proposed changes.

The implementation of the QA Classification and Implementation Plan and YMP Procedure-2.7Q complete the transition to the classification and grading process which has been in development for the past three years. As a result, changes to the Q-List are no longer processed through an assessment team. The QA Classification and Implementation Plan and YMP Administrative Procedure-2.7Q also collectively supersede YMP Administrative Procedure-6.17Q, Classification of Items Important to Safety and Waste Isolation.

During this reporting period, Revision 3 to the Q-List was approved. Revision 3, originally forecast to be completed in FY 1994 (as discussed in Progress Report #10), was delayed to include proposed changes as a result of the Determination of Importance Evaluation associated with the North Ramp excavation (i.e., ESF Package 2C). This Determination of Importance Evaluation resulted in the recommendation that the North Ramp be formally recognized as the assumed Waste Ramp on the Q-List.

Revision 2 to the Management Control List was also approved to add the Muck Storage Area.

Forecast: Revision 4 of the Q-List is expected to clarify the transition zone in ancillary excavations off the main ramp, and to add the multi-purpose canister based on a Waste Acceptance, Storage, and Transportation classification analysis. The Management Control List is expected to be deleted as a separate entity during the last half of the fiscal year.

2.3.4 Design Control

In an October 13, 1994, letter, (NRC, 1994e) NRC documented continued concerns with the design control process, as implemented by the M&O, and DOE oversight of the M&O QA program. The basis for these concerns was OCRWM corrective action requests that documented deficiencies in the CRWMS M&O QA program. Among these concerns were the potential impacts to site characterization testing and the site's waste isolation capabilities that could result from completion of work under ESF Design Package 2C.

(Design Package 2C addresses North Ramp excavation layouts, ground support, utilities, electrical power, site lighting, site grounding, and alcoves.) The NRC expressed concerns with tunnel boring machine operation and its potential to impact site characterization or the waste isolation capability of the site. Their primary concerns were that the M&O had not demonstrated effective implementation of its QA program for design control and DOE had not provided effective oversight that promptly identified and corrected deficiencies at an early stage.

In a November 14, 1994, response (DOE, 1994o), DOE described the criteria and results from the Determination of Importance Evaluation performed for Design Package 2C to ensure site impacts were limited to the extent practical. The DOE concluded that there is no specific demarcation point associated with excavating the North Ramp beyond which the potential for impacts increases. To acknowledge NRC concerns about compromising pneumatic data collection, however, a hold was placed on the tunnel boring machine operation. This hold ensures that excavation would not advance beyond a potentially critical stratigraphic contact before adequate pneumatic data were obtained from boreholes adjacent to the tunnel. Section 3.1.7 reports on the pneumatic data collected during this reporting period.

The DOE acknowledged that NRC had raised valid concerns and that some problems are recurring. Extensive remedial actions were taken to ensure that all design products released for construction had incorporated appropriate requirements. Some of the difficulty relates to the problem of demonstrating how 10 CFR Part 60 requirements flow down through the OCRWM document hierarchy to the design products. Thus, DOE committed to compile these considerations into a single document that describes (a) the criteria used to identify and minimize potential impacts and (b) the incorporation of 10 CFR Part 60 requirements into the ESF design.

Responding to that commitment, the M&O developed and submitted the Regulatory Compliance Review Report (DOE, 1995d) in March 1995. The Regulatory Compliance Review Report was formatted to address the overall implementation of 10 CFR Part 60 requirements into the current ESF design, and the specific issue of addressing site impacts during construction. The report briefly discussed the OCRWM document hierarchy, emphasizing the allocation of 10 CFR Part 60 requirements to the ESF. In the report, DOE selected a sample of 10 CFR Part 60 requirements and documented the implementation of those requirements through the Exploratory Studies Facility Design Requirements document (DOE, 1995c) and into the design products. The Exploratory Studies Facility Design Requirements document provides the allocation and traceability of 10 CFR Part 60 requirements for ESF configuration items.

The Regulatory Compliance Review Report discussed the integrated design for the ESF and the geologic repository operations area, including repository considerations in response to several 10 CFR Part 60 requirements. Design Package 2C was described, including the configuration items that make up the package. Fifteen 10 CFR Part 60 requirements, weighted to address NRC concerns, were selected for the report. Despite the difficulty in demonstrating requirements flowdown through the document hierarchy to the design, the report completed this demonstration for the selected requirements. Section 3 of the report

discusses 10 CFR 60.15(c)(1), which requires DOE to "limit adverse effects" to the site during characterization activities. The report described the Determination of Importance Evaluation process and listed the resulting controls imposed upon Design Package 2C to limit impacts.

Section 4 of the Regulatory Compliance Review Report also discussed performance assessment, waste isolation evaluations, and test interference evaluations that help control adverse effects to site characterization testing and the ability of the site to isolate waste. The discussion focused on the criteria for discrete assessments performed in support of individual design packages and also discussed the overall impact to the site of the ESF.

The report concluded that the allocation and implementation of 10 CFR Part 60 requirements, including those intended to limit adverse effects to the site, is adequate, considering the data presented. The major conclusions are as follows:

- The design process has adequately allocated and implemented 10 CFR Part 60 requirements in Design Package 2C.
- Adequate controls are in place to preclude significant adverse impacts on waste isolation and the ability to characterize the site.
- While some problems with the requirements allocation process have been identified as a result of this and previous similar reviews, DOE and M&O processes are being revised to address them.
- The problems encountered in the review of requirements implementation have resulted in conservative allocation of requirements in the past.
- The current construction efforts do not represent potential adverse impacts to the waste isolation capability of the site.

The DOE committed to revise the report for the remaining 10 CFR Part 60 requirements that apply to developing Design Package 2C and, for each major design package, to continually ensure that adverse impacts are adequately addressed, not only from a discrete perspective, but also in an integrated fashion as design progresses. After completing the revised report, DOE will evaluate lessons learned and determine improvements needed to document compliance with 10 CFR Part 60.

In a March 9, 1995, letter (NRC, 1995e), NRC provided the results of its initial staff review of the DOE November 14, 1994, response to their QA concerns and outlined a plan for a three-phase verification. As outlined in the letter, Phase 1 was NRC review of the DOE November letter, which indicated that the NRC staff thought the DOE response was acceptable. They reserved final approval, however, until verification of implementation of the corrective actions in Phases 2 and 3. Phase 2 was to include an independent, limited-scope, in-field verification to be conducted by a team of QA and technical staff from NRC and the

Center for Nuclear Waste Regulatory Analyses. This in-field verification was scheduled for April 3-6, 1995.

The NRC also outlined Phase 3, which will involve (a) review of the Regulatory Compliance Review Report, (b) review of the DOE response to the NRC letter regarding pneumatic pathways, and (c) a limited-scope, in-field verification of the acceptability and effectiveness of DOE and M&O activities related to these two documents.

Forecast: Phase 2 in-field verification will occur in early April. Work will continue on documenting the remaining 10 CFR Part 60 requirements that apply to the development of Design Package 2C, evaluating lessons learned, and determining improvements needed to document compliance with 10 CFR Part 60.

2.4 PROGRAM OUTREACH

The DOE communicates issues to the public in an effort to create a climate of understanding. According to provisions in the Nuclear Waste Policy Act, as amended, public involvement is an integral component of the site characterization process. To achieve public involvement, DOE manages a variety of public outreach programs, produces public information products, develops a media relations program, conducts stakeholder interactions programs, and supports policy development. This section discusses the activities accomplished during the reporting period.

Eighty-eight tours of Yucca Mountain, including five Public Open House tours, were conducted for approximately 2,100 members of the public and other interested parties. Tours of special interest included tours for Congressman Tom Bevill, D-Alabama; the Senior Technical Advisor to OCRWM; the Secretary of Energy's Independent Management Review Team; the British Broadcasting Corporation; guests from the National Science Teachers Association Area Conference; guests from the Nuclear Energy Institute; guests from Waste Management '95; Congressional staff; guests from the National Association of Regulatory Utility Commissioners; and the DOE Under Secretary.

Numerous programmatic and technical workshops, presentations, and meetings were held in various Nevada communities to provide current information to the public regarding site characterization progress. The Project coordinated and attended the National Stakeholders' Meetings, and coordinated and attended two Affected Units of Local Government meetings. Staff attended the Affected Units of Local Government Multi-Purpose Canister Environmental Impact Statement Workshop, held to acquaint the local governments with the Environmental Impact Statement process and to discuss specific issues concerning public safety, health, and transportation, in preparation for the multi-purpose canister Environmental Impact Statement scoping meetings, which were also attended. A total audience of approximately 14,300 people attended 133 speaking presentations during this period, which included 11 technical presentations, 39 general Project overview presentations, and 83 educational presentations.

The Yucca Mountain Science Centers, located in Las Vegas, Beatty, and Pahrump, Nevada, received approximately 5,400 visitors. At the Science Centers, Project staff presented three Yucca Mountain Speaker Series presentations, four Girl Scout geology workshops, one Boy Scout nuclear energy workshop, 31 teacher workshops, and 15 environmental, energy, and geology workshops for fifth graders. Other events included two speakers bureau brown bag luncheons, Science Bowl, JASON Project, and a Boy Scout Camporee. Project public information exhibits were staffed for 17 events, with approximately 9,500 visitors.

The Project produced and distributed a variety of public information products, including a new work update video, featuring the tunnel boring machine, Fran Ridge Large Block Test, and the computerized data collection system; an eight-minute updated video on sample management procedures, entitled "Rigorous Management of Samples for World Class Science;" an environmental video; four specialty videos; and a year-end video that included reviewing 1994 site characterization activities, program approach management changes, and increased public involvement. Staff completed text for the Winter 1995 *OCRWM Bulletin Of Mountains and Science* and updated several new work displays for the Yucca Mountain exhibits program and the Yucca Mountain Science Center. During this period, the following were created, revised, or modified and distributed: one new folder, seven fact sheets, five Outreach Program fact/fliers, 14 Outreach event announcements/fliers, nine Project displays, two "points of interest" documents, one Sample Management Facility sign, two signs for the Beatty Science Center, one billboard, one portable ESF model, two program overview presentations, and four information/fact cards.

2.5 INTERNATIONAL PROGRAM

The OCRWM international program cooperated with a number of countries and international organizations to exchange information of mutual interest, to work toward achieving consensus on common issues, and to develop and conduct cooperative activities of mutual benefit. Work continued on three major cooperative research agreements with Canada (Atomic Energy of Canada, Ltd), Switzerland (National Cooperative for the Disposal of Radioactive Waste), and Sweden (Nuclear Fuel and Waste Management Co.).

These countries possess major research facilities of a type not available in the United States; namely, the Underground Research Laboratory in Canada, the Grimsel research facility in Switzerland, and the Hard Rock Laboratory in Sweden. Under the cooperative agreements, scientists from the United States are able to obtain relevant data that otherwise would not be available for several years, if ever, from a similar facility in this country. In addition, the agreements result in valuable exchanges of ideas and information that assist in improving site characterization investigations at Yucca Mountain. The agreements also result in access to globally unique natural analog sites in Canada and in New Zealand. These agreements are, respectively, a site exceptionally high in uranium (thereby, permitting studies of migration of radionuclides, including some fission products) and a well-studied hydrothermal system in which conditions resemble those expected in a repository in welded tuff. The final category of international cooperation involves topics in which the widest feasible agreement and

consensus is highly desirable. This area includes thermodynamic and thermochemical data for radionuclides for input to computer codes needed in support of performance assessment and verification and confidence building in the codes themselves.

Canadian Program

The cooperative work with Canada included eight technical tasks: radionuclide retardation model development, field tracer test development, natural analog studies at Cigar Lake, fundamental materials investigations, in situ stress determination, spent fuel dissolution model development, hydrochemical tool testing, and performance assessment technology. These tasks, respectively, relate to the following sections of this report:

3.2.9	Study 8.3.1.3.4.3, Development of Sorption Models
3.1.14	Study 8.3.1.2.3.1, Characterization of the Site Saturated-Zone Ground-Water Flow System
3.2.14	Study 8.3.1.3.7.1, Retardation Sensitivity Analysis
5.2.6	Study 1.10.4.5, Characterize the Effects of Man-Made Materials on Water Chemistry in the Postemplacement Environment
3.11.9	Study 8.3.1.15.2.1, Characterization of the Site Ambient Stress Conditions
5.3.6	Activity 1.5.3.3, Generate Models for Release from Spent Fuel
3.1.15	Study 8.3.1.2.3.2, Characterization of the Saturated Zone Hydrochemistry
Chapter 6	Performance Assessment.

Swiss Program

The cooperative work with Switzerland included five technical tasks: transport characterization in fractured rocks, multi-phase flow in fractured porous rocks, seismic tomographic imaging, mechanistic approach to sorption of radionuclides, and borehole fluid logging. These tasks, respectively, relate to the following sections of this report:

3.1.16	Study 8.3.1.2.3.3, Saturated-Zone Hydrologic System Synthesis and Modeling (first two tasks)
3.3.4	Study 8.3.1.4.2.2, Characterization of the Structural Features within the Site Area
3.2.9	Study 8.3.1.3.4.3, Development of Sorption Models.

3.1.14 Study 8.3.1.2.3.1, Characterization of the Site Saturated-Zone Ground-Water Flow System

Swedish Program

The cooperative work with Sweden included five technical tasks: flow and transport characterization in fractured rocks, disturbed zone effects, geochemical modeling, ground-water flow and water-rock interactions using radiogenic isotopes, and development of capability for integration of construction and testing related to the ESF. These tasks, respectively, relate to the following sections of this report:

3.1.14 Study 8.3.1.2.3.1, Characterization of the Site Saturated-Zone Ground-Water Flow System

5.2.3 Study 1.10.4.2, Hydrologic Properties of the Waste Package Environment

3.2.14 Study 8.3.1.3.7.1, Retardation Sensitivity Analysis

3.1.3 Study 8.3.1.2.1.3, Characterization of the Regional Ground-Water Flow System

Chapter 7 Exploratory Studies Facility Design and Construction.

Thermochemical Data Base

Cooperative work has been under way for several years under the auspices of the Nuclear Energy Agency of the Organization of Economic Cooperation and Development. This task relates to Section 5.3.5, Activity 1.5.3.2, Develop Geochemical Speciation and Reaction Model, of this report

CHEMVAL

Cooperative work in support of the international CHEMVAL project relates to Section 3.2.14, Study 8.3.1.3.7.1, Retardation Sensitivity Analysis, of this report.

Taupo Volcanic Zone Natural Analog

Work conducted cooperatively between LLNL and the New Zealand Institute of Geological and Nuclear Sciences relates to Section 3.2.4, Study 8.3.1.3.3.1, Natural Analog of Hydrothermal Systems in Tuff, of this report.

CHAPTER 3 - SITE PROGRAMS

The site characterization effort for the Yucca Mountain, Nevada, site consists of a number of component programs. These programs, a reference to the section providing a summary of the progress during this reporting period, and a brief description of the activity are as follows:

- Geohydrology (Section 3.1) - investigates surface and subsurface hydrology on both site and regional scales, with ground water flow system characterization and modeling for both the unsaturated zone and saturated zone (SCP Section 8.3.1.2).

- Geochemistry (Section 3.2) - investigates and models rock chemistry and mineralogy, ground water chemistry, and geochemical behavior of materials along potential radionuclide transport pathways (SCP Section 8.3.1.3).

- Rock Characteristics (Section 3.3) - characterizes and models rock stratigraphic and structural features and distributions within the site area, and integrates geophysical and drilling activities to obtain subsurface stratigraphic and structural data (SCP Section 8.3.1.4).

- Climate (Section 3.4) - analyzes paleoclimate, paleohydrology, and paleo-environment, and characterizes modern climate, future climate, and future hydrology (SCP Section 8.3.1.5).

- Erosion (Section 3.5) - characterizes modern and past erosion and evaluates the potential effects of future climate and tectonics on erosion (SCP Section 8.3.1.6).

- Postclosure Tectonics (Section 3.6) - characterizes tectonic features, such as igneous activity and fault and fold deformation in the Yucca Mountain vicinity, with emphasis on volcanic activity, and analyzes the potential effects of tectonic processes on a potential repository and the site ground water system (SCP Section 8.3.1.8).

- Human Interference (Section 3.7) - evaluates the known and potential natural resources in the site area, and the potential for future human intrusion into the site area in search of such resources (SCP Section 8.3.1.9).

- Meteorology (Section 3.8) - characterizes the site and regional meteorological conditions of the Yucca Mountain vicinity (SCP Section 8.3.1.12).

- Offsite Installations and Operations (Section 3.9) - determines the presence, and potential impacts on the site area, of offsite industrial, transportation, and military installations and operations in the Yucca Mountain vicinity (SCP Section 8.3.1.13).

- Surface Characteristics (Section 3.10) - characterizes the topographic characteristics and properties of soil and rock in the site area (SCP Section 8.3.1.14).

- Thermal and Mechanical Rock Properties (Section 3.11) - determines rock thermal and mechanical properties from laboratory and in situ investigations and characterizes thermal and mechanical stress conditions at the site (SCP Section 8.3.1.15).

- Preclosure Hydrology (Section 3.12) - characterizes the potential for flooding, determines the location of an adequate water supply for repository construction and operation, and characterizes preclosure hydrologic conditions in the unsaturated zone at Yucca Mountain (SCP Section 8.3.1.16).

- Preclosure Tectonics (Section 3.13) - characterizes faults, seismicity and tectonic stress field, and evaluates the potential for faulting, ground motion, and volcanic activity in the site vicinity (SCP Section 8.3.1.17).

- Altered Zone Characterization (Section 3.14) - a new activity that was not addressed in the SCP, has been created to develop and validate techniques to analyze the performance of the natural system under potential changes resulting from waste emplacement (SCP Section - N/A)

These programs are discussed in detail in the referenced sections. In these sections are many references to study plans. The discussions in these sections reflect the impact, on individual studies and activities, of the SCP/Study Plan work scope consolidation and the Program Plan. These efforts identified SCP sections for which study plans have not yet been written and evaluated whether there is a rationale why a study plan need not be developed. Such rationale could include: transfer and/or aggregate work scope into other study plans; and report work already completed in a participant report, DOE technical report or working paper; or other rationale. The results of those evaluations, the explanations, and the resulting action(s), are discussed in each appropriate study/activity and summarized in Appendix A. The status of the study plans is summarized in Appendix G.

For the reader's reference, a map showing surface features in the Yucca Mountain vicinity is included as Figure 3-1. Figure 3-2 shows the location of boreholes in the proposed repository area.

3.1 GEOHYDROLOGY (SCP SECTION 8.3.1.2)

3.1.1 Study 8.3.1.2.1.1 - Characterization of the Meteorology for Regional Hydrology

The objectives of this study are (a) to characterize the area surrounding Yucca Mountain in terms of precipitation and its relationship to surface runoff, with particular

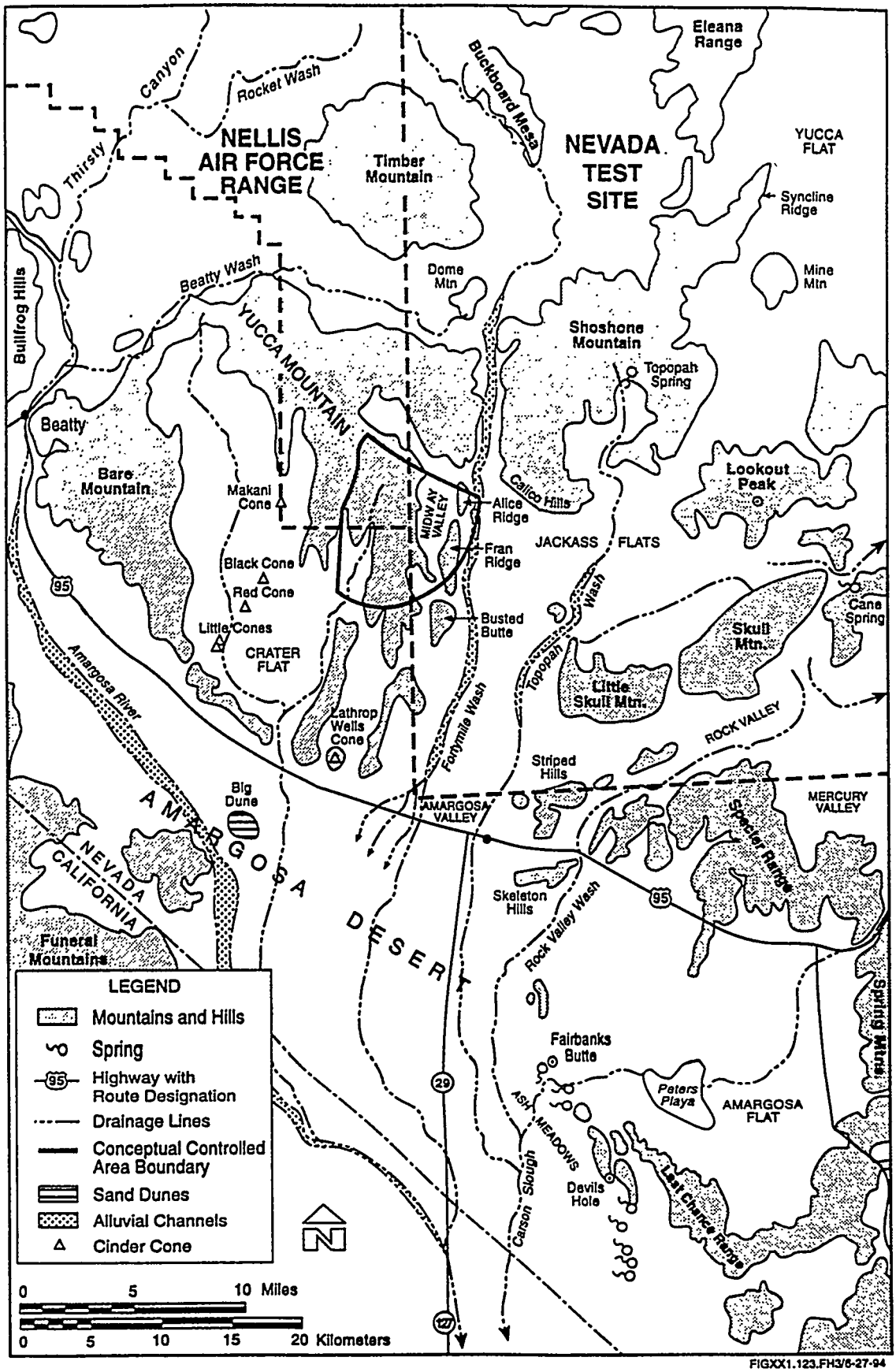


Figure 3-1. Map of Surface Features

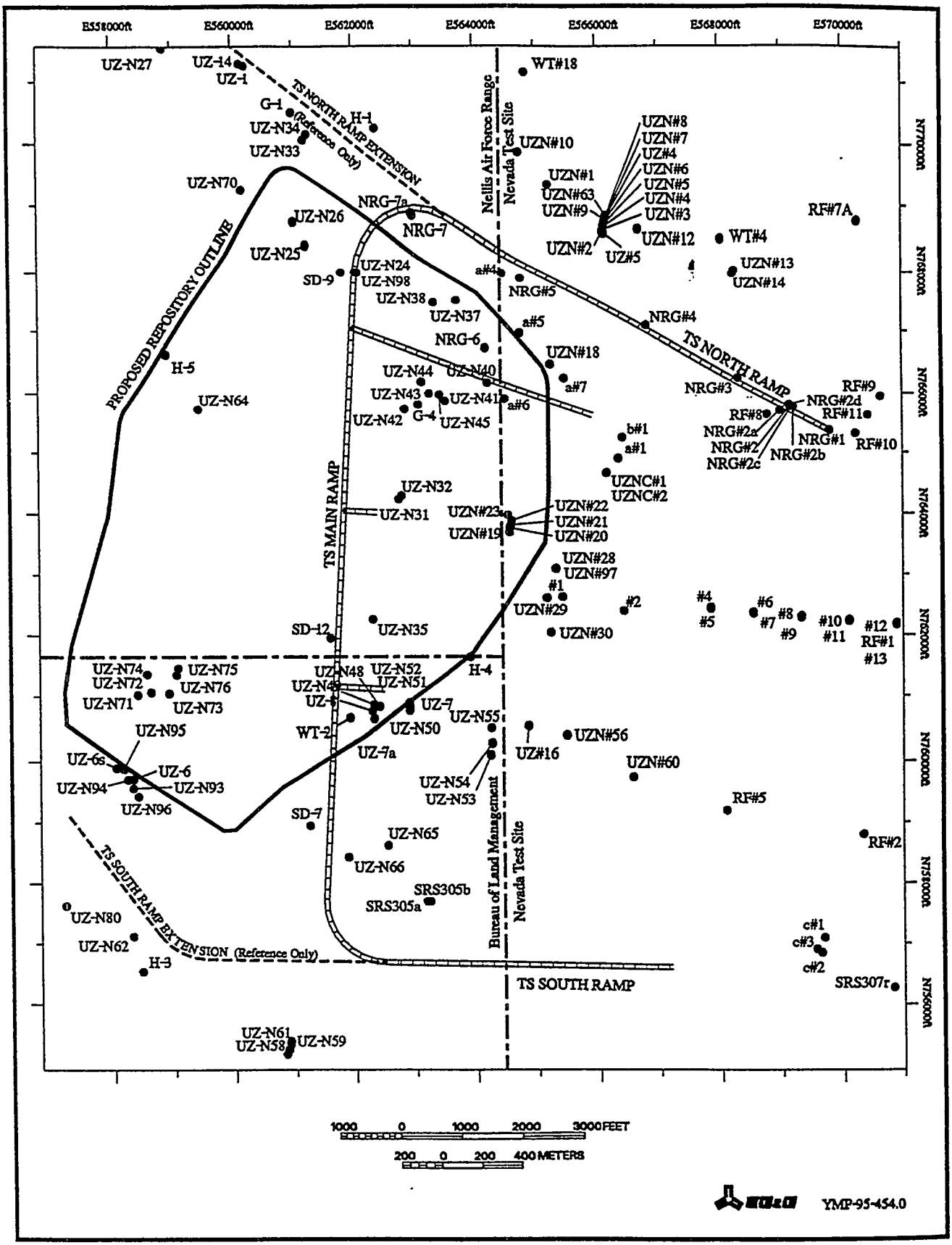


Figure 3-2. Map of Repository Area Boreholes

emphasis on the Fortymile Wash drainage basin, and (b) to provide input into the rainfall-runoff model development effort.

Activity 8.3.1.2.1.1.1 - Precipitation and meteorological monitoring. The objective of this activity is to provide site-specific information on storm precipitation at, and near, the network streamflow-measurement sites.

Measurements of the timing, amount, intensity, and duration of precipitation continued using an expanded site-scale network of 133 non-recording (storage) gauges, 14 tipping-bucket gauges, and 5 weather stations. The measurements are to map the spatial distribution of precipitation magnitude and intensity for individual storm events, which provide critical input to water-balance studies being conducted under the natural-infiltration activity (SCP 8.3.1.2.2.1.2.). Preliminary analysis of precipitation measurements indicate wetter-than-average conditions at Yucca Mountain for the winter season of 1994-95, caused by the influence of an active El Niño Southern Oscillation. Several storms, beginning on January 5, 1995, resulted in total monthly precipitation in excess of 127 mm (5 in.). The largest storm occurred January 21-27, 1995, had a maximum daily magnitude in excess of 25 mm (1 in.), and resulted in total precipitation exceeding 76.2 mm (3 in.) at most locations. The timing, duration, and magnitude of this storm completely saturated the upper 1 to 2 m of surficial materials at Yucca Mountain, resulting in surface runoff and lateral sub-surface flow along the alluvium-bedrock contact on most sideslopes. A later storm March 9-11, 1995, resulted in more than 63 mm (2.5 in.) at many locations, with greater amounts recorded along the northern part of the network. The higher-than-average precipitation intensities of this storm, along with the increased moisture content of surficial materials from the previous events, resulted in the most runoff in Pagany Wash and in the vicinity of Yucca Mountain since the 1983-84 El Niño Southern Oscillation episode. Preliminary comparison of storm totals with measured moisture profiles in 98 neutron-access boreholes indicated that the moisture in some boreholes exceeded the storm totals, suggesting that lateral flow occurred in the subsurface.

Additional tipping-bucket precipitation gauges at the periphery of the existing network were installed, including two pit gauges for analyzing measurement error caused by wind effects. The expanded network now fully covers the area of the three major drainages overlying the potential repository site: Drill Hole Wash drainage, Busted Butte drainage, and Solitario Canyon drainage. The tipping-bucket gauges were calibrated using a new technique for accurately defining gauge resolution and systematic measurement error as a function of precipitation intensity (Humphrey et al., 1994). A report was prepared documenting an analysis of precipitation measurements obtained from the non-recording gauge network for water years 1992 and 1993 (Ambos et al., in prep.) A second report on an analysis of meteorological measurements (precipitation, wind speed, wind direction, relative humidity, air temperature, and solar radiation) obtained from the five weather stations was also prepared (Flint and Davies, in prep.).

For the purpose of analyzing regional precipitation and synoptic-scale weather patterns influencing precipitation, satellite data, lightning data, synoptic weather charts, and video logs continued to be collected and archived on a daily basis. A data base was completed that includes daily measurements of precipitation depth (rain and snow), snow-cover depth, and

maximum and minimum air temperatures for 156 monitoring sites throughout the Nevada-California region that have lengths of record of 2 to 64 yr. The first draft of a report describing the influence of synoptic-scale weather patterns on meso-scale precipitation for water years 1992 and 1993 within the region surrounding Yucca Mountain was completed and submitted for technical review (Hevesi et al., in prep.). Geostatistical analysis of average annual precipitation over the Death Valley ground-water unit was continued as a method for mapping recharge. Results from these studies will (a) help characterize current climatic conditions for the Yucca Mountain region, (b) provide current climatic information on the temporal and spatial distribution of Yucca Mountain precipitation needed for ground-water flow models, and (c) provide information concerning the spatial and temporal variability of regional precipitation patterns due to physiography, geography, and synoptic-scale weather systems.

Forecast: Analysis of precipitation data obtained from the site-scale network will continue in an ongoing effort to document and characterize all storms affecting Yucca Mountain. These studies will include a refinement of existing geostatistical models for the isohyetal mapping of storm totals and intensity, which provides critical input for the development and calibration of arid-land watershed models (see SCP 8.3.1.2.2.1.2). This work will involve a detailed analysis of the complete record of tipping-bucket and non-recording-gauge data to establish correlations between the two networks, and for developing a statistical characterization of the temporal distribution of precipitation intensity. Work on establishing a data base consisting of both site-scale and regional hourly precipitation intensities will continue. The regional meteorological data base will be updated to include new data from calendar year 1994. The data will continue to be analyzed for (a) developing stochastic precipitation models, (b) establishing base-line climatological conditions, and (c) defining the spatial and temporal variability of precipitation over the Yucca Mountain region. Correlation of precipitation magnitude and frequency data with elevation and location will continue; these data will be input for the precipitation models. Synoptic data will continue to be collected for establishing correlations between regional weather patterns and precipitation, with the intent of developing a dynamic link between global-scale climate models and meso-scale stochastic precipitation models.

3.1.2 Study 8.3.1.2.1.2 - Characterization of Runoff and Streamflow

The objectives of this study are to (a) collect basic data on surface-water runoff at, and peripheral to, Yucca Mountain and its hydrologic flow system; (b) use the streamflow data to describe the runoff characteristics of the area and assess the response of runoff to precipitation; (c) assess the potential for flood hazards and related fluvial-debris hazards to the YMP; and (d) provide basic data and interpretations of surface-water runoff to investigations that evaluate the amounts and processes of ground-water recharge at Yucca Mountain and surrounding areas.

Activity 8.3.1.2.1.2.1 - Surface-water runoff monitoring. The objectives of this activity are (a) to develop needed basic data on the characteristics, magnitudes, frequencies, and timing of surface-water runoff to develop an understanding of the relationships between

specific runoff events and the characteristics of the storms and associated precipitation; and (b) to develop a streamflow data base adequate to provide the necessary calibration data for precipitation-runoff modeling efforts for the regional study area.

Monitoring activities continued at 17 continuous-recording stream gauges, 12 peak flow sites, and 29 storage-type precipitation gauges. Record precipitation in southern Nevada during January 1995 produced runoff at numerous sites in the vicinity of Yucca Mountain. Runoff was recorded in Topopah, Fortymile, Yucca, Dune, Split, Pagany, Wren, and Drill Hole washes. Runoff was sufficient to allow current-meter measurements and water-quality sampling at several sites. Storms during mid March produced more runoff in Fortymile Wash than since 1984. Runoff caused significant scour and redeposition of alluvial materials in Fortymile and Pagany washes.

Records for streamflow and precipitation data collected during water year 1994 were processed for publication. Detailed plans were prepared for the installation of two new continuous-recording gauges in Drill Hole and Solitario Canyon washes, and for 12 new peak-flow gauges in Yucca, Teacup, Wren, Coyote, Pagany, WT-2, and Split washes. The plans were submitted to YMSCO for processing of environmental and cultural permits. The new runoff-monitoring sites were selected to support the development of a numerical infiltration model (SCP 8.3.1.2.2.1.2) that will link precipitation, evapotranspiration, infiltration, and runoff. The infiltration model will provide estimates of spatially distributed infiltration flux needed to address the suitability of the Yucca Mountain site. Streamflow and precipitation data also will be used for flood-frequency analyses and performance assessment.

Activity 8.3.1.2.1.2.2 - Transport of debris by severe runoff. The objective of this activity is to document, both quantitatively and qualitatively, the characteristics of debris transported by intense surface runoff.

No progress was made during the reporting period; this was an unfunded activity.

Forecast: Collection and analysis of streamflow and precipitation data will continue, with emphasis on providing hydrologic information to support the unsaturated-zone infiltration study (SCP 8.3.1.2.2.1). Two additional continuous-recording gauges and 12 additional peak-flow gauges (described under Activity 8.3.1.2.1.2.1) will be installed. Streamflow and precipitation data collected near Yucca Mountain during water year 1994 will be published in the USGS annual water data report for Nevada. The runoff and streamflow study will be focused on measuring runoff in the small watersheds that drain the Yucca Mountain site. As a result, monitoring of regional runoff and streamflow may be de-emphasized.

3.1.3 Study 8.3.1.2.1.3 - Characterization of the Regional Ground-Water Flow System

The objectives of this study are to further define the distribution of hydraulic properties of the regional ground-water flow system; and to use hydrologic, hydrochemical, and heat-flow data to determine the magnitude and direction of ground-water flow.

Activity 8.3.1.2.1.3.1 - Assessment of regional hydrologic data needs in the saturated zone. The objective of this activity is to prioritize data needs for use in the regional ground-water flow description.

This activity was evaluated during the completion of the study plan in which prioritization of Project data needs was largely completed. It was determined that, as new project data become available, data needs may change based on previously unrecognized hydrologic conditions. The current data uncertainty was used to prioritize data collection needs, as documented in the study plan.

Activity 8.3.1.2.1.3.2 - Regional potentiometric-level distribution and hydrogeologic framework studies. The objectives of this activity are to determine the potentiometric distribution within the regional ground-water flow system, and to characterize the hydrogeologic framework of the regional ground-water flow system to support reliable estimates of ground-water flow direction and magnitude within the saturated zone.

Temperature data from borehole USW G-2 were analyzed to determine transient responses within a nearly uniform temperature region within the saturated zone. Hydraulic testing on USW G-2 has been delayed as a result of drilling rig and crew availability. Core obtained from Borehole USW G-2 was examined, and a qualitative analysis of fracture transmissivity completed for the interval from 518 to 808 m (1,700 to 2,650 ft) below land surface. A flow survey of USW G-2 was completed using a heat-pulse flow meter. Before the flow meter survey, an acoustic televiewer survey was run. Downhole television surveys of USW G-2 were completed to document water dripping down the borehole walls in the air-filled part of the borehole. Water was observed to be dripping from the same locations observed in the 1981 television camera logs, 13 yr before. A poster related to these findings was presented at the American Geophysical Union Annual Fall Meeting (Czarnecki et al., 1994). In addition, hydrochemical samples were obtained at three different depths in USW G-2 using a wireline point sampler.

Activity 8.3.1.2.1.3.3 - Fortymile Wash recharge study. The objective of this study is to determine to what extent (quantitatively, if feasible) Fortymile Wash has been a source of recharge to the saturated zone under present and past conditions.

Soil-moisture and depth-to-water measurements were completed in upper Fortymile Wash on a regular basis. Ground-water levels rose, and unsaturated-zone soil moisture increased after streamflow events in January and March, 1995. Water samples were collected from overland flow sites and streamflow channels during the January streamflow event. Splits of the samples were distributed to other YMP researchers. Two neutron-access boreholes were temporarily covered by sediment after the March streamflow event and are unaccessible. Precipitation, streamflow, unsaturated-zone, and saturated-zone data for Fortymile Wash collected during water year 1992 were published (Savard, 1995). Precipitation, streamflow, unsaturated-zone, and saturated-zone data for water year 1993-94 were compiled for inclusion in a future USGS data report. Surface water data from Fortymile Wash during 1994 were analyzed for transmission losses (infiltration of streamflow into streambed gravels) and presented at the American Geophysical Union Annual Fall Meeting

(Savard and Beck, 1994). Infiltration tests in the Fortymile Wash channel system were initiated.

Activity 8.3.1.2.1.3.4 - Evapotranspiration studies. The objective of this activity is to improve estimates of ground-water discharge by evapotranspiration in the Amargosa Desert to provide boundary-condition data for regional ground-water flow models.

No progress was made during the reporting period; this was an unfunded activity.

Related International Work

See Section 3.1.17 for related work (under the heading, Ground-Water Flow and Water-Rock Interactions using Radiogenic Isotopes) performed under the auspices of the OCRWM international program.

Forecast: Hydraulic and hydrochemical testing of the upper saturated interval in Borehole USW G-2 will be performed, pending drilling rig and crew availability. Hydrochemical sampling of deep piezometer nests in boreholes in the Amargosa Desert will be performed while incorporating automated monitoring of pH and specific conductance of the discharge water if personnel are available. Water levels, soil moisture, and precipitation will continue to be monitored in Fortymile Wash. An infiltration test will be done using a 0.91 cm (3 ft) ring infiltrometer. Wells in upper Fortymile Wash will be pumped and sampled if permits are available. Long-term hydrographs of water levels from wells in the subregional ground-water flow system will be constructed to document long-term water-table fluctuations. A poster (Czarnecki et al., 1994) will be presented at the American Institute of Hydrogeology meeting in Denver.

3.1.4 Study 8.3.1.2.1.4 - Regional Hydrologic System Synthesis and Modeling

The objectives of this study are to synthesize the available data into a model and make a qualitative analysis of how the system is functioning, and to represent quantitative observations of hydrogeologic data pertaining to the ground-water flow system in a comprehensive numerical model of ground-water flow.

Activity 8.3.1.2.1.4.1 - Conceptualization of regional hydrologic flow models. The objectives of this activity are to synthesize available data into a conceptual model that incorporates alternative hypotheses and/or existing hypotheses, and to make a qualitative analysis of how the regional and subregional ground-water flow systems function.

No progress was made during the reporting period; this was an unfunded activity.

Activity 8.3.1.2.1.4.2 - Subregional two-dimensional areal hydrologic modeling. The objective of this activity is to improve estimates of regional ground-water flow by updating an existing two-dimensional, subregional, parameter-estimation model through the incorporation of additional hydrogeologic data.

No progress was made during the reporting period; this was an out-year activity.

Activity 8.3.1.2.1.4.3 - Subregional two-dimensional cross-sectional hydrologic modeling. The objectives of this activity are to estimate the ground-water flow direction and magnitude along a potential flow path through the repository block to the accessible environment, and extending into the region, to help test the assumption of horizontal flow.

No progress was made during the reporting period; this was an out-year activity.

Activity 8.3.1.2.1.4.4 - Regional three-dimensional hydrologic modeling. The objective of this activity is to construct a three-dimensional model of the regional ground-water flow system of Yucca Mountain and vicinity.

The three-dimensional hydrogeologic framework model of the Death Valley regional ground-water flow system, developed for numerical modeling efforts, continued to be updated during this period. The framework model was used in the discretization of the revised regional numerical model. This numerical model consists of three layers representing local, subregional, and regional ground-water flow paths. Regional boundaries were modified in an effort to attain more efficient computational times and a more numerically stable model. Regional ground-water modelers developed a protocol that includes a strategy for calibration. Long-term regional water-levels and spring discharge fluxes are being used in this exercise.

Because this model will be used to evaluate the effects of the regional carbonate aquifer on the site ground-water flow system and to evaluate site model boundaries, a rigorous sensitivity analysis plan was developed that uses the USGS MODFLOWP code. This code estimates parameter sensitivities using a nonlinear regression technique. Input to this code is similar to MODFLOW and, as a result, modifications to the existing model were few.

Modeling results to date show good agreement between water balance estimates and regional potentiometric-surface trends. Calibration of the model using MODFLOWP will continue through the next half of the year.

Boundary conditions of the regional model, as well as site-model boundaries, were evaluated. Outputs from the regional model continued to be analyzed after simulations to determine potential site-model boundaries and results of the analyses were prepared.

Additional work conducted by the regional modeling group members included (a) documenting basic regional Geographic Information System data sets for transfer to the technical data base, (b) preparing a hydrogeologic map report, (c) completing several reports that document regional ground-water data, and (d) developing the regional modeling report.

Forecast: The hydrogeologic framework model and other framework data will be reviewed, documented, and submitted to the technical data base. Calibration and sensitivity analyses of the regional ground-water model will continue, with updates completed to reflect

progress. Evaluations of boundary conditions of both regional and site models will be updated. Work on the regional modeling report manuscript will continue.

3.1.5 Study 8.3.1.2.2.1 - Characterization of Unsaturated-Zone Infiltration

The objective of this study is to determine the (a) present-day net-infiltration rates (fluxes) occurring under natural precipitation events, (b) range of expected net infiltration rates and pathways under possible future wetter climate conditions, and (c) hydrologic properties of surficial materials.

In response to the Technical Site Suitability initiative, the infiltration study has been reconfigured and accelerated. The primary goal of the reconfigured study is to define the upper-boundary condition, in terms of a spatially and temporally distributed moisture flux, for site-scale models of unsaturated-zone ground-water flow and transport. In this context, the boundary condition will be developed as a conceptual and numerical model based on arid-land watershed processes. The model is intended to provide a dynamic link between infiltration flux and known climatic variability, potential climatic trends, potential changes in the surface environment (such as loss of vegetation), and sporadic, but extreme, meteorological events. Given the infiltration flux at the upper boundary of the unsaturated zone, the site-scale model will be used to simulate flow across the potential repository horizon for the set of conditions chosen. The integration of hydrologic-process models for the surface and near-surface environments with mapped surficial-material hydrologic properties and mapped present-day net infiltration rates (in terms of both matrix and fracture flow) will result in a stochastic-deterministic simulation of future upper-boundary conditions, including the probability and magnitude of potential fast pathways of net infiltration.

In accordance with the above rationale, the infiltration study has been divided into three broad and closely interrelated areas of study: infiltration properties, infiltration processes, and infiltration distribution. Progress on infiltration properties is reported under the first activity below, while progress on infiltration processes and distribution is reported under the second. With reconfiguration of the study, the third activity (8.3.1.2.2.1.3, Artificial Infiltration) will be used only for field validation of the infiltration model described above for simulated wetter climatic conditions. Therefore, Activity 8.3.1.2.2.1.3 will be treated as an out-year activity until field-validation studies begin.

Activity 8.3.1.2.2.1.1 - Characterization of hydrologic properties of surficial materials. The objective of this activity is to characterize the infiltration-related hydrologic properties and conditions of the surficial soils and rocks covering Yucca Mountain.

Characterization of the hydraulic and physical properties of unconsolidated surficial materials continued. Measurements of field bulk density, rock and sand-fraction sieving, particle-size analysis, $CaCO_3$ content, pH, porosity, particle density, water retention, and saturated hydraulic conductivity were completed on surface and pit samples. The selected sampling locations represent type-sample locations for the surficial geologic map units. These

samples and the sample analysis are part of the characterization of surficial materials for the preliminary properties map(s) milestone.

Six slope classes were established for the Yucca Mountain region. Slope breaks of 0 to 5, 6 to 10, 11 to 15, 16 to 25, 26 to 45, and greater than 45 percent will be used as part of a preliminary slope-class map. This refined slope class map was developed and is being used to estimate the depth to bedrock in the study region. A draft version of the surficial geology map has been incorporated into a Geographic Information System and is being used to help predict hydrologic properties of alluvial/colluvial materials. To incorporate all the measured physical and hydrologic surficial-materials properties with the available map, a surficial properties data base is being developed. Estimations of the surficial-material thicknesses, used in conjunction with the measured water-holding capacities of soils and their associated hydrologic properties, are an integral part of the preliminary properties map(s) milestone and the site-scale unsaturated-zone modeling milestone.

Because of the unusually large amount of precipitation during January 1995, a large-scale soil-sampling program was begun. The objective of this program is to determine the water-holding capacity of various surficial materials. Thirty-two sites were sampled (three samples per site) one, two, four, and seven days after the last storm. Gravimetric-water contents were determined for 465 surface soil samples. Preliminary evaluation of the data suggests a relationship between water-holding capacity and the geomorphic position of the samples. Sampling will continue at periodic intervals.

Surface infiltration rates and sorptivity values were determined at selected locations using the double-ring infiltrometer. Double-ring infiltration tests were performed in Fortymile Wash, supporting both the infiltration-properties activity and the Fortymile Wash Recharge activity (8.3.1.2.1.3.3). Bulk density and sidewall samples were collected at each site and analyzed to determine a number of physical and hydrologic characteristics, which are an important input to the preliminary-properties-map(s) milestone and the site-scale unsaturated-zone model (Activity 8.3.1.2.2.9.3).

The first phase of the ponding experiment at UE-25 UZN#7 in Pagany Wash was completed. Approximately 60.5 m^3 of water were applied over a 63-hour period. Changes in water content in four neutron boreholes were monitored during and after water application for the first 72 hours of the ponding experiment. Because of the large infiltration rates, a ponded-water surface was maintained for only the first 63 hours. During the first six hours of ponding, water moved to a depth of 6 m. Plans were made to complete the final water applications following the wet winter months.

Gamma-gamma logs were run in Boreholes UE-25 UZN#4, 5, 6, 7, 8, 9, 63, 98, and 24 and processed to detect changes in density and water content. This information is being used to determine whether washout zones are present behind the casing in these boreholes. All boreholes are being logged, using different gamma-gamma orientations, to determine the casing-to-soil attenuation (air gap).

Activity 8.3.1.2.2.1.2 - Evaluation of natural infiltration. The objective of this activity is to characterize present-day infiltration processes and net-infiltration rates in the surficial soils and rocks covering Yucca Mountain.

Infiltration Processes

The conceptual model of shallow infiltration for the arid-land watersheds at Yucca Mountain was up-dated and expanded to include an analysis of two- to ten-year records of relative changes in water-content profiles from 99 boreholes, beginning in 1984 (Flint and Flint, in prep.). Evaluation of moisture profiles and measured precipitation indicates that (a) infiltration occurs as fracture flow where a shallow alluvial cover intercepts overland flow, (b) lateral subsurface flow occurs along the alluvium-bedrock contact, and (c) saturated or near-saturated conditions are maintained at a depth sufficient to mitigate evapotranspiration. These concepts have been supported by new data collected during the 1994-95 winter season, which was wetter than normal (see Activity 8.3.1.2.1.1.1).

Development of a numerical model of shallow infiltration continued. A temporal, stochastic model for daily precipitation at Yucca Mountain was defined, using an analysis of precipitation records from 156 monitoring sites in the Nevada-California region. The current model incorporates a Markov chain process for defining the probability of wet-period and dry-period sequences, and both modified exponential and Weibull cumulative distribution functions for defining the probability of daily-precipitation magnitudes during wet-periods. Because the model parameters are based on monthly precipitation statistics, the seasonal variability in precipitation is well represented. Analysis of simulation results indicated the probability of greater than 100 mm/day magnitude storms and durations for wet periods of six days or more. These results were consistent with precipitation that occurred during the 1994-95 winter season, during which there was a six-day period of continuous precipitation, resulting in some of the wettest conditions ever recorded at Yucca Mountain. The development of a more detailed, Poisson-cluster process model was initiated, using continuous records of precipitation intensity obtained from eight-year records of tipping-bucket rain gauges at Yucca Mountain. Research on methodologies for integrating the temporal-distribution models with the geostatistical models of spatial distributions of precipitation continued.

Development of the evapotranspiration component of the numerical arid-land watershed model continued, using the available 30-m-digital elevation model for Yucca Mountain. Simulations of potential evapotranspiration were performed for Split Wash as part of a preliminary analysis of the influence of slope, aspect, and blocking ridges on evapo-transpiration. These simulations are based on a deterministic model of solar radiation, an empirical model of ground heat flux, and the Priestley-Taylor energy-balance equation. The results were used to help identify areas of potential high-infiltration rates. A detailed water-balance study of Split Wash was initiated for developing and calibrating the evapotranspiration model. The study includes:

- Monitoring of evapotranspiration, using both the Bowen ratio and eddy-correlation techniques

- Monitoring of potential evapotranspiration, using Penman weather stations and a network of radiometers

- Measurement of potential evaporation, using a Class A evaporation pan

- Continuous measurement of near-surface moisture contents and water potentials, using a combination of time-domain reflectometry, heat dissipation probes, tensiometers, and Peltier thermocouple psychrometers

- Measurement of ground heat flux, using heat flux plates

- Measurement of deeper changes in water content, using the network of neutron-access boreholes. Results from the water-balance study will be compared with results of a study conducted March 14-20, 1995, using the scanning water RAMAN-LIDAR technique to obtain a mapping of short-term areal measurements of evapotranspiration in Split Wash (see discussion on Soil/Moisture/Atmospheric Interactions below).

The combined results of these studies are needed for calibrating the evapotranspiration model, as a function of moisture content, season, alluvial cover and thickness, and potential evapotranspiration, defined using deterministically modeled solar radiation and ground heat flux, and stochastically modeled air temperature and cloud cover.

Infiltration Distribution

A net-infiltration flux map and a potential fast-pathways flux map are being developed as part of this activity. The coverage of these maps is based on Scott and Bonk (1984). The basis for these infiltration-flux maps is estimated water fluxes derived from the water-potential distribution at the bedrock-alluvium contact, the distribution of geologic units, hydraulic properties of the geologic units, distribution and density of faults, and hydraulic properties of faults. Hydraulic properties, fracture densities, and fracture/fault hydraulic properties are being assigned to each unit. Potential fast pathways are defined as faults identified on the map by Scott and Bonk. Samples of fracture/fault fill material were collected from 11 locations around Yucca Mountain to characterize the hydrologic properties of this material. Samples composed of $CaCO_3$, silica, or a mixture of $CaCO_3$ and silica were collected. For each sample, the following properties were measured: bulk density, porosity, particle density, water content in equilibrium with an atmosphere at a relative humidity of 65 percent and a temperature of 60°C, calcium-carbonate equivalent, pH, and particle density.

Work was performed to associate fault orientation and offset with fault hydrologic properties, fracture densities, and fracture sizes. Because 47 percent of the area of the Scott and Bonk map is identified as alluvium and colluvium, work began on a map of the bedrock closest to the surface in the area of the infiltration-flux maps. A preliminary slope-class map, covering the net-infiltration map area, was derived from the USGS digital elevation model to help identify the depth to bedrock under alluvium. The depth to bedrock, combined with an

estimate of the alluvium porosity and water retention characteristics, will allow the calculation of alluvial water-storage capacity.

Preliminary estimates of potential evapotranspiration in Split Wash were calculated from radiation load, slope, aspect, and influence of blocking ridges. Blocking ridges at 90-m intervals were determined in the area of the net infiltration map to provide data for preliminary estimates of potential evapotranspiration. These calculations, covering the areal extent of the net-infiltration map, will be used to correlate rainfall, evapotranspiration, storage, and net infiltration. Preliminary fault information and preliminary results of the evapotranspiration modeling in Split Wash were used to identify a likely area of greater infiltration at the intersection of the Ghost Dance and Sundance faults. At this location, the bedrock is highly fractured, and evapotranspiration during the winter months is low. Nests of tensiometers, heat dissipation probes, and time-domain reflectometry probes were installed near this location to monitor changes in water potential and water content at the bedrock-alluvium contact. These data will help define the time period during which this interface remains wet enough to support rapid infiltration through fractures.

Sample locations for the net-infiltration flux maps and the potential fast-pathways flux maps are as follows: (1) Ghost Dance fault Zone from the south face of the USW UZ-7a drill pad in WT-2 Wash, (2) Whale Back Ridge Pavement on the crest of Whale Back Ridge between USW UZ-N35 and USW UZ-N49, (3) south-facing Antler Ridge Pavement in H-4 Wash north of USW UZ-N35, (4) southwest facing slope of upper Split Wash northwest of USW UZ-N31 and USW UZ-N32, (5) Fran Ridge Pavement at the Large Block Test site, (6) east face of the UE-25 NRG#5 drill pad in Drill Hole Wash, (7) east-facing slope of Abandoned Wash southwest of USW UZ-N57, (8) Ghost Dance fault Zone in Ghost Dance Wash south of USW UZ-N66, (9) west fault arm west of the USW SD-7 drill pad, (10) west face of the UE-25 NRG#3 drill pad, and (11) south-facing slope of Coyote Wash northwest of USW UZ-N44.

Soil Moisture/Atmospheric Interactions

Project scientists are measuring evaporation rates over large areas at Yucca Mountain using the Monin-Obukov similarity method on vertical transects derived from two dimensional vertical LIDAR scans. Project scientists collected data on the effect of differential radiation (caused by changes in topography) on evapotranspiration at Split Wash, Yucca Mountain, using a water-vapor RAMAN-LIDAR. Four eddy-correlation energy-balance systems were placed at key points within the Split Wash area, and sequential vertical scans at 5-degree intervals were made. Preliminary results indicated that west-facing slopes were considerably drier than east-facing slopes, which confirms previous YMP models on the energy balance at Yucca Mountain. The vertical scans will be used to compute the evapotranspiration of Split Wash in grid cells between 20 and 30 m in size; these grid cells will then be used in validating the advanced energy-balance models. As the analysis of the LIDAR and point data progresses, it is hoped that differences and similarities between topographic and vegetation associations will be useful for validating hydrology models.

Activity 8.3.1.2.2.1.3 - Evaluation of artificial infiltration. The objective of this activity is to characterize the possible range and spatial variability of infiltration in the upper 5 m at Yucca Mountain.

Because of reconfiguration of the infiltration study, there is no progress to report for this period; this is now an out-year activity.

Forecast: Hydrologic properties for the preliminary surficial materials maps will continue to be measured, with emphasis on quantifying the range and variability of hydrologic properties within identified units. Laboratory, field, and borehole geophysical measurements will be made.

Precipitation and subsurface moisture data collected during the 1994-95 winter season will be incorporated into the conceptual model of infiltration. These data are especially important because they document the wettest conditions at Yucca Mountain since 1984. Precipitation data, hydrographs from continuous-recording streamflow gauges, and moisture profiles from the network of neutron-access boreholes will be used for calibrating watershed models. Parameters for the initial infiltration component of each watershed model will be defined, using measurements of field capacity, residual water content, and alluvial cover and thicknesses that were obtained as part of an intensive sampling program described under Activity 8.3.1.2.2.1.1. Development of the model algorithm and code will continue, with the objective of completing the first draft of a full watershed model by the end of the fiscal year. The code will be developed using modifications to the KINEROS model for incorporating overland flow. The model code also will include a more efficient modularization of the solar-radiation component for modeling potential evapotranspiration, and the stochastic precipitation module. The infiltration module will be refined, using neutron-moisture profiles in conjunction with measurements of water potentials for calibrating deeper infiltration and redistribution. Packer systems for instrumenting neutron-access boreholes for monitoring water potential will continue to be designed and constructed. These boreholes are located within fracture/fault zones where it is important to measure water potential at the alluvium-bedrock contact.

Measurements of properties for the fracture/fault materials will continue, with an emphasis on measuring permeability. The preliminary net-infiltration flux map and the preliminary potential fast-pathways map will be developed to the point of having estimates of the areal and temporal distributions of fluxes. Hydraulic properties, including the effects of fractures and faults, will be assigned to the units identified on these maps. Temporal and areal distribution of the water potentials at the bedrock unit nearest the surface also will be estimated. Work will continue to identify the bedrock units directly under the alluvium, as well as thickness of the alluvium.

The spatial distribution of water vapor at additional locations at the Yucca Mountain site will be mapped by LIDAR scans and applied to the development of an evaporative model. This model will be used to further understand the evaporative flux at Yucca Mountain and the implications for unsaturated zone hydrology.

3.1.6 Study 8.3.1.2.2.2 - Water Movement Test

The objective of this study is to obtain information from isotopic measurements of soil, tuff, and water samples collected to help quantify the amount of percolation from precipitation into the unsaturated zone at Yucca Mountain.

Activity 8.3.1.2.2.2.1 - Chloride and chlorine-36 measurements of percolation at Yucca Mountain. The objective of this activity is to help quantify the amount of percolation from precipitation into the unsaturated zone at Yucca Mountain. The data will be used as part of the input to characterize the movement of water through the unsaturated zone at Yucca Mountain.

Project hydrologists analyzed 57 water, soil, and ream-cutting samples for Cl-36. In many instances, the USW UZ-14 and USW UZ-16 ream-cuttings were taken from the same depths at which elevated levels of tritium had been previously observed in porewaters. Project hydrologists found that all analyzed USW UZ-16 samples from the Calico Hills nonwelded unit (sampled interval, 426 to 440 m) had Cl-36 signals that were slightly (15 to 30 percent) elevated above present-day meteoric background. Such an elevation in concentration of Cl-36 could indicate the presence of a component from global atmospheric weapons testing fallout in this unit, and support the presence of high tritium concentrations just discussed. Another potential explanation for this elevated Cl-36 concentration is a higher atmospheric production rate of Cl-36 in the past. Evidence in the literature indicates that 20,000 yr ago the meteoric background value for Cl-36 may have been as much as 40 percent higher than it is today. If this is the case, the Cl-36 concentrations in the Calico Hills samples could indicate residence times on the order of 100,000 yr or less. The deepest USW UZ-16 sample (493 m) from the Prow Pass welded unit underlying the Calico Hills unit had a Cl-36 signal about half that of present-day meteoric background, giving an uncorrected residence time of 300,000 yr. Additional samples from the Prow Pass unit were submitted for analysis to evaluate the hydrologic connection between the Calico Hills and the water table.

Two papers were prepared (Fabryka-Martin et al., in prep.[a]) and (Liu et al. 1995) further elaborating on the results above. The remaining results were being prepared for a letter report (Fabryka-Martin et al., in prep.[b]).

Project hydrologists analyzed alluvial samples from USW UZ-14 (depth 2 to 9 m). Results of these analyses indicated that Cl-36 from global atmospheric weapons testing fallout had penetrated to 4 m at this location. So far, none of the deeper cuttings samples had shown elevated Cl-36 concentrations, even at those depths where high tritium had been detected previously. The highest Cl-36 value, 90 percent of present-day background, was observed in the shallowest cuttings sample analyzed (81 m, Paintbrush nonwelded unit). Deeper in the profile, concentrations in the Topopah Spring welded unit (depth intervals from 383 to 427 m) increased monotonically with depth, from a low of 33 percent of meteoric background to a high of 60 percent of background. Chlorine-36 from global atmospheric weapons testing fallout is probably present, however, in the subsurface because high concentrations were previously measured in USW UZ-1 cuttings samples from depth intervals of 30 to 152 m

(Norris et al., 1990) and elevated Cl-36 signals were also detected in the perched water collected from this borehole (see below).

The issue of the origin and stability of perched water underlying Yucca Mountain, particularly that encountered in drilling USW UZ-1, USW UZ-14, USW NRG-7A, and USW SD-9 in and near Drill Hole Wash continue to be addressed. Data were collected on a few additional samples and three bailed perched water samples from USW UZ-14 were all found to be at or slightly above present-day meteoric background and within the range of values established by the previous set of water samples from this borehole. These samples showed changes over time for the water composition from this hole, which may suggest the presence of more than one source of water feeding the perched water at this location. These changes may be a consequence of drilling operations releasing chloride from the rock to the water. Water from USW NRG-7A had the same Cl-36 content as measured for the two other samples from this hole, consistent with the hypothesis of a well-mixed water body at this location. Fabryka-Martin et al. (in prep.[a]), Fabryka-Martin et al., (in prep.[b]), and Liu et al. (in prep.) discuss these results.

Two pore water samples extracted from USW UZ-14 drill core by Project hydrologists were analyzed for chloride and bromide. The sample from the Paintbrush nonwelded unit (depth 56 m) contained 101 mg/L chloride, a high value that is consistent with a fairly low infiltration rate through the channel bottom of Drill Hole Wash. In contrast, the sample from the Calico Hills unit (483 m) had 11 mg/L chloride, a low value that indicates either higher infiltration rates in the past, or a significant contribution of water via a fast path. The chloride concentration and chloride-to-bromide ratio were within the range of values measured for the USW UZ-14 perched water, which occurred higher in the profile at about 381 m. Fabryka-Martin et al. (in prep.[b]) describe these results.

The bromide-to-chloride ratios for samples analyzed in this study are a key parameter needed to correct water residence time estimates for deep rock samples, based on Cl-36 measurements; without this correction, apparent residence times will be variably longer than the true times. Several actions were taken to continue to develop an acceptable correction method. To characterize the atmospheric component, a suite of 76 surface soil samples collected from across the conceptual Perimeter Drift Boundary were analyzed for chloride and bromide. In contrast with the nearly uniform ratio observed earlier in deeper soil profiles, this set of shallow samples showed considerable variability, with no obvious correlation with location. Fabryka-Martin et al. (in prep.[a]) discuss these results. One hypothesis being investigated is the influence of root-zone processes on the halide ratio.

Extensive suites of additional surface soil and rain water samples were also obtained (see below) to expand the data base. Prototype laboratory experiments were begun to try to determine the suitability of two methods for determining the bromide-to-chloride ratio in Yucca Mountain tuff samples: acid dissolution in a diffusion cell and step-leaching. The latter approach involves alternately leaching and grinding the tuff sample to ever-finer sizes until a constant ratio is obtained in the leachate, which is assumed to be representative of the rock component.

Project scientists collected samples from four locations for Cl-36 analysis: (1) cuttings from USW NRG-7A, Nye County Drillhole UE-25 ONC#1, and USW UZ-7a; (2) rocks from the ESF, primarily focusing on the Bow Ridge fault zone and fractures; (3) perched water from USW SD-7; and (4) spring discharges, which include overland flow and water accumulated in the bottom of shallow neutron hole UE-25 UZN#2. Project scientists collected four sample suites for chloride and bromide analysis to evaluate the extent to which the atmospheric signal is modified by chloride released from the rock during sample collection and processing. These sample suites include (a) pore waters extracted from core intervals corresponding to intervals from which ream-cuttings were collected for this activity; (b) surface soil from the vicinity of its neutron boreholes; (c) surface soil from the outcrop of the Paintbrush nonwelded unit along the west face of the Solitario Canyon escarpment; and (d) rain water from rainfall monitoring gauges. Analyses of these sample sets were in the preliminary stages.

Fabryka-Martin et al. (in prep.[a]) present all Cl-36 data obtained to date for this activity and provide preliminary interpretation in terms of infiltration rates, identification of fast-transport paths, and estimation of water residence times. The authors update previous work in Fabryka-Martin et al. (1993), as well as expanding the scope of the previous paper by including sections on (a) Cl-36 measured in water samples from the unsaturated zone and the regional flow system, (b) comparisons of Cl-36 results to other radiometric age indicators (tritium, C-14) measured by Project hydrologists in Yucca Mountain boreholes, and (c) illustrations of how the Cl-36 results are being used by Project hydrologic modelers to evaluate the validity of site-scale flow and transport models.

Forecast: Collection of cuttings will continue from deep surface-based unsaturated zone and neutron boreholes in the unsaturated zone at Yucca Mountain to determine the depth to which Cl-36 from global atmospheric weapons testing fallout has penetrated, to correlate such distribution with lithology and structural features, and to estimate the average residence time of infiltrating water as a function of depth. Surface soil samples, soil profiles, and cuttings from neutron-access boreholes within the controlled area to determine the pre-weapons testing meteoric Cl-36/Cl ratio, assess the variability in meteoric chlorine/ bromine and Cl-37/Cl-35 ratios, and estimate present-day shallow infiltration rates will be collected. Numerical simulations using FEHMN will be used to analyze the Cl-36 data and to understand implications of the data for water residence time.

3.1.7 Study 8.3.1.2.2.3 - Characterization of Percolation in the Unsaturated Zone–Surface-Based Study

The objectives of this study are to determine the present in situ hydrologic properties of the unsaturated zone hydrogeologic units and structural features; to determine the present vertical and lateral variation of percolation flux through the hydrogeologic units and structural features; to investigate the relationships between present flux and past climatic conditions; and to determine the effective hydraulic conductivity, storage properties, and transport properties as functions of moisture content or potential.

Activity 8.3.1.2.2.3.1. - Matrix hydrologic properties testing. The objectives of this activity are to conduct laboratory measurements of rock-matrix hydrologic properties on borehole and Exploratory Studies Facility samples from geohydrologic units in the unsaturated zone, and the application of statistical and geostatistical methods to characterize spatial distribution of hydrologic properties within the unsaturated zone.

In support of the Technical Site Suitability initiative, this activity has been focused to provide two primary information products: (1) a data base of hydrologic properties of rock matrix from a series of boreholes that is qualified for site characterization use, and (2) an interpretation of the hydrologic properties as they pertain to hydrogeologic units. Hydrogeologic units will be determined, based on similarities within and differences between lithostratigraphic units, for the purpose of developing hydrologic flow models.

During the reporting period, matrix-property measurements, including bulk density, porosity, particle density, water content, and water potential, were performed on approximately 2,000 core samples from Boreholes USW SD-9, USW UZ-14, USW UZ-16, and USW SD-12. Core samples from 23 neutron-access boreholes also were processed. Particle densities, using helium pycnometry and saturated hydraulic conductivities, were measured on more than 400 core samples from USW UZ-16. Air-permeability measurements were completed on samples from radial boreholes in ESF Alcove #1, as well as selected samples from USW UZ-16. Additional core analyses included 122 saturated hydraulic conductivity measurements for Borehole USW SD-9, 125 physical property, water-content, and water-potential measurements for Borehole USW NRG-6; and development of 38 moisture-retention curves with van Genuchten curve fits for USW UZ-16.

Preliminary analyses were completed, using all data from samples from the 23 neutron boreholes plus USW UZ-16, to identify correlations of hydrologic properties to preliminary lithology descriptions. Because final lithologic descriptions for all core samples were needed to finalize the hydrologic-properties correlations, a number of discussions and meetings were held to finalize the project lithologic logs. An integrated approach was developed that resulted in finalized logs needed to identify and correlate core samples. Updating of all core data included the final lithologies, and data were being organized for input into a data base for ease of use. All data will be identified with a scaled stratigraphic altitude for each subzone and each major flow unit to allow comparison of unit properties laterally over the site.

Activity 8.3.1.2.2.3.2 - Site vertical borehole studies. The objectives of this activity are to define the distribution of water content and water potential within the unsaturated zone; and to determine in situ bulk-permeability and bulk-hydraulic properties (i.e., combined fracture and matrix of the media within the unsaturated zone).

Drilling

Final preparations for drilling USW UZ-7a were completed during the reporting period. This borehole will be drilled into the Ghost Dance fault zone to a depth of approximately 228 m (750 ft). The drill pad for this borehole was constructed in November and December

1994. A vertical cut into the slope adjoining the southern boundary of the drill pad was made to expose the character and extent of the fault zone. Information from this cut was used to determine the dip of the main fault trace and to assist in finalizing the location for USW UZ-7a. The cut uncovered the eastern trace of the Ghost Dance fault, and also revealed that the hanging wall side of the fault consists of an intensely shattered rock zone that is at least 55 m (180 ft) wide. The USW UZ-7a borehole will be dry drilled and cored using the LM-300 drill rig. Post drilling plans for this borehole include air-permeability testing and in situ instrumentation and monitoring.

Vertical Seismic Profiling

Borehole UE-25 UZ#16 was instrumented in January and February 1995 with 96 three-component, oriented geophones, spaced at 4.9-m (16-ft) intervals. The deepest geophone station was located at a depth of 492 m (1,615 ft), 3 m (10 ft) below the regional water table. Each geophone was grouted in place to couple the geophone element to the formation rock. Intervening sand layers were placed between geophone stations. Final preparations are being completed for the first collection of field data. Approximately 190 seismic-source locations will be occupied in the initial survey. The initial survey will be conducted along three line segments emanating in a general north-northwest, west, and south-southeast direction from UE-25 UZ#16. The initial survey lines are arrayed to provide coverage of the Ghost Dance fault structure, the imbricate normal fault system on the eastern flank of Yucca Mountain, and the northwest-trending Sundance fault. The initial collection of field data will generate approximately 18,000 source-receiver combinations, or 54,000 single-component (P-wave, shear horizontal, and shear vertical) data sets. These data will be used to image the major structural features that are traversed in the survey.

Borehole Instrumentation and Monitoring

Two boreholes, located along the northern boundary of the repository block, and immediately south of Drill Hole Wash, were instrumented during the reporting period. USW NRG-7A was instrumented to a depth of 203 m (667 ft) in October 1994, and USW NRG-6 to a depth of 220 m (720 ft) in November 1994. Five instrument stations, two above and three below the vitric caprock of the Topopah Spring Tuff, were established in USW NRG-7A. Eight instrument stations, three above and five below the Topopah Spring caprock were established in USW NRG-6. Each instrument station contains sensors to monitor in situ pneumatic pressure, temperature, and water potential. These boreholes were instrumented so the effects of North Ramp (ESF) tunneling operations on in situ rock-gas pressures could be evaluated.

Data from these two boreholes capture most of the winter barometric pressure cycle. These data indicate that there is a marked, if not striking, difference in the observed pneumatic-pressure responses between instrument stations located above and those located below the Topopah Spring vitric caprock. In situ pressure responses to surface barometric-pressure changes in the upper instrument stations display systematic lagging and damping effects with increasing depth below the ground surface. Below the vitric caprock, pressure lagging and damping effects, between successive instrument stations, are negligible to

nonexistent. Pressure responses in the deeper instrument stations, however, are lagged and damped with respect to surface barometric pressure changes. At USW NRG-7A, pressure amplitudes at the deeper stations are about 30 percent of the surface-barometric pressure amplitudes. Pressure highs at these stations tend to lag surface-barometric pressure highs by about 72 hours. At USW NRG-6, the pressure response characteristics of the deeper stations are 50 percent (amplitude damping) and 24 hours (pressure-high lagging). The pressure-damping and lagging effects observed at the instrument stations located beneath the vitric caprock are capable of producing upward, pneumatic-pressure gradients that are on the order of 1 kPa depending on the magnitude and direction of surface barometric-pressure disturbances. These pressure differentials are sufficient to produce flow in an open borehole at these two locations. The uniform and consistent pressure responses observed at the deeper instrument stations suggest the possibility that these stations may be responding to pressure disturbances that are propagated laterally rather than vertically (i.e., from a nearby fault or fault zone). For USW NRG-6 and USW NRG-7A, the proximity of the Drill Hole Wash fault to these boreholes suggests a possible mechanism to propagate surface barometric-pressure disturbances vertically to significant depths (with minimal damping and lagging effects), and then laterally to perturb pressures at deep stations in nearby boreholes (Buesch et al., 1994).

Hydrologic Data Acquisition System

The Hydrologic Data Acquisition System was deployed at two locations: USW NRG-6 and USW NRG-7A. All sensors at USW NRG-6 and USW NRG-7A are being monitored every 3.5 to 5 hours. Generally, the data acquisition system has operated reliably, although occasionally there have been problems with power and temperature regulation at the shelters, caused by the use of generators and older shelters. The radio modem interface from the remote sites to the Hydrologic Research Facility also has been reliable in both directions.

An option was added to the IDISPLAY program that allows the absolute concentration of vapor to be computed (i.e., the specific humidity [grams of water/1,000 grams of dry air]). Specific humidity represents a measure of the mass of water at a station, independent of the changes in pressure and temperature. Additional options were added to IDISPLAY to provide different types of smoothing to curves, and to thin curves to provide a more manageable number of points.

Evaluation of data from the prototype Hydrologic Research Facility boreholes continued throughout the reporting period. Sensors in these boreholes have been operating for 40 months and continue to provide reliable data.

Surfaced-Based Air-Permeability Testing

Because permeability and permeability contrasts between hydrostratigraphic units greatly influence the flow of gas and liquid water, surface-based air-permeability testing is being conducted to quantify the permeability of Yucca Mountain tuffs. Testing has been completed in Boreholes UE-25 UZ#16, USW NRG-7A, and USW NRG-6. Borehole UE-25 UZ#16 was drilled with the LM-300, which produced a 31-cm-diameter borehole. Borehole USW NRG-7A was drilled with the ODEX unit, which produced a 14-cm-diameter borehole.

Borehole USW NRG-6 was drilled with the ODEX system followed by reaming, which produced a 22-cm-diameter borehole. To test in the three different diameter boreholes (31, 22, and 14 cm), technicians manufactured three different diameter packer assemblies: 20, 13, and 9 cm. All three assemblies operated successfully and provided excellent test results.

Because the three tested boreholes were drilled using three different drilling methods, there were concerns that drilling methods might influence the test results. Early testing indicated a possible skin effect in USW NRG-7A. The possibility of skin and storage effects is being evaluated for all tests that have been completed.

On behalf of Nye County, Nevada, a review of the Project air permeability testing and data analysis was performed by a consultant (Advance Resources International of Lakewood, Colorado) in December 1994. The consultant's report was critical of the USGS methodologies, as presented in LeCain and Walker (1994). A meeting was held on February 8, 1995, between the USGS, DOE, Nye County, and Advance Resources International, to discuss and clarify differences and to attempt resolution. Resolution was not achieved, and it was determined that an independent, third party review of the program would be pursued later in FY 1995.

Activity 8.3.1.2.2.3.3 - Solitario Canyon horizontal borehole study. The objectives of this activity are to determine the extent of fracturing, brecciation, and gouge development in the Solitario Canyon fault zone; to evaluate the effects of fault zone on ground-water movement in the unsaturated zone; and to identify additional fault-zone-related data needs.

No progress was made during the reporting period; this was an out-year activity.

Forecast: Matrix-hydrologic properties of borehole core samples will continue to be measured as boreholes are cored. Planned boreholes include USW SD-7, which will penetrate a thick section of the Tiva Canyon Tuff on Highway Ridge; USW UZ-7a, which will penetrate the Ghost Dance fault in WT-2 Wash; and possibly WT-24, which is located on Bleach Bone Ridge and will penetrate a thick section of the Tiva Canyon Tuff, as well as a thick section of nonwelded tuffs underlying the Tiva Canyon Tuff. Processing of core from Boreholes USW NRG-6 and USW NRG-7A also will be completed. Enhancements of present measurements will result from use of a high-pressure permeameter, which will measure saturated hydraulic conductivities less than 10^{-12} m^2. Measurements of moisture retention will be improved through using the submersible, pressurized, outflow cell system, which will give better resolution of curves at the wet end, as well as hysteretic effects on samples. To facilitate steady-state measurement of unsaturated conductivity, an ultra-centrifuge is expected to be delivered and set up within several months. The unsaturated-conductivity data, along with sorptivities measured at various initial water contents, will be used to evaluate methodology for determining modeling parameters.

Evaluation of hydrogeologic units will continue and will incorporate larger scale features, such as fracture density and orientation, and accumulation of clays and zeolites in particular zones, to help delineate units that have different hydrologic behavior. Detailed

estimates of units, with associated properties and modeling parameters, will be provided for smaller-scale modeling efforts. For the site-scale modeling efforts, however, larger-scale units will be suggested as the minimum necessary to represent large-scale hydrologic features of the rock matrix at Yucca Mountain.

Boreholes UE-25 UZ#4 and UE-25 UZ#5 are scheduled to be instrumented in June and July 1995. Work-over activities at these two boreholes will begin in late March; sensors for these boreholes are currently undergoing calibration. A report documenting the monitoring results at USW NRG-6 and USW NRG-7A is scheduled for completion in mid May. Drilling of USW UZ-7A is scheduled for completion no later than August 30, 1995; instrumentation will take place in the first quarter of FY 1996. The first vertical seismic profiling data-collection episode at UE-25 UZ#16 may begin in May 1995 and will take approximately one month to complete.

Air-permeability testing will be conducted in Boreholes USW SD-12, USW UZ-4, USW UZ-5, and USW UZ-7A before borehole instrumentation. Data packages for each borehole will be prepared and submitted as they are tested. A second, surface-based, air-permeability-testing unit will be constructed, allowing cross-hole testing to be conducted when multiple-borehole sites are available in the future.

Forecast: A panel of independent experts will be selected to review the data, the differing opinions on testing and analytical procedures, and, subsequently, to provide recommendations on the USGS air permeability testing program. This review and the report of the results are expected before the end of June 1995.

3.1.8 Study 8.3.1.2.2.4 - Characterization of the Yucca Mountain Unsaturated Zone in the Exploratory Studies Facility

The objectives of this study are to supplement and complement the surface-based hydrologic information needed to characterize the Yucca Mountain site, and to provide information for analyzing fluid flow and the potential for radionuclide transport through unsaturated tuff.

Activity 8.3.1.2.2.4.1 - Intact-fracture test in the Exploratory Studies Facility. The objective of this activity is to evaluate fluid-flow and chemical-transport properties of single, relatively undisturbed fractures.

Comment resolution was completed on the DOE review of the "Intact-Fracture Test" section of Study Plan 8.3.1.2.2.4. A report describing the use of optical methods for mapping fracture surfaces was completed (Cardenas-Garcia and Severson, in prep.). Of the several optical techniques described in the report, phase-measuring profilometry will be used to obtain digital data of the fracture-plane topography of single fractures for the planned intact-fracture tests.

In preparing for sampling in the ESF, technical procedures for collecting radial and axial fracture cores were approved. Preliminary core-sampling sites were identified in Alcove 1 of the ESF. Information was provided to Los Alamos, to include intact-fracture sampling in the Consolidated Sampling Test Planning Package for Alcoves 1 and 2.

Work continued on preparing for the axial-fracture blank test. The success of this design will determine the final design of a high-pressure vessel. Wiring of the data-collection stacks was completed. Gas permeabilities of rocks from G-Tunnel Bed Level 5 (similar to Calico Hills unit) material were completed. This will be the first material tested in the low-pressure vessel. Steady-state and transient pressure data were collected. This was an opportunity to obtain permeabilities of the material to be tested in the low-pressure vessel and to troubleshoot the gas-permeability instrumentation (mass flowmeters, controllers, pressure transducers, and manifold) and the data-collection software. The liquid-flow manifolds and plumbing were completed.

The data collected from this test will include air and water permeabilities under known applied stresses, boundary conditions (gradient), water potentials (fracture plane and matrix), and degree of saturation (fracture plane and matrix). All the parameters measured in the Intact Fracture Test will be used to calibrate models of fluid flow in fractured rock (Study 8.3.1.2.2.8).

Activity 8.3.1.2.2.4.2 - Percolation Tests in the Exploratory Studies Facility. The objective of this activity is to determine the hydrologic conditions that control the occurrence of fluid flow within fractures and matrix and to provide experimental data against which the validity of numerical and conceptual models can be tested.

A prototype ponding test continues on a large, fractured block of welded tuff from the Tiva Canyon columnar unit. The block dimensions are 54.3 cm long x 47.5 cm wide x 80.6 cm high. Water flow rate was measured at different upper-boundary pressures. The water pressure was gradually increased from -20 to +5 cm of water at the top of the block. The flow rate varied between 0 and 50 cm^3/day, respectively; in some instances, the flow rate was intermittent. After the top water pressure reached +5 cm of water, it was gradually decreased to -10 cm of water. The plan is to keep decreasing the water pressure until flow stops. This will be the second cycle of pressure variations on this block (the first cycle was made during FYs 1993 and 1994).

A report containing the data from a series of imbibition tests conducted on cores of welded tuff (Ciesnik et al., 1995) was completed. The rock samples used in the imbibition tests were taken from the trimmings of the percolation-test block described above.

Results from this activity will be used to (a) develop parameters for single- and multiple-fracture networks, including testing for hysteresis and air blockage effects; (b) develop relative permeability and relative transmissivity for the block; and (c) refine the evolving conceptual model of gas and water flow through unsaturated fractures. The prototype block eventually will be split apart to investigate relations between fracture

roughness and hydraulic parameters. The parameters developed in this study will be used to calibrate and refine fracture-flow models developed in Study 8.3.1.2.2.8.

Activity 8.3.1.2.2.4.3 - Bulk-permeability test in the Exploratory Studies Facility. The objectives of this activity are (a) to determine the scale at which the host rock behaves as an equivalent anisotropic porous medium, (b) to compare hydraulic test results against a distribution of simulated results calculated from a large number of realizations of the possible fracture networks conditioned on average fracture orientation and/or fracture density data, (c) to use a numerical fracture-flow model to establish the minimum dimensions at which other rock masses with the same fracture characteristics behave as equivalent porous media, and (d) to examine the dependence of rock-mass dimensions on changing saturation.

No progress was made during the reporting period; this was an unfunded activity.

Activity 8.3.1.2.2.4.4 - Radial borehole tests in the Exploratory Studies Facility. The objectives of this activity are to detect vertical movement of water in both the vapor and liquid forms and to evaluate the potential for lateral movement of water along the hydrogeologic contacts, as well as to evaluate the radial extent of excavation effects on the hydrologic properties of unsaturated hydrogeologic units.

Single-hole, air-permeability testing was completed in the Tiva Canyon Alcove 1 anisotropy radial boreholes. The boreholes consist of three 30-m long, nearly horizontal boreholes drilled in an expanding equilateral triangle. Instrumentation for testing included a downhole television camera, downhole packers, mass-flow controllers, pressure transducers, thermistors, data loggers, and field computers. Testing consisted of television logging to identify fractures and breakout zones, and single-hole, gas-injection testing using a downhole packer system. A total of 118 gas-injection tests were conducted. Because of the high borehole rugosity, however, most of the boreholes were not tested. Permeability values range from 1×10^{-13} to 1×10^{-11} m^2. These values are similar to the air-permeability values obtained from the Tiva Canyon surface-based testing. However, the high rugosity and numerous breakout zones prevented testing of heavily-fractured zones. The heavily-fractured zones probably have higher permeability values and, therefore, testing probably has underestimated the overall permeability. Because of the shallow depth of the alcove and extensive fracturing visible on the ESF and alcove walls, permeability values of 1×10^{-10} m^2, and possibly larger, were expected.

Activity 8.3.1.2.2.4.5 - Excavation Effects Test in the Exploratory Studies Facility. The objective of this activity is to monitor changes to both the stress state and fractured rock permeability caused by excavating. The objective is to use these data, as well as other physical properties gathered during the activity, to validate and calibrate a coupled hydraulic-mechanical finite-element model. The model will be used to predict stress and ensuing permeability changes around excavation openings.

Preparation of a technical procedure for using borehole pressure cells continued. The cells will be used to monitor changes in rock pressure around an excavation in the ESF. All equipment needed for the field test has been received, and the first field test is scheduled to

start during FY 1996. Preliminary locations were identified and presented in Progress Report #11.

Activity 8.3.1.2.2.4.6 - Calico Hills testing in the Exploratory Studies Facility. This activity was deleted from the study plan in Revision 9 of the Site Characterization Program Baseline. Testing in the Calico Hills unit will be conducted as part of other ESF test activities and will be described in revisions of the ESF study plans.

Activity 8.3.1.2.2.4.7 - Perched-water test in the Exploratory Studies Facility. The objectives of this activity are to detect the occurrence of any perched-water zones; to estimate the hydraulic properties of the zones; and to determine the implication of the existence of such zones on flux, flow paths, and travel times.

Monitoring for perched water in the ESF and in the first alcove continued during this reporting period, without detecting any perched water. Moisture was observed in small friable, broken zones in rocks of the Tiva Canyon Tuff, after heavy winter rainfall, but no free water was present and no samples could be collected.

Perched water was encountered during drilling of surface borehole USW SD-7, which is located near the planned turn in the ESF from the Main Ramp to the South Ramp. Perched water was encountered in the upper part of the Calico Hills Formation at a depth of about 485 m (1,590 ft). Late in this reporting period, water-chemistry samples were collected and a series of pumping tests were begun.

Analysis of all available data on perched water encountered in boreholes at Yucca Mountain revealed that perched water generally occurs where highly fractured rock units are underlain by rock units that are less fractured, but have more permeable matrix properties. This discovery has helped determine where perched water is most likely to be observed in the future, both in the ESF and in surface-based boreholes.

Activity 8.3.1.2.2.4.8 - Hydrochemistry tests in the Exploratory Studies Facility. The objectives of this activity are to understand the gas transport processes within the unsaturated zone and to provide independent evidence of flow direction, flux, and travel time of gas; to design and implement methods for extracting uncontaminated pore fluid from rock excavated during ramp construction; to determine the flow direction, flux, and travel time of water in the unsaturated zone by isotope geochemistry techniques; and to determine the extent of the water-rock interaction so that geochemical modeling can be performed to deduce the flow path and to understand the geochemical evolution of the unsaturated zone water.

Shut-in pressure monitoring in ESF Alcove 1 radial boreholes was conducted in November and December 1994. Analysis of these data reveals that the radial boreholes respond almost simultaneously to changes in barometric pressure at the surface. This indicates that the high permeability of the Tiva Canyon Tuff, coupled with the proximity of Alcove 1 to the surface, allows free gaseous exchange between Alcove 1 and the atmosphere.

The radial boreholes have been instrumented with multiple-zone packer strings equipped with pressure transducers and sampling tubes. Detailed gas chemistry and isotope sampling will begin in late March. These samples are expected to verify the assumption of free exchange between the Alcove 1 boreholes and the atmosphere.

Activity 8.3.1.2.2.4.9 - Multipurpose-borehole testing. This activity was originally planned to monitor hydrologic and engineering interference effects from construction of Exploratory Shafts 1 and 2 on tests in these shafts and interference effects between tests in the shafts. In the current ESF design, with two ramps, testing is no longer planned in a scientific shaft.

This activity was deleted from the study plan in Revision 10 of the Site Characterization Program Baseline.

Activity 8.3.1.2.2.4.10 - Hydrologic properties of major faults encountered in Main Test Level of the Exploratory Studies Facility. The objective of this activity is to investigate the permeability and flow conditions of the major faults encountered in the ramps and in drifts at both the Calico Hills and Topopah Spring levels of the ESF.

The tunnel boring machine reached the Bow Ridge fault at 199 m (653 ft). The fault trace is approximately north-south and dips at approximately 60 degrees to the west. The fault offset may be greater than 100 m (328 ft). The fault zone is 2 to 3 m wide. The down-dropped side is pre-Rainier Mesa nonwelded tuff, and the hanging wall is Tiva Canyon lower lithophysal. There are two shear zones that run parallel to the main fault. The geologic mappers, tunnel boring machine construction staff, and the investigators of major faults and hydrochemistry have inspected the fault and agreed on the location of the test alcove. The alcove will be constructed in the hanging wall with a center line at approximately 172 m (564 ft). The alcove will extend north, parallel to the fault, approximately 43 m (141 ft). This configuration of the alcove will ensure that the three test boreholes will be perpendicular to the fault when they pass through the fault plane.

Forecast: For the Intact Fracture test, gas- and water-permeability tests will be run on the end-cap porous plates of the low-pressure vessel. Final calibrations of all measurement equipment will be made before conducting liquid- and gas-permeability tests on the blank sample. These tests will be run to confirm that the air-entry values and permeabilities have not changed during fabrication of the low-pressure vessel. The intact-fracture activity will complete air- and water-permeability tests under applied stresses under different fluid-pressure boundary conditions on a blank sample and a nonwelded core sample from G-Tunnel. Core samples will be collected from ESF Alcove 1 and Alcove 2. The G-Tunnel sample will be used only as a test of the system in rock, consisting of a matrix and a fracture. Subsequently, ESF samples will be tested under the same conditions used to test the G-Tunnel core samples.

Testing of the prototype percolation block will continue until June 1995. Testing will include alternating the pressure head from one extreme to the other to ensure flow rates have gone through at least two complete cycles. This will add confidence that the results are true and not an artifact of the procedure. Petrographic analysis of several thin sections from the

block will determine whether there is a relationship between pore and fracture-face geometry and morphology with hydraulic parameters of the block. Preparation for percolation testing in the ESF will follow.

The three-dimensional, multiple-zone packer system for the Radial Boreholes Test has been completed and is field ready. The system will allow isolation of 15 monitor intervals in each borehole and will provide point sampling of gas geochemistry, pressure, and tracers. Testing scheduled for the next six months includes gas sampling followed by cross-hole, air-permeability, and tracer testing. The goal is to quantify the anisotropy of the Tiva Canyon upper lithophysal zone.

Instrument calibration for the Excavation Effects Test will be conducted within six months before starting the first field test so that calibrations will be valid during the test. Calibration is planned to begin in July 1995.

Monitoring for perched water in the ESF will continue. If perched water is not encountered in the ESF, emphasis will be placed on improving the methods for sampling and testing perched water encountered in surface-based boreholes in the vicinity of the ESF, and in maintaining readiness to expand the monitoring if perched water is encountered in the ESF.

Gas-chemistry and isotope sampling in Alcove 1 boreholes will continue during April. These data will be analyzed to compare the atmospheric gas chemistry with gas chemistry analyses of samples obtained from inside Alcove 1, to determine whether the packer string and borehole construction effectively prevent contamination of the rock gases from the alcove and ESF drift gases. Multiple-zone packer systems also will be installed in the Alcove 2 boreholes to allow discretized chemistry sampling in multiple zones in each borehole that penetrates the Bow Ridge fault. These data will be analyzed to help characterize the hydraulic and transport properties of the fault. To gain further insight into the role of the Bow Ridge fault in gas-phase circulation and chemical transport, a tracer test between Alcove 2 boreholes and surface-based boreholes at the UE-25 NRG#2 pad will be conducted. When construction of Alcove 3 is completed, boreholes there will be treated similarly to the boreholes in Alcoves 1 and 2. Gas sampling and tracer testing will be conducted in conjunction with the ESF Radial Boreholes and Major Faults Tests.

During the next reporting period, Alcove 2 at the Bow Ridge fault will be constructed, and three boreholes will be drilled in support of the Major Faults Test. Following the construction phase, packer systems will be installed and gas sampling and air-permeability testing conducted. The testing schedule will depend upon construction progress. Gas sampling will provide information on the age of gas in the fault zone, and the pneumatic testing will provide a permeability estimate for the fault. These tests will provide insight into the pneumatic behavior of the fault and determine whether the fault is a fast pathway or a barrier for fluid flow.

3.1.9 Study 8.3.1.2.2.5 - Diffusion tests in the Exploratory Studies Facility

The objective of this study is to determine in situ the extent to which nonsorbing tracers diffuse into the water-filled pores of the tuffs of the Topopah Spring welded unit at the Main Test Level of the ESF. A diffusion test is also proposed in the Calico Hills unit.

Because of a staffing change, revisions to the study plan, and pending availability of testing alcoves appropriate for the diffusion tests, there was no progress during the reporting period.

Forecast: The study plan will be completed in FY 1995. A 3-month diffusion test will be conducted in FY 1996.

3.1.10 Study 8.3.1.2.2.6 - Characterization of Gaseous-Phase Movement in the Unsaturated Zone

The objectives of this study are to (1) describe the pre-waste-emplacement, gas-flow field in the presence of open boreholes and the ESF excavations; (2) develop an understanding of the factors that produce and affect this flow field, including topographic, stratigraphic, and structural controls; (3) determine transmissive and storative properties for gaseous flow; (4) develop a history of air circulation at the instrumented boreholes from the time of drilling until the holes are stemmed, as an aid in evaluating the time following stemming before ambient conditions are restored; (5) determine fracture porosity-gas filled matrix porosity ratios and factors controlling gaseous exchange between the two, and/or the dispersivity of the fracture network to gas flow and transport; (6) determine changes caused in the gas-phase flow field as ESF excavations are advanced beyond open boreholes near the line of the ESF excavations; and (7) to develop a preliminary model of the transport of individual gaseous species.

This study was developed in response to the recognition, in January 1986, that there is potential for substantial topographically affected gas circulation through Yucca Mountain. At the time of Kemper's presentation the phenomenon was little recognized, and its potential significance to repository performance was unknown. Since 1986, gas circulation at Yucca Mountain crest through open boreholes has received much preliminary study. Work at Borehole USW UZ-1 supports the absence of thermal-topographic gas flow at that site.

The data in these papers can be very briefly summarized as follows. About 1.3 x 10^6 m^3/yr of gas exit USW UZ-6s, with 80 percent of the flow from the upper 30.5 m of the borehole. All of the rock gas sampled to date from the top of the Tiva Canyon formation has a post-bomb C-14 signature. These observations, documented in detail in the cited publications, show that substantial thermal-topographic gas flow occurs at the location of USW UZ-6s and USW UZ-6 on Yucca Mountain crest, and that gas flow of undetermined magnitude might be anticipated at Yucca Mountain crest under natural conditions. The observations to date are that the thermal-topographic flow is primarily very shallow and thus the effects on performance assessment remain indeterminate.

The main focus of the study has been, and continues to be, to measure flow, temperature, and composition of the gas circulating to or from the two boreholes, with the emphasis to date being on the thermal-topographic flow in USW UZ-6s. Boreholes USW UZ-6 and USW UZ-6s were drilled in 1984 and 1985 to provide access for unsaturated-zone instrumentation, and still remain open through thick sections of the unsaturated zone. The wells are as yet unstemmed, and thus continue to provide the opportunity to study gaseous-phase circulation.

Activity 8.3.1.2.2.6.1 - Gaseous-phase circulation study. The objectives of this activity are to determine the air circulation in open Boreholes USW UZ-6 and USW UZ-6s as a function of barometric pressure and air temperature; to reconstruct the air-circulation history for these boreholes from the time of borehole emplacement to the time of measurement; to determine the zones in which most gas exchange occurs based on logs of flow, temperature, and gas composition with depth; to determine near-field air conductivities, storativity, and anisotropy; and to develop a data base suitable for calibrating gas-phase circulation models for the unsaturated-zone at the Yucca Mountain site.

The Gaseous-Phase Circulation study continued several types of data-collection activities including (a) composite borehole shut-in pressure tests, (b) downhole gas-flow-velocity surveys, (c) gas-column temperature surveys, (d) packed-off-zone shut-in pressure tests, (e) multiple-borehole tracer tests, and (f) gas-chemistry and isotope-chemistry sampling from selected open boreholes and packed-off zones in boreholes. Data continue to be collected from a large number of boreholes on an "as available" basis. The current emphasis is on collecting as much data as possible in boreholes that are most likely to indicate the effects of ESF construction on the gas-circulation system.

Shut-in pressure testing in Boreholes UE-25 NRG#4, UE-25 NRG#2b, UE-25 NRG#3, UE-25 WT#18, and UE-25 WT#4 support results of other tests that indicate the high permeability of the welded Tiva Canyon Tuff. These shut-in tests demonstrate that gas pressure in these boreholes responds essentially simultaneously to changes in barometric pressure at the surface. Monitoring of shut-in pressures continues at UE-25 NRG#2b, and UE-25 NRG#3, to determine if the passage of the tunnel boring machine affects the shut-in pressures in these boreholes.

Multiple-zone shut-in pressure data from Borehole USW SD-9 indicates the presence of two barriers to gas flow. These barriers are thought to be the Paintbrush Tuff nonwelded units separating the Tiva Canyon Tuff from the Topopah Spring Tuff, and the basal vitrophere of the Topopah Spring Tuff separating the Topopah Spring Tuff from the upper units of the Calico Hills Formation. The lower barrier may be a low permeability geologic unit or it may be caused by the presence of perched water near the top of the Calico Hills Formation. If perched water, it may be creating a zone of zero air permeability that, if areally extensive, would prevent barometric pressure changes from causing any response below the perched water.

The instrumentation has already been installed to allow a radially convergent tracer test between USW UZ-6 and UZ-6s. This test will be conducted immediately after gas-sampling for C-14 analysis is completed.

Activity 8.3.1.2.2.6.2 - Measurement of Near-Surface Gas Flow Fields. The objective of this study is to demonstrate how a water vapor RAMAN-LIDAR can be used to monitor and characterize preferred pneumatic pathways. The ability of this technology to measure the rate of water vapor exchange between the atmosphere and the preferred pathways will be validated and will provide benchmark data for convective transport models. This study will characterize known pneumatic pathways and locate the surficial expression of unknown pneumatic pathways at Devils Hole, Nevada using RAMAN-LIDAR. This information will aid the hydrology program by locating potential pneumatic pathways at Yucca Mountain.

Measurement of water-vapor content and evaporative flux are some of the most difficult to make. Commonly, estimates of evaporation are made from measurements of water vapor gradients by traditional instruments, such as Bowen Ratio technique, eddy correlation. These approaches assume that measurements made at a single location represent the properties of a larger region. Data from LIDAR experiments show that the assumption of horizontal homogeneity can be inappropriate and that time averaging at a point will not necessarily achieve a representative spatial flux.

The LIDAR instrument provides new methods of observing water vapor concentrations (atmospheric structures) on temporal and spatial scales. The LIDAR has provided a better understanding of the physical processes involved in turbulent structure transport and evolution. By characterizing the physical processes involving coherent structures, confidence in using the LIDAR instrument to map point source plumes increased and a model for plume transport signatures from multidimensional LIDAR data was obtained. Furthermore, the LIDAR has been shown to measure fluxes with quality at least as good as traditional methods, but with the additional ability to derive them in space as well as time.

The LIDAR team made progress in understanding the capabilities and the limitations of the LIDAR system for locating and characterizing preferred pneumatic pathways. In late January, a team of Yucca Mountain scientists went to Devils Hole, Nevada. Vertical, horizontal, and time series scan data were collected for a known pneumatic pathway, thus enabling the LIDAR team to locate and characterize the pathway. Additionally, coincident point measurements from two temperature/humidity hygrometers were acquired. One hygrometer was positioned directly over the pathway, while the other hygrometer was located 2.5 m away from the pathway, in order to collect ambient atmospheric conditions. In addition, the vertical wind speed of the air emanating from the pathway was measured, as well as ambient atmospheric pressure from a precision barometer. The data were viewed in real-time as the system acquired scans that allowed the team members to evaluate the performance of the LIDAR and the activity of the pathway. The real-time data acquisition and display was a major improvement to the LIDAR system. The LIDAR was operated 24 hours a day for 3 days. The scanning program started with a time series scan over the pathway, then several vertical scans were acquired, and finally another time series scan was initiated. This scanning process was repeated every hour.

A search and discovery process, using repeated horizontal scans, located two additional surface hydro-plumes that demonstrated the ability of the LIDAR to locate unknown pathways. The spatial/temporal characteristics of a coherent water vapor "plume" potential of a second pneumatic pathway was revealed by time series data. This pneumatic pathway was characterized using the automated scan sequence on the LIDAR system. A third sink hole was found to be a pneumatic pathway, and it was characterized also.

The data collected on the field trip at Devils Hole are being analyzed. As the analysis of the LIDAR and point data progresses, it is hoped that the attributes and limitations of the LIDAR system for locating preferred pneumatic pathways will be quantified and described for use at the potential repository at Yucca Mountain.

Forecast: Selected NRG, UZ, SD, and WT boreholes will be monitored for pressure, flow, and gas chemistry before, during, and after the tunnel boring machine passes, to establish the effects of ESF North Ramp excavation. Boreholes USW NRG-5 and USW UZ-6s will be instrumented with Seamist borehole liners equipped with sampling tubes and transducers. These liners will allow gas sampling and discretized, downhole-pressure monitoring to assess any effects from passage of the tunnel boring machine. Borehole USW NRG-5 should also provide insight into the effects of the nearby Drill Hole Wash fault on gas circulation. The removal of the casing from Borehole USW SD-9 will begin to allow a downhole-packer system or borehole liner to be installed to further discretize the Topopah Spring Tuff, and to further assess the effects of the passage of the tunnel boring machine. This borehole should also provide information on the effects of the Ghost Dance fault on gas circulation. A series of convergent-tracer tests will be conducted to validate various conceptual models governing gas-phase flow at Yucca Mountain. Efforts to simulate the results of the airflow, pressure, and chemistry data will continue and will contribute to the site-scale, unsaturated-zone modeling effort.

The preferred pneumatic pathways will be examined using a series of vertical profiles across the sites in question. The contribution of the pathways to the total evaporative flux will be estimated. Detection schemes will be developed to locate other pathways with the horizontal scanning capability of the upgraded LIDAR.

3.1.11 Study 8.3.1.2.2.7 - Hydrochemical Characterization of the Unsaturated Zone

The objectives of this study are to characterize the hydrochemistry of the unsaturated zone by determining the transport mechanisms, flow directions, and travel times for gas and water; determining the extent of water/rock interactions; and developing conceptual hydrologic and geochemical models.

Activity 8.3.1.2.2.7.1 - Gaseous-phase chemical investigations. The objectives of this activity are to understand gas-phase transport mechanisms within the unsaturated zone at Yucca Mountain, as well as to seek evidence of gas-flow direction, volume, rate, and travel time within the unsaturated zone.

Batch-type adsorption experiments (Rattray et al., in press) demonstrated that SF_6, a tracer gas widely thought to behave conservatively, adsorbs onto Yucca Mountain tuffs that have a high zeolite content. This adsorption will cause the transport of SF_6 to be retarded in these materials, resulting in slower observed velocities than would be predicted from modeling of conservative tracer behavior. A retention equation was formulated to provide a direct means of predicting the amount of SF_6 that may be adsorbed by tuffs. Alternatively, distribution coefficients, which showed a correlation with the surface area of the tuffs, may be estimated and used in retardation models to predict the relative transport velocity of SF_6. This information is important for understanding air circulation and air permeability tests, using SF_6, and for understanding the effectiveness of SF_6 to identify contamination of rock gas by air used in drilling.

The USW UZ-1 C-14 (gas) data indicate that transport of CO_2 in the Topopah Spring Tuff is faster than in the overlying nonwelded units. The C-14 data agree well with results of the gas-diffusion modeling, indicating that diffusion is the likely gas transport mechanism. Initial gas sampling was performed in Boreholes USW NRG-6 and USW SD-12, but analytical results are not yet available.

Activity 8.3.1.2.2.7.2 - Aqueous-phase chemical investigations. The objectives of this activity are to design, test, and implement methods for pore-water extraction from core samples; to obtain hydrochemical data to evaluate ground-water flow direction, flux, and travel time in the unsaturated zone; to evaluate extent of water-rock chemical interactions; and to model geochemical evolution of water in the unsaturated zone.

An effective procedure for extracting pore water from core samples with a high-pressure, one-dimensional compression cell was developed. A report on the development of the equipment and validation of the testing procedure was prepared for submittal to a technical journal for publication (Higgins et al., in prep.). The high-pressure, one-dimensional compression cell can load a rock core sample up to 827 MPa. Tests may be staged (loaded in increments) or loaded continuously up to the maximum pressure, depending on the strength and degree of saturation of the rock. The minimum degree of saturation for successful extraction of pore water from nonwelded tuff is about 7.5 percent, and about 34 percent for densely welded tuff. These established minimum saturations are presently used as guidelines for selecting cores appropriate for extracting pore water. Cores with lower saturations are selected for water extraction by vacuum distillation.

The high-pressure one-dimensional compression cell was originally designed to extract pore water from 2.44-in-diameter rock core. Because some available cores are PQ size (3.27 to 3.34 in-diameter), however another procedure is being developed to compress chips chiseled from the core. The testing procedure developed to date requires the chips to be double wrapped in Teflon sheets during compression to reduce the risk of scouring damage to the compression cell sample sleeve. Pore water has been successfully extracted from chips with saturations similar to those for tuff cores that have yielded water. More tests are required to establish specific guidelines as to minimum saturations of chips samples from which water can be extracted.

Pore-water chemistries indicate that unsaturated-zone pore water has significantly higher chemical concentrations than the perched-water body encountered in Boreholes USW SD-9 and USW NRG-7A. Chemical changes induced by rock-sample compression appear minor, evidenced by results of compression- and centrifugation-extraction procedures.

Two conceptual flow models (piston-flow and well-mixed) were used for fitting the tritium data from UE-25 UZ#16 to estimate the residence time of unsaturated-zone water. The tritium-input function was obtained from measured tritium values in precipitation at Salt Lake City, Utah. The piston-flow model gives a 32-to-35 yr residence time for tritium values of about 100 tritium units in Calico Hills Tuff. For a residence time of about 30 yr, the well-mixed model estimates a tritium value of about 50 tritium units. Therefore, it seems that piston flow, or preferential flow along discrete pathways, is predominant in this area of Yucca Mountain (i.e., fracture flow is the dominant flow rather than matrix flow). Chlorine-36 dates also showed elevated signals in Calico Hills Tuff from UE-25 UZ#16.

The UE-25 UZ#16 bedded-unit pore-water carbon-14 apparent ages are younger than the gas carbon-14 ages. The observed apparent age differences may result from gravity-driven flow of liquid water in fractures, a process that is faster than that for diffusive gas flow. The isotopic data indicate that vertical flow in the fractures of welded tuff and lateral flow in bedded units (such as the Calico Hills Tuff) are likely the dominant hydrologic flow mechanisms in the unsaturated zone at Yucca Mountain.

Perched water samples were collected from Boreholes USW UZ-14, USW NRG-7A, and USW SD-9. Chemical and isotopic compositions of the perched water indicated that (a) some USW UZ-1 and USW UZ-14 samples are contaminated with USW G-1 drilling mud; (b) some USW UZ-14 samples have stable hydrogen and oxygen isotopic compositions and C-14 ages similar to those obtained for samples from UE-25 J#13; (c) plots of the stable hydrogen and oxygen isotopic compositions of perched water samples fall near the Yucca Mountain precipitation line on a graph, indicating that perched water rapidly infiltrated into fractures; (d) perched waters from USW NRG-7A and USW SD-9 are of the same water type and have similar stable hydrogen and oxygen isotopic compositions as ground water, indicating that the same source and flow path is recharging both perched water and ground water; and (e) the apparent C-14 ages of perched water collected from Boreholes USW NRG-7A and USW SD-9 at a depth of about 457 m (1,500 ft) are similar to apparent C-14 ages of Calico Hills Tuff pore water.

Forecast: Gas samples will be collected, analyzed, and tabulated from newly drilled boreholes (USW SD-7 and USW SD-12), existing holes being deepened and instrumented (UE-25 UZ#4 and UE-25 UZ#5), and recently instrumented boreholes (USW NRG-6 and USW NRG-7A). Perched water (USW SD-7) and pore water extracted from core samples (USW UZ-14, UE-25 UZ#16, USW SD-7, and USW SD-12) will be analyzed for cations, anions, and isotopic compositions. An interpretive report of the unsaturated-zone hydrochemistry at Yucca Mountain, based on the available gaseous and aqueous data, will be prepared.

3.1.12 Study 8.3.1.2.2.8 - Fluid Flow in Unsaturated, Fractured Rock

The objective of this study is to develop and refine conceptual and numerical models describing both gas flow as well as liquid water and solute movement in unsaturated, fractured rock.

Activity 8.3.1.2.2.8.1 - Development of conceptual and numerical models of fluid flow in unsaturated, fractured rock. The objective of this activity is to develop detailed conceptual and numerical models of fluid flow and transport within unsaturated, fractured rock at Yucca Mountain.

A simulated fracture network has been developed using the FracMan fracture-generation code for the ESF Starter Tunnel area (about 10,000 m^2). The area includes part of the upper lithophysal zone, Tiva Canyon unit. The simulated network matches well with mapped fracture data from the Starter Tunnel, Alcove 1, and other surface mapping. Criteria used for matching includes the number of fractures per meter, number of fractures per m^2, total length of fractures per m^2, termination percentage, and fractal dimension. A first-cut attempt has been made to analyze the connectivity of the simulated fracture network for the ESF Starter Tunnel area. Several parts are involved. Air permeabilities, determined from testing in three radial boreholes in Alcove 1, were used to derive a transmissivity distribution and fracture frequency for the most connected fractures. The ratio of the connected fracture frequency to the initial fracture frequency and the initial fracture intensity (fracture area/rock volume) was used to simulate a new connected fracture system and eliminate the non-connected fractures from the initial fracture network. The analysis also determined the number of connected fractures, the number of connected fracture systems in the network, their position in space, their volume, and how they are connected to tunnels and boreholes.

A report was published summarizing work on the conductivity of variable-aperture rock fractures (Zimmerman and Bodvarsson, 1994). It was shown that conductivity could be accurately predicted based on knowledge of the mean and standard deviation of the aperture distribution.

A paper was published in a special issue of the journal *Radioactive Waste Management and Environmental Restoration* (Zimmerman et al., 1994). A draft of a report has been written, describing the new semi-analytical method for simulating flow in fractured rocks, and summarizing work on fracture/matrix flow interactions (Zimmerman et al., in prep.[a]).

A procedure has been developed for predicting the gridblock-scale hydraulic conductivity of a fracture network, under saturated or unsaturated conditions. Predictions of the method compare well with the numerical results of Kwicklis and Healy (1993). A paper was prepared for presentation at the 1995 High-Level Waste Conference (Zimmerman and Bodvarsson, in prep.).

A procedure for "correcting" the laboratory-measured hydraulic conductivities and water-retention curves to account for the presence of rock fragments has been developed and

tested on various data sets from the literature. A report describing this work is being prepared (Zimmerman et al., in prep.[b]).

Simulations have been run of transient infiltration, under ponded conditions at the surface, into a one-dimensional vertical column of gridblocks taken from the three-dimensional site-scale model, using both the equivalent-porous-medium approach and the dual-porosity approach. The results show that the equivalent-porous-medium model underestimates the depth of penetration of the wetting front.

Activity 8.3.1.2.2.8.2 - Validation of conceptual and numerical models of fluid flow through unsaturated, fractured rock. The objective of this activity is to evaluate the reasonableness of the concepts on which the models developed under Activity 8.3.1.2.2.8.1 are based, by using the results of laboratory tests and tests performed in the ESF to access the adequacy of model performances.

No progress was made during the reporting period; this was an out-year activity.

Forecast: The connected three-dimensional fracture network will be continually refined. Generation of a grid system will begin on the connected fracture network to simulate one- and two-phase flow through the network; it will be determined at what scale, if any, the fracture network becomes a continuous porous medium. Data from the air-permeability, cross-hole testing in the radial boreholes, Alcove 1, will be analyzed and incorporated into the fracture flow model. If the fracture distribution in the radial boreholes is mapped, permeability distributions for different fracture orientations can be determined, and fracture porosity can be calculated by calibrating to tracer velocities. A sensitivity analysis will be completed for various parameters to the system. Fracture mapping in the Tiva Canyon unit from other parts of Yucca Mountain is being compiled and analyzed; these data will be used to expand the three-dimensional fracture network for the ESF area to a site scale. Relative permeability and transmissivity distributions for fractures, Tiva Canyon unit, delineation of potential fast pathway, and clustering of fractures will be used to evaluate properties for the site scale model.

The semi-analytical dual-porosity procedure will be used to simulate transient infiltration into two- and three-dimensional segments of the three-dimensional site-scale model. The inverse procedure that has been developed for determining unsaturated hydraulic conductivities from measurements of sorptivity and water-retention curves will be used on recently measured data for Yucca Mountain tuffs. The procedure that has been developed to estimate the effect of rock fragments on the hydraulic properties of near-surface soils will be applied to data from Yucca Mountain.

3.1.13 Study 8.3.1.2.2.9 - Site Unsaturated-Zone Modeling and Synthesis

The objectives of this study are to develop appropriate conceptual models for the site unsaturated-zone hydrogeologic system; to select, modify, or develop numerical hydrologic models capable of simulating the hydrogeologic system and its component subsystems; to

apply the models to predict the system response to changing external and internal conditions; to evaluate the accuracy of the models using stochastic modeling, conventional statistical analyses, and sensitivity analyses; and to integrate data and analyses to synthesize a comprehensive, qualitative, and quantitative description of the site unsaturated-zone hydrogeologic system under present as well as probable, or possible, future conditions.

Activity 8.3.1.2.2.9.1 - Conceptualization of the unsaturated-zone hydrogeologic system. The objectives of this activity are to develop conceptual models for the overall moisture flow system within the unsaturated zone at Yucca Mountain and to develop an internally consistent set of hypotheses that describe those aspects of the site hydrogeologic system that are needed to assess the capability of the site to isolate nuclear waste for a period of 10,000 yr or longer.

Considerable effort was expended during the reporting period developing a conceptual and numerical model of the gas-flow system of Yucca Mountain. The ultimate objectives of this work are to (a) infer permeability and effective porosity values at a relatively large scale through calibration against borehole flowmeter surveys and gas isotope data; (b) examine the potential for natural gas circulation to redistribute moisture within Yucca Mountain; (c) identify potential pneumatic pathways important for understanding the migration of gaseous radionuclides, and the redistribution of water vapor by waste-generated heat; and (d) build confidence in models of gas and vapor flow for the thermally perturbed system by modeling the natural gas-flow system.

As a first step, summary papers of gas isotope data from Yucca Mountain were examined. Among the significant findings of that work were the following:

- All gas samples at depths <100 m (328 ft) at Yucca Crest (from USW UZ-6s and several neutron holes) have C-14 activities >100 percent modern, suggesting that the shallow flow system in the Tiva Canyon Tuff is dynamic.

- Conversely, the fractured tuffs of the Topopah Spring Tuff at both UE-25 UZ#1 and UE-25 UZ#6 show pre-weapons testing activities of C-14.

- The eastern slope of Yucca Mountain is a significant, even major, source of gas exhausting from boreholes at Yucca Crest, based on estimates of the size of the CO_2 reservoir needed to sustain the observed CO_2 fluxes.

- A considerable (v=50 m/yr) downward advective velocity is necessary along the eastern slope to capture CO_2 at rates observed exhausting from USW UZ-6s.

A two-dimensional, east-west cross section through Yucca Mountain was prepared and used to investigate the magnitude of topographically induced, buoyancy-driven, steady-state gas flow. Gas pressures along the ground surface were assumed to be a function of temperature and elevation, and the water table constituted a no-flow boundary for gas flow. To date, the effects of assuming varying degrees of fracturing within the PTn unit overlying the potential repository horizon have been investigated. As the permeability ratio between the welded and nonwelded units was increased from 1:1 to 1,000:1 (with permeability for the

welded units held constant at 1 x 10^{-12} m^2), the gas flow system became increasingly segregated into shallow and deep components. At permeability ratios between the welded and nonwelded tuffs indicated by air-injection testing of USW NRG-7a, USW SD-9 and UE-25 UZ#16 (approximately 10:1 to 100:1), the nonwelded units function as a leaky aquitard. Most of the gas entering Yucca Mountain along the east slope moves rapidly upslope through the Tiva Canyon Tuff, but a much smaller component penetrates the nonwelded units and migrates slowly upslope within the upper part of the welded Topopah Spring Tuff. This relatively old gas reemerges in the Tiva Canyon Tuff beneath Yucca Crest, where it mixes with the younger gas, before exiting the mountain. Thus, the convergence of gas flow paths beneath Yucca Crest can lead to mixing of gases of much different ages. For permeability ratios of 10:1 to 1,000:1, shallow convection was predicted to occur beneath Solitario Canyon. This shallow convection beneath Solitario Canyon, while not as strong as near Yucca Crest, can introduce relatively young gas into the Topopah Spring Tuff in that location.

A great deal of effort was expended attempting to devise a method for using existing TOUGH2 subroutines to maintain time-varying prescribed pressure and temperature conditions. This capability is necessary to be able to simulate the time-varying gas flow observed at USW UZ-6s as a means of determining local permeability values. This attempt has not yet resulted in a usable methodology, and possible code modifications are being considered.

Fractal and geostatistical methods were investigated as a means for describing the spatial structure of the bulk permeability values calculated from borehole air-injection testing. Identification of the spatial structure is viewed as important not only for interpolation of values between measurement points, but also for estimating bulk-permeability values at larger-scales than are currently tested. Software was written for performing a rescaled range analysis, which is a fractal-based technique. The spatial structure of permeability values from UE-25 UZ#16 was analyzed with both variogram and rescaled range scaling techniques. The UE-25 UZ#16 data were fit reasonably well with variograms having a range of approximately 27 m (90 ft). The data from UE-25 UZ#16 did not seem to follow fractal scaling laws, although this tentative conclusion needs to be examined further and the software needs to be verified. Analyses of data from USW NRG-7A and NRG-6 are under way.

Papers originating from the hydrogenic deposits activity were reviewed for information on the spatial and temporal distribution of fracture coatings and what could be inferred with regard to the timing and location of past fracture flow at Yucca Mountain. Among the significant observations in those papers are that fractures within the PTn unit overlying the potential repository unit are generally not mineralized, suggesting that even in a wetter past, fracture flow through that unit was not widespread. Also, some calcite coatings have been dated, using the C-14 methods, as having formed as recently as 22 ka, indicating that flow was occurring in fractures as recently as the last pluvial period.

Activity 8.3.1.2.2.9.2 - Selection, development, and testing of hydrologic-modeling computer codes. The objectives of this activity are to select, evaluate, and adapt existing numerical hydrologic-modeling codes for application to the site unsaturated-zone

hydrogeologic system; and to modify existing codes or develop new codes, as needed, to simulate particular problems or aspects that are unique to the Yucca Mountain system.

No progress was made during the reporting period; this was an unfunded activity.

Activity 8.3.1.2.2.9.3 - Simulation of the natural hydrogeologic system. The objectives of this activity are to construct appropriate hydrologic models for the natural site hydrogeologic system to simulate and investigate the present existing state of the system and to predict probable future and past states of the system under changes in the environmental conditions.

The development of the three-dimensional site-scale model of the unsaturated zone at Yucca Mountain continued. New data were received, reviewed, and incorporated, as needed, into the model. Work was performed to optimize the computational efficiency of the TOUGH2 code and decrease model run times. The model has been used to predict profiles of state variables such as saturation, capillary pressure, temperature, and gas pressure in the new Nye County Borehole UE-25 ONC#1.

Modeling results in support of the Earth Vision Model development have been forwarded to DOE and EG&G. The delivered data included the coordinates for the three-dimensional model and two-dimensional submodel elements described in a draft report (Wittwer et al., in prep.). The delivery also included the model output files for a number of infiltration rates for the three-dimensional model and a two-dimensional submodel.

A two-dimensional model of gas flow near Borehole USW UZ-6s has been generated to extend the capacity to simulate gas flow to the site-scale three-dimensional model. The model included realistic surface topography, layering similar to the three-dimensional model, and direct use of the hydrologic-material properties from the three-dimensional model. The boundary conditions included simulating atmospheric conditions and infiltration of moisture at the top of the model, and a geothermal gradient. Initial modeling efforts yielded density-driven flow at Borehole USW UZ-6s, but required high permeabilities in the hydrogeologic layers relative to measured permeability values. Additional gas-flow modeling, which included revising the boundary conditions and the numerical grid, resulted in gas flows more in agreement with measured flow data. These results have been extrapolated to the three-dimensional model, and a letter report describing the two-dimensional gas flow modeling has been prepared.

Available saturation, capillary pressure, temperature, and gas flow data have been collected and evaluated for use in calibrating the three-dimensional model. Gas- and heat-flow features have been incorporated into the model, and calibration is proceeding. The North Ramp of the ESF has been incorporated into the three-dimensional model to allow predictions of pressure, temperature, and saturation conditions encountered in the ESF, as well as changes caused by excavating the ESF. Several two-dimensional submodels of the ESF have been used to evaluate saturations and gas pressures around the ESF. The results of the simulations using the submodels indicate that the tunnel ventilation systems will affect

saturations only in the rock units immediately surrounding the tunnel. Simulations quantifying this effect are in progress.

The extension of the three-dimensional model boundaries to evaluate the effects of major faults, such as the Bow Ridge and Solitario Canyon, on moisture flow began with a review of available geological data outside present model boundaries. The LYNX model was provided by USGS and is being used to generate contour maps and cross-sections for comparing thicknesses of the hydrogeologic layers in the three-dimensional model with the LYNX data.

Work on a new grid generator to be used to incorporate the ESF and other tunnels into the model numerical grid has been completed and is in the testing phase. This generator is designed to be flexible and user-friendly, and can be used with the TOUGH2 code, as well as other integral finite-difference and finite-element modeling programs. The program makes grid generation of geological layering and fault offsets an automatic feature. It has been tested against the existing three-dimensional site-scale model grid and other complex grids.

Activity 8.3.1.2.2.9.4 - Stochastic modeling and uncertainty analysis. The objective of this activity is to assess the probable limits of uncertainty of numerical-model predictions caused by uncertainties in the material-property and boundary-condition data.

Progress in this area is reported under Activities 8.3.1.2.2.9.1 and 8.3.1.2.2.9.3.

Activity 8.3.1.2.2.9.5 - Site unsaturated zone integration and synthesis. The objective of this activity is to integrate all applicable site data and analyses to synthesize a continually updated, comprehensive representation for the site unsaturated-zone hydrogeologic system.

Progress in this area is reported under Activities 8.3.1.2.2.9.1 and 8.3.1.2.2.9.3.

Forecast: The numerical modeling of gas flow at Yucca Crest will continue. A three-dimensional numerical model has been created to represent an area near USW UZ-6s. This model will be calibrated against observed rates of airflow from the borehole and used to help interpret results of planned tracer tests.

The spatial structure of air-permeability data collected from air-injection testing at USW NRG-7A and USW NRG-6 will be examined, as was done for data from UE-25 UZ#16. Recent measurements of barometric pressure fluctuations at the same holes will be analyzed to infer vertical permeabilities over longer depth intervals. Permeability data from these two sources will be compared and analyzed for directional and scale effects.

Available data will continue to be collected and the numerical models revised based on the new data. The numerical grid of the site-scale model will be extended to include most of the boreholes in the Yucca Mountain vicinity. The extended grid will include important features, such as the Solitario Canyon, Bow Ridge, and Paintbrush faults, and the steep water-table gradient north of the existing model domain. The existing model grid will be compared with the geologic data contained in the USGS LYNX model. Existing isopach and contour

maps of the model hydrogeologic layers will be extended outward to the new boundaries. The existing isopach and contour maps also will be revised within the current model boundaries, where necessary, to reflect additional borehole information generated from the site investigation program.

Numerical modeling of gas flow near Borehole USW UZ-6s will continue. Modeling results will be used to calibrate the three-dimensional model for gas flow. The three-dimensional model calibration will continue, using available hydrologic data such as saturation, capillary pressure, and temperature profiles from surface-based boreholes. The model will be further tested and calibrated using available isotope data and observations of seeps or perched water from the excavation of the ESF. Geologic-layer thickness and state-variable predictions will be made for new borehole locations as a means of further testing the model. After calibration, extensive sensitivity studies will be performed with the model to identify which hydrologic parameters are of critical importance to the site and may require additional investigation during FY 1996.

Work will continue on submodels evaluating the effect of the ESF on saturations in the surrounding formations. The numerical grid generator will be thoroughly tested and a user's manual written. The generator and accompanying documentation will be made available to interested parties.

3.1.14 Study 8.3.1.2.3.1 - Characterization of the Site Saturated-Zone Ground-Water Flow System

The objective of this study is to obtain the hydrologic data needed to describe ground-water flow paths, fluxes, velocities, and travel times within the site saturated-zone geohydrologic system at Yucca Mountain.

Related International Work

See Section 3.1.17 for related work (under the headings, Borehole Fluid Logging, and Flow and Transport Characterization in Fractured Rocks) performed under the auspices of the OCRWM international program.

Activity 8.3.1.2.3.1.1 - Solitario Canyon fault study in the saturated zone. The objectives of this activity are to characterize the hydrologic nature, significance, and implications of the Solitario Canyon fault, as well as to determine if the fault is a barrier to eastward flow of water in the saturated zone beneath the repository block.

No progress was made during the reporting period; this was an out-year activity.

Activity 8.3.1.2.3.1.2 - Site potentiometric-level evaluation. The objectives of this activity are to analyze the character and magnitudes of potentiometric-level fluctuations with depth and time to estimate transmissive and storage properties, to measure water-level variation with time to determine hydraulic gradient, to correlate water-level variations with

earth crustal strain changes, to better define altitude distribution of uppermost potentiometric surface, to determine barometric and dilatational efficiency, and to determine the frequency response function of the well/formation to barometric and earth-tide induced strains.

Monitoring of water levels in the saturated zone at Yucca Mountain continued. Monthly water-level measurements were made in 18 wells. Hourly water-level data were collected from 17 zones in 12 wells, and continuous data were obtained in 4 zones in 2 wells. Additional water-level measurements were made in support of other activities at the C-hole complex, well USW SD-7 (perched water), and well USW UZ-14. Water levels have essentially remained stable during the reporting period; however, water levels in well USW UZ-14 continued to rise as the well recovers from drilling operations. A report documenting water levels for 1993 (Tucci et al., in prep.) was completed and being processed for publication. Monthly water-level data for 1994 were reviewed and approved, and work began on evaluating the 1994 hourly water-level data.

Four zones in two wells were monitored continuously to detect water-level fluctuations caused by earthquakes and underground nuclear testing. No major earthquake-related water-level fluctuations were observed in the Yucca Mountain area during the reporting period, and there were no underground tests.

Plans for cleaning, reconfiguring, and hydraulic testing of 15 WT-series wells were completed; however, no tests were conducted. These tests are expected to provide qualitative information on hydraulic characteristics of the water-bearing rocks in the vicinity of Yucca Mountain, provide background water-quality data for environmental monitoring, and allow for later hydrochemical sampling.

A draft report documenting the potentiometric-surface map for 1993 conditions and the analysis of water-level trends for 1986-93 was prepared and submitted for review. Such information will provide valuable input to the site saturated-zone, three-dimensional, ground-water flow model. Potentiometric levels are not significantly different from those documented for 1988 conditions.

Activity 8.3.1.2.3.1.3 - Analysis of single- and multiple-well hydraulic-stress tests. The objectives of this activity are to determine intraborehole flow profiles for each of the C-holes under static and pumping conditions, to correlate intraborehole flow rates with lithology and fractures, to identify test-scale hydrologic boundaries, and to estimate aquifer properties (e.g., transmissivity, storage coefficient).

The report presenting the results of the analysis of historic C-hole test data, and summarized in Progress Report #11, was approved for publication (Geldon, 1994).

Background pressure data from packed-off zones in UE-25 c#1, UE-25 c#2, and UE-25 c#3 were collected during the period from January to November 1994. These data will be analyzed for the effects of atmospheric loading and earth tides to obtain barometric efficiency and aquifer characteristics.

Related International Work

See Section 3.1.17 for related work (under the heading, Field Tracer Test Development) performed under the auspices of the OCRWM international program.

Activity 8.3.1.2.3.1.4 - Multiple-well interference testing. The objectives of this activity are to discriminate between equivalent-porous-medium and fracture-network models at the scale of the tests, to determine effective aquifer properties (e.g., transmissivity, storage coefficient), and to evaluate the three-dimensional nature of the flow field in the test vicinity.

The USGS Modular Ground-Water Flow (MODFLOW) program was used to develop a three-dimensional equivalent-porous-medium model of the C-hole complex and vicinity. The model was described in Progress Report #11. Model results are presented in a report being prepared (Geldon, in prep.).

Existing packer and transducer strings were removed from boreholes UE-25 c#1 and UE-25 c#2 and replaced with new strings that contain five packers (instead of the original two), and high-accuracy ParoScientific quartz crystal ASCII transducers (instead of the original less-accurate current-type Druck transducers). The existing packer and transducer string in UE-25 c#3 also was removed, but the hole was kept open to prepare for pump emplacement and the beginning of open-hole hydraulic testing.

Activity 8.3.1.2.3.1.5 - Testing of the C-hole sites with conservative tracers. The objectives of this activity are to determine aquifer transport properties, to evaluate applicability of equivalent-porous-medium models versus fracture network models, to evaluate adequacy of single-well tests versus multiple-well tests to characterize hydraulic properties, and to evaluate spatial correlation and scale dependency of transport parameters.

During the reinstrumentation of Boreholes UE-25 c#1 and UE-25 c#2, in-line components were added to the drill stem that will allow for landing a tracer injector at any of the five screened intervals in the five isolated zones in the boreholes. This will allow for the intermingling of cross-hole tracer tests with the upcoming cross-hole hydraulic tests.

Progress was made toward completing the tracer injection and sampling system to be used during the upcoming tracer tests. A prototype was constructed of the surface-based automated sampling system that will be controlled by the PC-based computerized Data Acquisition System. Coordination continued in identifying conservative tracers to be used at the C-holes, preparation of the tracers for injection, and analysis of samples during tracer testing using high pressure liquid chromatography. Other requirements of the tracer injection system, such as surface-based plumbing, and assembly of the already-procured down-hole part of the tracer injection system, have been requested from Nevada Test Site contractors by a Criteria Letter.

Activity 8.3.1.2.3.1.6 - Well testing with conservative tracers throughout the site. The objectives of this activity are to determine aquifer transport properties at selected site locations; to evaluate vertical and horizontal spatial variability of flow parameters; and to

examine spatial correlation, cross correlation, and scale dependency of flow and transport parameters.

No progress was made during the reporting period; this was an unfunded activity.

Activity 8.3.1.2.3.1.7 - Testing of the C-hole sites with reactive tracers. The objective of this activity is to characterize the chemical and physical properties of the geologic media in the saturated zone in the vicinity of the C-holes that will affect radionuclide retardation during ground-water flow within the saturated zone.

Project hydrologists collected data on the validity of using batch sorption data to predict transport behavior at laboratory scale. Using lithium bromide as a tracer, five crushed-tuff column experiments were conducted. The bromide was expected to act as a conservative nonsorbing solute, and the lithium was expected to be retarded by weak sorption to the tuff. To investigate kinetic effects, the flow rates were varied over a range of 3:1; to investigate isotherm effects, lithium-bromide concentrations were varied from 5 to 20 ppm. Preliminary analysis of some samples indicated that the column transport of lithium can be predicted reasonably well by assuming local equilibrium (i.e., a K_d modeling approach), using the batch sorption isotherm parameters obtained previously. There is, however, some evidence of kinetically-controlled sorption at higher flow rates. A letter report on this subject was being prepared (Robinson et al., in prep.).

Project hydrologists collected data (at laboratory scale) on the validity of a matrix-diffusion model for transport of a dissolved species. Results of these experiments may have important implications for confirming that the saturated zone is a significant barrier to radionuclide migration. Using iodide and polystyrene microsphere tracers, transport experiments were conducted in three fractured tuff samples: one Bandelier Tuff fracture and two C-hole specimens. The tracer breakthrough curves for the three fractures were similar; the microsphere tracers arrived at the outlet 10 to 25 percent sooner than the dissolved tracer, and the dissolved tracer exhibited a much more gradual approach to the steady-state concentration than did the microspheres. These results can be attributed to the different sizes and diffusion coefficients of the tracers. The earlier arrival of the microspheres was probably caused by some of the microspheres remaining in high-velocity fluid streamlines near the centerline of the fractures, whereas the iodide was able to diffuse across streamlines and experience more of an average fluid velocity in the fractures. The slower approach of the iodide to the steady-state concentration can be attributed to diffusion into the porous matrix, a phenomenon that does not affect the microspheres because of their large size and small diffusion coefficients. The results of these laboratory-scale studies were documented in a paper (Reimus et al., in press) and a letter report (Reimus, in prep.[a]).

A paper (Robinson, 1994) presented a conceptual model for radionuclide migration in the saturated zone. This model consists of fracture flow within the uppermost 100 to 200 m of the saturated zone, with transport by diffusion into the rock matrix. At the ground-water conditions expected to apply at Yucca Mountain, radionuclides should have ample time to diffuse fully within the matrix blocks. The result is a predicted solute transport time that is several orders of magnitude greater than the ground-water travel time. This is important

because it would make the saturated zone a significant barrier to radionuclide migration. To validate this model, a suite of interwell tracer tests are proposed using both conservative and sorbing tracers. These tracer tests will be carried out at the C-holes in the saturated zone at Yucca Mountain.

Activity 8.3.1.2.3.1.8 - Well testing with reactive tracers throughout the site. The objective of this activity is to characterize chemical and physical properties of the geologic media in the saturated zone throughout the site that will affect radionuclide retardation during ground-water flow within the saturated zone.

No progress was made during the reporting period; this was an out-year activity.

Forecast: Routine monthly, hourly, and continuous water-level monitoring will continue; however, the configuration of the network may undergo additional changes. Cleaning, reconfiguring, and hydraulic testing for three WT-series wells will begin, and drilling of USW WT-24 may begin. The 1993 potentiometric-surface map report will be completed, and work will begin on the 1994 data report. A pump will be emplaced in UE-25 c#3 during April 1995, and open-hole pumping will commence. Boreholes UE-25 c#1 and UE-25 c#2, which have each been instrumented with five packers and six pressure transducers, will be the observation wells. In the latter part of May 1995, the 400 gpm pump will be removed from UE-25 c#3 and the borehole instrumented with five packers and six pressure transducers, in the same fashion as boreholes UE-25 c#1 and UE-25 c#2, and also with the USGS 200 gpm pump and pump shroud. This will enable packed-off cross-hole and tracer tests to commence at the C-holes.

A few cross-hole hydraulic and tracer tests are expected to be completed during the forecast period. The tests will begin with the screened interval open in only one of the five packed-off zones in UE-25 c#3 and the pressure transients observed in all packed-off intervals of Boreholes UE-25 c#1 and UE-25 c#2. On the basis of the quickness of response in the observation holes, a particular zone will be chosen in UE-25 c#1 or UE-25 c#2 to inject a conservative tracer. Depending on the success of this conservative tracer test, a decision will be made as to whether to conduct a reactive tracer test in the same zone, or to conduct additional conservative tracer tests with different operational parameters (such as pumping rate) to further understand the flow regime before conducting the reactive tracer test.

The C-hole tests will demonstrate the applicability of laboratory sorption measurements for predicting field transport behavior using a model of fluid flow and transport in fractures, coupled to transport via molecular diffusion with the surrounding rock matrix. This model, if shown to be valid, would add several orders of magnitude to the radionuclide migration time in the saturated zone above that predicted for pure fracture flow and transport. The polystyrene microsphere part of the study will show whether colloidal-sized particles can transport over field-scale distances in the saturated zone. The microsphere breakthrough curves will also provide a basis for estimating transport rates through the saturated zone in the absence of matrix diffusion. This work will continue at field-scale.

3.1.15 Study 8.3.1.2.3.2 - Characterization of the Saturated-Zone Hydrochemistry

The objective of this study is to describe the composition of, and spatial compositional variations in, saturated-zone ground waters using new and extant data; to identify the chemical and physical processes that influence ground-water chemistry; and to aid in the identification and quantification of fluxes to, from, and within the saturated zone.

Activity 8.3.1.2.3.2.1 - Assessment of saturated-zone hydrochemical data availability and needs. The objectives of this activity are to compile and evaluate extant hydrochemical data for the saturated zone, to identify data deficiencies and potential sampling sites and assemble requisite material for sample and field data collection, and to augment extant information by collecting and analyzing new hydrochemical samples and data.

A report, compiling and assessing hydrochemical data within a three-degree square region containing Death Valley and the Nevada Test Site was distributed (Perfect et al., 1994).

Activity 8.3.1.2.3.2.2 - Hydrochemical characterization of water in the upper part of the saturated zone. The objectives of this activity are to describe the hydrochemistry of the upper part of the saturated zone by collecting representative water samples from intervals within the upper 100 m of the saturated zone, within and adjacent to the site area, and studying their chemical and isotopic compositions; and to estimate flux to or from the saturated zone by collecting interstitial water and gas samples from immediately above the water table and studying their chemical and isotopic compositions.

As part of efforts to prepare for borehole cleanout and USW WT-24 construction, preliminary dimensions for the borehole were used to prepare specifications for packer purchases requisite to lower unsaturated-zone sampling at that borehole. Work plans for upcoming borehole cleanout efforts at and in the vicinity of the site were reviewed to identify sample and logistical needs and concerns, which were relayed to the work coordinators. The assembly of equipment requisite to collecting samples and field data attendant to the clean-out was begun. Water samples and field data were collected at an Environmental Restoration and Monitoring Program borehole near Rainier Mesa.

Activity 8.3.1.2.3.2.3 - Regional hydrochemical tests and analyses. The objective of this study is to describe regional spatial variations in ground-water chemistry in the saturated zone by collecting representative water samples from wells and springs within the region and by studying their chemical and isotopic compositions.

Plans for reconnaissance and sampling with Death Valley National Park staff were discussed. Several sites were identified for re-visits to complete prior sample collection, and two new sites were identified for new work. During a second visit, additional Park staff were briefed about agreed-upon sites and on data collected to date and their significance. Following the briefing, five previously visited sites were revisited to complete sample collection, and one new site was examined to plan for sample and data collection there. Samples and data were collected at the new sites on a subsequent visit.

Activity 8.3.1.2.3.2.4 - Synthesis of saturated-zone hydrochemistry. The objectives of this study are to describe the saturated-zone hydrochemistry; to identify chemical and physical processes that influence ground-water chemistry; and to aid in the identification and/or quantification of ground-water travel times, climatic conditions during periods of recharge, flowpaths, and fluxes to, from, and within the saturated zone.

No progress was made during the reporting period; this was an out-year activity.

Related International Work

See Section 3.1.17 for related work (under the heading, Hydrochemical Tool Testing) performed under the auspices of the OCRWM international program.

Forecast: Data deriving from field efforts in Death Valley National Park and the site area will be analyzed and a report prepared. Samples and selected field data will be collected as opportunities present themselves.

3.1.16 Study 8.3.1.2.3.3 - Saturated-Zone Hydrologic System Synthesis and Modeling

The objectives of this study are to synthesize the available data into a model and make a qualitative analysis of how the system is functioning and to represent quantitative observations of hydrogeologic data pertaining to the ground-water flow system in a comprehensive flow model.

Activity 8.3.1.2.3.3.1 - Conceptualization of saturated-zone flow models within the boundaries of the accessible environment. The objectives of this study are to synthesize the available hydrogeologic data to develop a conceptual model and to make a qualitative analysis of how the site saturated-zone hydrogeologic system is functioning.

The simulation code FEHMN was chosen for simulation of the site saturated-zone flow system. The software, including interface software, and hardware required to run the code were acquired and tested. Changes were requested to allow the use of the ANSI C-compiler for compiling a version of the code that includes the Advanced Visual Systems modules. These modules are required for producing output that will permit three-dimensional visualization of the model output using Advanced Visual Systems software.

Testing of the FEHMN ground-water flow, heat, and solute transport code was completed using test problems supplied by the developers of the code. FEHMN is fully functional for running three-dimensional ground-water flow, heat, and mass-transport problems for variably and fully saturated, porous, fractured, and dual-porosity media. A simple three-dimensional mesh and input data set for the FEHMN heat and flow simulator was developed, which identified some disconnects with the mesh generator and the input requirements for FEHMN.

Work began on constructing the saturated-zone hydrogeologic framework model that will be used as a basis for the flow model. Available geologic cross sections have been acquired, and work began on digitizing them. Hydrostratigraphic units for the model were selected, on the basis of available published information and assigned to the cross sections. Preliminary site model boundaries were selected, and preliminary information on site boundary conditions were provided by the regional flow model, discussed in Activity 8.3.1.2.1.4.4. Evaluation of hydraulic properties of the water-bearing formations began on the basis of water-level fluctuation data provided by Activity 8.3.1.2.3.1.2. Preliminary results of this evaluation indicate that the method used provides hydraulic properties consistent with those previously reported for the Yucca Mountain area.

The basis for constructing a numerical model of the saturated-zone flow system and a documentation of the understanding of the saturated-zone ground-water flow system is described in a report; the report has received technical review and is in comment resolution.

Four sites in the Amargosa Desert were visited to sample carbonate deposits for age dating and comparison with hydrogenic deposits elsewhere in the region. The deposits may help validate results of model simulations showing new areas of discharge under wetter climate conditions.

Activity 8.3.1.2.3.3.2 - Development of fracture network model. The objectives of this activity are to develop and evaluate methods for simulating ground-water flow and conservative solute transport in saturated fractured rock beneath Yucca Mountain, to relate results of hydraulic and conservative-tracer tests in wells to fracture-network characteristics at Yucca Mountain, to develop methods for identifying transmissive fracture zones in rocks penetrated by boreholes, and to identify geohydrologic conditions at Yucca Mountain where ground-water flow and conservative solute transport can be properly evaluated using the porous-medium assumption.

No progress was made during the reporting period; this was an unfunded activity.

Activity 8.3.1.2.3.3.3 - Calculation of flow paths, fluxes, and velocities within the saturated zone to the accessible environment. The objectives of this activity are to estimate ground-water flow direction and magnitude for input into travel-time calculations; and to evaluate the porous-media concept and fracture-network concept for determining flow paths, fluxes, and velocities.

No progress was made during the reporting period; this was an out-year activity.

Related International Work

See Section 3.1.17 for related work (under the headings, Transport Characterization in Fractured Rocks, and Phenomenological Studies of Multi-Phase Flow in Fractured Porous Rocks) performed under the auspices of the OCRWM international program.

Forecast: Construction of finite-element model simulations of the revised subregional model domain with dense mesh refinement at Yucca Mountain will be continued. Interfaces with ARC INFO to build three-dimensional layers in the three-dimensional version of the USGS MODFE model will be researched.

3.1.17 Related International Hydrological Work

Ground-water Flow and Water-rock Interactions using Radiogenic Isotopes

The following is work related to Study 8.3.1.2.1.3 (Section 3.1.1) conducted cooperatively with Sweden under the auspices of the OCRWM international program.

This task is aimed at developing a stable and radiogenic isotope methodology for characterizing flow systems in fractured igneous rock and for reconstructing paleohydrology from hydrogenic deposits in fractures (Wallin and Peterman, 1994). During the previous reporting period, strontium, oxygen, hydrogen, carbon, and sulfur isotopic analyses of water samples from a 1-km-deep drillhole at Laxemar, a few kilometers east of Äspö, identified two distinct waters with only limited mixing of the two. A third distinctive (more saline water) type exists at Äspö. Surprisingly, these data indicated that the present deep saline waters in the region are not injected Baltic Sea water as previously proposed on the basis of water quality alone. This type of approach will be applied at Yucca Mountain to help delineate flow systems, to assess the degree and extent of leakage of the Paleozoic aquifer waters into the Tertiary aquifer, and to determine past fluctuations in the water table.

During this reporting period, this task aimed at developing and testing a stable and radiogenic methodology for characterizing and understanding flow systems in fractured igneous rocks and for reconstructing paleohydrology from hydrogenic deposits in fractures. A report describing accomplishments during the first year of this investigation was issued by the Swedish Nuclear Fuel and Waste Management Company (Wallin and Peterman, 1994). During the FY 1995 reporting period, a third annual collection of ground water samples from surface wells and from side wells in the tunnel were collected for isotopic analyses of strontium, oxygen, hydrogen, carbon, and sulfur (USGS and Geokema AB) and for water quality analyses (Swedish Nuclear Fuel and Waste Management Company). Two of the tunnel side wells penetrate low conductivity zones that were sampled to compare the extent of diffusive communication between water in the low conductivity zones with water in the fractures. In addition, precipitation samples were collected by Swedish Nuclear Fuel and Waste Management Company personnel for strontium isotope analyses to be used to fully characterize the flow system. All the 1994 samples have been analyzed for strontium isotopic compositions.

The strontium isotopic compositions (expressed as $\delta^{87}Sr$) in the undisturbed ground-water system increase systematically with depth from values of +9.9 to +13.9. This increase is accompanied with increases in the dissolved load of cations and anions. This compositional depth progression has been disturbed in the tunnel where many fractures exhibit significant water flow into the tunnel, and the strontium and stable isotopes clearly identify the fracture

zones where the ambient flow system has been substantially modified by tunnel construction. Multiple samples obtained from the REDOX experiment fracture zone (surface wells and tunnel side wells) show a progressive depth increase in strontium concentration (0.08 to 11 mg/L) but little difference in $\delta^{87}Sr$ values (+9.7 to +9.9) as though the infiltrating water were obtaining increasing amounts of strontium from an isotopically uniform reservoir. These variations are consistent with the ion exchange model of Viani and Bruton if the exchanger is isotopically uniform and can act as an "infinite" reservoir with regard to supplying strontium to the ground water. Time series samples from the side wells into the fracture zone similarly show decreases in strontium concentration for the past three years but near constant $\delta^{87}Sr$ values indicating the inflow of near surface water through the fracture.

The deep, saline water at the hard rock laboratory is characterized with large strontium contents (60 mg/L) and $\delta^{87}Sr$ values of about +13.8. The systematic compositional and isotopic depth variations suggest that the near-surface waters and the deep saline waters are the two end members in the ambient system with long-term mixing of the two being the cause of the depth variations. Draw-down of the ground-water system in the tunnel has resulted in the inflow of modern Baltic Sea water, which also has unique compositional and isotopic characteristics (strontium concentration is 1.5 mg/L and $\delta^{87}Sr$ is +0.3). Inflow of Baltic Sea water can be easily detected by its unique isotopic characteristics and by its high tritium contents (about 40 tritium units). Strontium isotopic data collected from low conductivity zones in the tunnel indicate that the waters in these zones are not in effective communication with the fracture water.

Forecast: Isotopic data obtained to date will be integrated with conventional aqueous geochemistry to constrain the origin and evolution of ground water better in fracture-dominated flow systems. A fourth suite of ground-water samples will be collected in June 1995 and analyzed during the last half of FY 1995. Additional samples from the low conductivity zones will be emphasized because information gained on these zones will be important in interpreting the relation between matrix and fracture water at Yucca Mountain. In addition, core samples from the REDOX fracture zone will be collected to determine the isotopic character of the potential ion exchanger, presumably clay, in this zone. The isotopic data will be more fully integrated with water quality data for the same samples on which the isotopic data were acquired. A modeling effort will be started to try to simulate the stable and radiogenic isotope systematics in both the fractures and in the matrix. Isotopic data obtained on these samples will indicate the amount of communication between matrix water and fracture water, a problem that directly applies to both the saturated and unsaturated zones at Yucca Mountain.

Borehole Fluid Logging

The following is work related to Study 8.3.1.2.3.1 (Section 3.1.14) conducted cooperatively with Switzerland under the auspices of the OCRWM international program.

During the previous reporting period, advances were made in analyzing dynamic borehole fluid electric conductivity and temperature logs, providing additional techniques for the determination of the hydraulic properties of inflow zones and fractures. The method

involves flushing the borehole with water of known temperature (different from that in fractures), pumping slowly, and measuring temperature as a function of time. The logs show distinctive features as flow from each borehole enters. The techniques offer the potential for identifying flow zones at lower cost than by using conventional packer systems. The borehole simulator facility has been enhanced and can now handle inclined boreholes. An objective is to extend the applicability to the unsaturated zone; if this succeeds, it will be directly relevant to site characterization at Yucca Mountain. Tsang et al., (1994) provides more details.

During this reporting period, the type curve-fitting technique to analyze dynamic fluid electric conductivity logs has been completed. The classes of type curves have now been defined. A preliminary draft report summarizing the calculational results was prepared and presented to the Swiss National Cooperative Society for the Storage of Radioactive Wastes (crystalline rock project) for their review and comments. The borehole fluid logging method was successfully applied to the Raymond field site, and USGS is considering applying it to the C-hole complex. The borehole simulator facility was improved with supplementary technology transfer funding. A continuously inclinable borehole from vertical to nearly horizontal has been constructed.

Forecast: The use of this method on the Yucca Mountain program will be discussed further, and reports on recent results will be prepared.

Flow and Transport Characterization in Fractured Rocks

The following work is related to Study 8.3.1.2.3.1 (Section 3.1.14) and conducted cooperatively with Sweden under the auspices of the OCRWM international program.

During the previous reporting period, techniques were developed to quantify the spatial resolution and averaging associated with estimates of local scale (grid-block) permeabilities derived through the inversion of tracer and/or pressure data. By examining the spatial resolution and averaging kernels as a function of various data types, the relative importance of tracer versus pressure data for heterogeneity characterization can be quantitatively evaluated and estimates obtained by combining the data types improved. The following specific questions are addressed: given a data type, what is the length scale at which variability can be resolved and what are the associated uncertainties? The formalism developed assesses the impact of the various hydrologic data types (e.g., tracer data, head data) during heterogeneity characterization. These techniques directly apply to site characterization work at Yucca Mountain, as well as to field tracer tests at the Swedish Hard Rock Laboratory. Significant benefit accrues because the techniques permit carrying out resolution studies prior to conducting experiments and a priori determination of the worth of data. Eight nations participate in this effort; this wide participation should bolster confidence in the methods adopted.

During this reporting period, a preliminary analysis of the proposed tracer retention understanding experiment at the Hard Rock Laboratory was completed. The main objective of this program is to understand radionuclide retention mechanisms and to build confidence in

the predictions of transport models. The experiments will be conducted within a hydraulic feature, with a continuity on the order of 10 m. Two well configurations were evaluated: a conventional 5-spot and a set of nested triangles. A series of four tracer tests were simulated for the 5-spot: two dipoles, a converging tracer test, and a diverging tracer test. Significantly more resolution was found around the withdrawal well than the injection well. The dipoles must be repeated in the reverse direction (pumping well switched to injecter) to obtain symmetric resolution. For the nested triangles a diverging tracer test, a converging tracer test, and three double dipole tests were simulated. The series of tests were conducted for both a homogeneous fracture and a heterogeneous fracture.

Forecast: The initial development of the geophysical inverse techniques for hydrologic characterization is complete. The methodology will be applied to the C-holes experiment at Yucca Mountain to evaluate proposed hydrologic tests.

Field Tracer Test Development

The following is work related to Activity 8.3.1.2.3.1.4 (Section 3.1.14) and Study 8.3.1.4.2.2 (Section 3.3.4) conducted cooperatively with Canada under the auspices of the OCRWM international program.

During the previous reporting period, an inversion algorithm was developed to analyze massive cross-hole injection tests, wherein 4,200 transient interference sets were collected. Analyses showed that fracture flow connectivity can be successfully imaged using such tests. A new tracer injection system was developed, wherein the dead volume in the injection zone is minimized and more tracers are delivered directly to the target formation. Pulse injection and asymmetric two-well recirculation tracer tests were conducted at the Raymond Field Site using the newly developed system. Tracers included deuterium, fluorescein, and fluorescent microspheres. The tracer tests pointed out the difficulty of ensuring that most of the injected mass of tracer is captured by the pumping well. Umari et al. (1994) and Karasaki et al. (1994) provide more details of the experiments. The results are currently being analyzed.

Another aspect of this investigation involved seismic tomographic imaging. During the last half of 1994, the field data were analyzed to determine the geologic structure from high resolution seismic imaging. The results indicate that seismic imaging using amplitude attributes directly correlated with the hydrologic tests in defining the permeable fracture zones. These results directly apply to the C-hole tests at Yucca Mountain through testing of prototype equipment, determination of scale effects, comparisons between fracture network and equivalent porous medium models, and development and improvement of equipment and multidisciplinary approaches to understanding fluid flow.

During this reporting period, the following activities were conducted:

- A non-symmetric two-well recirculation tracer test was conducted at the Raymond Field Site.

- A sorbing tracer Li^+ was used along with non-sorbing tracers, Br^- and fluoresceine. The same tracers are planned to be used in the C-holes.

- Preliminary analysis of the test indicated that a simple equilibrium ion exchange model cannot explain the data.

- Grain size and macroscopic and microscopic fracture intervals and porosity are being correlated. A significant correlation between grain size and fracture density has been found.

- An innovative method of taking fracture samples was developed that enables the study of in situ aperture and tortuosity of fracture. The method involves injecting resin into a fracture and taking a core after the resin hardens. A cross section of the core can be scanned to obtain a digitized fracture image, and a thin section can be used to analyze alteration near the fracture. The data will be useful for modeling flow in fractures using actual data at a scale larger than a core.

- Surface profiles of large fracture surfaces was collected at the Shaw Quarry. The profiles extend over 4 m, which is probably among the largest fracture surface profile ever taken. We have developed a method to digitize such data for analysis. We are using tectono-fractographic technique to study the fracturing processes.

- The Borehole Scanner System was deployed to survey the selected boreholes at the Raymond Field Site. The scanner produces extremely high resolution color image of the borehole wall, which can be used to analyze the fractures in situ in great detail. The scanner will be tested in the Yucca Mountain holes when available.

- Tomographic inversions of crosshole seismic data from all ten pairs of wells at the Raymond Field Site were completed. The algorithm jointly inverts the velocity and attenuation. The resulting image confirms the existence of two subhorizontal fracture zones.

- Binary and scalar inversion of the massive crosshole injection test results are being conducted. The inversion algorithm produces an image of hydraulically connected fracture flow paths.

- A solar powered data acquisition system was constructed and installed at the Raymond Field Site to enable unattended background monitoring without running the generator.

Five papers were presented at the American Geophysical Union 1994 Fall Meeting: Freifeld et al. (1994); Cohen et al. (1994); Shvidler and Karasaki (1994); Mauldon et al. (1994; and Grossenbacher et al. (1994).

A paper (Friefeld et al., in prep.), prepared for presentation at the 1995 High-Level Waste Conference discusses the limitations of the advection-dispersion model to describe tracer transport in fractures.

Forecast: A tracer test will be conducted using the same tracer injection system and the same tracers (fluorinated benzoic acids) that will be used during the tracer tests at the C-holes.

A cored borehole may be drilled at the Raymond Quarry using the USGS drilling rig. The purpose of this borehole is to complete all elements of the geohydrologic site characterization process that was (and is being) done at the C-hole complex and is being simulated at the Raymond site. A final report will be written to synthesize all the work performed at the Raymond Quarry site.

Work will continue to improve techniques for characterizing fractured rock mass using surface-based testing. Pressure and tracer testing methods and analysis and modeling techniques are being developed to be used at UE-25 C-hole complex and other saturated zone testing.

Hydrochemical Tool Testing

The following is work, related to Study 8.3.1.2.3.2 (Section 3.1.15), conducted cooperatively with Canada under the auspices of the OCRWM international program.

During the previous reporting period, the Swedish hydrochemical electrode system was tested at the Atomic Energy of Canada Limited Whiteshell Laboratories. These tests revealed several problems, some of which were fixed, but eventually the equipment was returned to the Swedish manufacturer for inspection, testing, and repair. During this reporting period, the system was repaired and returned to the USGS. Such a system provides perhaps the best known means for obtaining uncontaminated and unmodified geochemical data (Eh, pH, pressure, and temperature) from the saturated zone underlying Yucca Mountain. Such data provide substantial support to hydrological and geochemical models needed as input to performance assessment computations of radionuclide transport through the saturated zone.

Forecast: Bench testing will take place early in the second half of FY 95 at the Nevada Test Site, followed by the completion of testing at the Borehole Instrumentation Test Facility, at the Whiteshell Laboratory, and in selected boreholes in the vicinity of the Underground Rock Laboratory. Reports describing each phase of the task will be prepared as planned.

Transport Characterization in Fractured Rocks

The following is work, related to Study 8.3.1.2.3.3 (Section 3.1.16), conducted cooperatively with Switzerland under the auspices of the OCRWM international program.

During the previous reporting period, investigations conducted at the Grimsel Test Site, Switzerland, led to the conclusion that the barriers to flow are resolvable by transient pressure data and that it is more difficult to determine high permeability features (Datta Gupta et al., 1994). A conjugate gradient algorithm was used to invert the transient pressure data and produced a reasonable fit. This means that it is now possible to discern the features that are reliable, as well as the poorly known regions. This will help evaluate a particular distribution of permeabilities that results from the characterization of a region. Another significant development was that of a method for predicting fracture-relative permeability on the basis of geometric parameters that can be measured in the field. This method uses a semi-analytical expression for predicting relative permeability of a fracture network with distributed apertures. The expression successfully predicted permeabilities when compared against those obtained by a numerical model. The same techniques apply to Yucca Mountain and promise to significantly increase confidence in models, at least for the saturated zone that constitutes a large part of the most likely transport pathway to the accessible environment (Karasaki et al., 1994).

Forecast: Future work will experiment with different grids and boundary conditions in conjunction with the use of pressure data. The results noted are being drafted for submission to the journal, *Water Resources Research.* The expression for predicting permeabilities will be verified against larger scale numerical simulations and laboratory data using actual fractures.

Phenomenological Studies of Multi-phase Flow in Fractured Porous Rocks

The following is work, related to Study 8.3.1.2.3.3 (Section 3.1.16), conducted cooperatively with Switzerland under the auspices of the OCRWM international program.

Laboratory Studies

During the previous reporting period, two-phase flow visualization and relative permeability experiments in rough-walled fractures were analyzed. The main results were (a) relative permeability and capillary pressure behavior of fractures was found to have general similarities with the characteristics of three-dimensional porous media, (b) phase interference was strong (i.e., at intermediate saturations, gas and water relative permeabilities summed to much less than 1), and (c) there was a tendency for unstable and time-varying flows, even when great care was taken to apply constant boundary conditions. These results were presented in a paper at the 1994 High-Level Waste Conference (Pruess et al., 1994). First results were obtained from flow visualization experiments in larger (approximately 1 square ft) transparent replicas of rough-walled fractures, using various tilt angles to vary the relative strengths of gravity and capillary forces. Pronounced fingering was observed, in which infiltrating liquid contacted only a small fraction of the fracture walls. Also, time-dependent and intermittent flows appeared to be the rule rather than the exception. Both phenomena have strong implications for matrix-fracture interaction of waters infiltrating at Yucca Mountain.

During this reporting period, new transparent replicas of rough-walled fractures were made. These are approximately 1 square ft, and are being used in flow visualization experiments at various tilt angles to vary the relative strengths of gravity and capillary forces. Pronounced fingering was observed, in which infiltrating liquid contacted only a small fraction of the fracture walls. Also, time-dependent and intermittent flows appeared to be the rule rather than the exception. Both phenomena have strong implications for matrix-fracture interaction of waters infiltrating at Yucca Mountain. A summary of the fracture flow visualization experiments was submitted to the 1995 High-Level Waste Conference (Geller and Pruess, 1995).

To understand the mechanisms giving rise to intermittent flows, experimental setups with special pore structures have been assembled. First trials with an assembly of parallel plates of different apertures succeeded in generating intermittent flows. These setups are currently being refined. In addition to studying liquid percolation downward, the complementary problem of gas percolating upward through an otherwise saturated medium will be examined.

The sophisticated endcap design used in previous two-phase flow experiments in horizontal fractures is being adapted for infiltration experiments in inclined fractures. The goal is to study fingering patterns and percolation rates in dependence upon capillary pressures applied at the infiltration boundary.

Theoretical Studies

During the previous reporting period, numerical simulation experiments of infiltration in two-dimensional heterogeneous media, representing fractures, indicated that infiltration plumes had a tendency to spread laterally as they descended. For certain styles of heterogeneity (absence of long-range correlations between asperities), the spreading proceeded in analogy to a Fickian diffusion process. These results were presented in Pruess (1994). For long-range correlations between asperities, many phenomena were seen that had been observed in field situations of infiltration in thick, fractured unsaturated zones (e.g., at Rainier Mesa), including bypassing, ponding, and fingering. Strong efforts continued to enhance further the inverse modeling capabilities and to apply them to analysis and design of laboratory and field experiments. This work was presented in a paper at the 1994 High-Level Waste Conference (Finsterle and Pruess, 1994).

During this reporting period, gravity-driven percolation of liquid phase in two-dimensional unsaturated heterogeneous media, representing fractures, was studied using numerical simulation experiments. Some of these results are included in an extended summary submitted to the 1995 High-Level Waste Conference (Geller and Pruess, 1995), and in a paper presented at the TOUGH Workshop 95 (Pruess and Antunez, 1995).

Efforts continued to further enhance inverse modeling capabilities and to apply them to analysis and design of laboratory and field experiments. A paper on inverse modeling in two-phase flow was revised and accepted for publication in *Water Resources Research* (Finsterle and Pruess, 1995a). Recent applications of ITOUGH2 were presented in a poster at

the Technical Program Review of the Yucca Mountain Project, February 1995 in Las Vegas, and at the TOUGH workshop (Finsterle and Pruess, 1995b).

Design and Analysis of Field Experiments.

Cooperation continued with the Swiss National Cooperative Society for the Storage of Radioactive Wastes in developing a detailed comprehensive program for field studies of two-phase gas-water flow at the Grimsel rock laboratory. The program is to be implemented over a two-year period from 1994 to 1996 and has the following main objectives: (1) measuring gas entry (threshold) pressures, (2) determining the relationship between laboratory and field measurements of relative permeability and capillary pressure characteristics, (3) evaluating the ability of two-phase numerical simulation codes, such as TOUGH2, to predict field behavior, (4) developing instrumentation for in situ measurements of gas saturation, and (5) developing techniques for measuring capillary pressure curves in brittle and ductile cores from shear zones. The TOUGH2 and ITOUGH2 codes were extensively used in design and analysis activities during the development of the field studies program.

Participation continued in the design and analysis of field experiments at the Grimsel rock laboratory and at Wellenberg, which was chosen as the site for the first low- and intermediate-level nuclear waste repository in Switzerland. The ITOUGH2 code was used for detailed design calculations of hydraulic tests at Wellenberg, with the goal of identifying the presence of free gas in situ and determining two-phase flow parameters (Finsterle, 1995).

Forecast: Laboratory experiments on multiphase flow in fractures will be continued. Numerical experiments on infiltration in heterogeneous fractures will be performed. The report on inverse modeling applications to field tests will be completed.

3.2 GEOCHEMISTRY (SCP SECTION 8.3.1.3)

3.2.1 Study 8.3.1.3.1.1 - Ground-Water Chemistry Model

The objective of this study is to develop a ground-water chemistry model that will initially describe pre-emplacement conditions. Future changes in these properties and processes will then be considered, including infiltration changes as influenced by climatic conditions; long-term mineralogic changes, particularly those influenced by the thermal pulse from emplaced waste; and material property changes caused by the emplaced waste, or possible igneous activity.

The purpose of the ground-water chemistry modeling task is to define the variations in ground-water chemistry to be expected in the present-day Yucca Mountain flow system and to predict ground-water compositional variations in the far-field environment of the proposed repository. The modeling is based on analyses of water samples obtained from wells in and around Yucca Mountain, on conceptual models of water/rock interactions, and on laboratory

data. The well samples provide only a limited representation of the overall range in water chemistry at the site, particularly in the unsaturated zone. To better understand the controls on water compositions within Yucca Mountain flow system, laboratory experiments will be conducted involving a range of water compositions and rock types. The results of the laboratory experiments combined with the known water compositions and conceptual models of water/rock interactions will be used to develop ranges of the ground-water compositional variations to be expected within Yucca Mountain. This information will be used to design laboratory experiments in radionuclide solubility, radionuclide sorption, and waste form dissolution experiments and near-field rock/water interaction studies and waste package corrosion rates. This information will also be included in a coupled hydrology/chemistry flow model (FEHM) to be used in sensitivity analyses and performance assessment calculations.

Considerable progress has been made in this reporting period on the development of conceptual models of water/rock (tuff) interactions and in understanding of the evolution of unsaturated zone ground-water compositions. Because of the high rates of evapotranspiration on Yucca Mountain, the solutes in precipitation (snow and rain) are highly concentrated in the soils and rocks in the near surface of Yucca Mountain. When this evapotranspiration process is combined with processes involving dissolution of near-surface minerals (e.g., calcareous dusts), the result is a process that has a strong impact on the water chemistry in the unsaturated zone at Yucca Mountain. In effect, the unsaturated-zone water chemistry is a function of the composition of precipitation, near-surface dusts, and the local infiltration rate. Areas with low infiltration rates would have waters with higher total dissolved solid contents than areas with higher infiltration rates. Other controls on unsaturated-zone water compositions include hydrolysis reactions with silicate and carbonate minerals, dissolution and precipitation reactions, and ion exchange reactions. The hydrolysis reactions involve the uptake of hydrogen ions by silicate and carbonate minerals. Because carbonate minerals are relatively abundant in the near-surface zones of Yucca Mountain and because carbonate hydrolysis reactions are relatively rapid, the acidic pH of infiltrating precipitation is rapidly neutralized in these zones. At the same time, the silica concentration of infiltrating precipitation is rapidly increased to levels near saturation with opal-A. These near-surface reactions lead to water compositions that are relatively unreactive with respect to subsequent silicate mineral hydrolysis reactions and precipitation/dissolution reactions. This is one of the main reasons volcanic glass is still found in abundance within the unsaturated zone of Yucca Mountain. This conclusion combined with the fact that the gas phase in the unsaturated zone has carbon dioxide contents at or above atmospheric levels suggests that the pH of unsaturated zone waters will not deviate far from the 7.0 to 7.5 range.

Ion exchange reactions will impact unsaturated zone water compositions in those zones that contain significant quantities of clays and zeolites. These zones include the nonwelded parts of the Paintbrush Group (PTn) and portions of the Calico Hill unit. Although the details of these reactions remain to be worked out, the main impact on water compositions will be to decrease the concentrations of alkaline earth ions and the heavier alkali ions and to increase the concentration of sodium ions in unsaturated-zone ground waters.

Experiments to investigate rock-water interactions are under way to quantify the various reactions that can impact the chemistry of unsaturated zone waters. Experiments will also be conducted on saturated zone water and rock compositions.

This work is addressed in a paper (Meijer, in prep.) evaluating which ground-water compositional parameters have the greatest impact on the sorption of each radionuclide of concern to the Project. The paper also recommends ground-water compositions to be used in future sorption experiments. This information will be used to ensure that the sorption coefficient data base bounds the range of sorption behavior that can be expected for each of the radionuclides of concern.

Forecast: Hypotheses about the variables, parameters, and geochemical processes that could affect ground-water composition will be formulated on the basis of a thorough review and evaluation of the literature. Preliminary conceptual models will be developed to provide qualitative understanding of the potential effects of variations in individual or small groups of geochemical parameters and/or processes on ground-water compositions. The potential effects of state variables, chemical parameters, and various geochemical processes will be evaluated. Preliminary conceptual models will be integrated into general conceptual models for the ground-water chemistry of each of the major hydrologic units within Yucca Mountain. Computer simulations will be performed to quantify the processes that appear to control the composition of present-day ground waters in Yucca Mountain and to identify those parameters that have the greatest influence on the composition of the ground waters. The laboratory tests are designed (a) to obtain data that cannot be obtained directly from the literature or (b) to challenge key conceptual models.

3.2.2 Study 8.3.1.3.2.1 - Mineralogy, Petrology, and Chemistry of Transport Pathways

The objectives of this study are to determine the three-dimensional distribution of mineral types, compositions, abundances, and petrographic textures within the potential host rock; and to determine the three-dimensional distribution of mineral types, composition, and abundances in rocks beyond the host rock that provide pathways to the accessible environment.

Activity 8.3.1.3.2.1.1. - Petrologic stratigraphy of the Topopah Spring Member. The objective of this activity is to determine the petrologic variability within the devitrified Topopah Spring Tuff at Yucca Mountain and to define the stratigraphic distribution of variability.

Additional data collection on fracture-minerals and matrix-mineral distributions was completed, and a report was revised and published (Chipera et al., 1995). Before this report was revised, it was known that the stratification of silica minerals (cristobalite, tridymite, and quartz) and of opal near the potential repository horizon followed models previously developed from other core studies. The additional fracture-mineralogy data do not modify the conclusion that silica polymorphs are distributed as expected, but the zeolite distributions in both fractures and matrix differ significantly from previous experience in studies of the

potential host rock. Mordenite was not found in any of the fractures of the Topopah Spring Tuff in this drill core, unlike previous cores drilled at Yucca Mountain. The zeolite stellerite, however, is common within the matrix of the Topopah Spring Tuff at the potential repository horizon and is the dominant fracture mineral within this interval. So far, UE-25 UZ#16 is the only core in which thermally sensitive zeolites occur within the potential repository horizon. Ongoing studies of core samples within the repository block will address the question of whether this is a concern for site suitability evaluations.

Activity 8.3.1.3.2.1.2. - Mineral distributions between the host rock and the accessible environment. The objective of this activity is to determine the three-dimensional distribution chemistry and the total abundance of all major rock-matrix minerals, between the host rock and the accessible environment. The analysis of the three-dimensional stratigraphy will be most heavily weighted toward those units that will first be encountered along potential flow paths away from the repository (i.e., Calico Hills).

Project mineralogists have expended considerable effort examining core samples in which the occurrence of the zeolite erionite was suspected. The current status of the hazardous-minerals studies is summarized in a paper (Guthrie et al., in press[a]), wherein the full range of potentially hazardous minerals is considered, but current Project emphasis is on the mineral erionite. Erionite is of concern to the Project because it is a known carcinogen; tuff intervals that may contain erionite are being handled with caution until analyses can be performed to determine whether this mineral is present in a particular core. Results of recent studies have strengthened the conclusions drawn from previous work, which indicate that erionite is restricted to the upper margin, center, or lower margin of the basal vitrophyre of the Topopah Spring Tuff. This conclusion was reached following careful study of three originally known occurrences (in core from UE-25 J#12, UE-25 a#1, and USW G-4) and two newly discovered occurrences (in cores UE-25 UZ#16 and USW H-5). Project scientists have increased their understanding of the occurrence of this mineral by studying the most abundant occurrence found to date, in core USW UZ-14.

Except for the erionite occurrence in USW UZ-14, all occurrences are minor, being either of limited abundance or apparently restricted to small fractures. To date, the unique aspect of the erionite occurrence in USW UZ-14 is the extensive and abundant matrix zeolitization of the lower part of this basal vitrophyre. Analysis of more samples from the USW UZ-14 occurrence constrains this zone of up to 34 percent erionite to depths between 414.2 and 419.2 m in this drill core. Most of the effort, however, has been devoted to precise x-ray diffraction analysis of samples from cores in which erionite was suspected but not found. Scientists analyzed 36 samples from drill cores USW NRG-7A, USW SD-9, USW SD-12, and UE-25 ONC#1. It is inherently more difficult to provide reliable constraints on the absence of a mineral at even minute levels than to detect the presence of that mineral in significant amounts. Using detection limits that extend down to the range of 220 to 360 ppm, the analyses of 36 samples from these four cores did not indicate the presence of any erionite.

Sample analysis was completed for materials from the UE-25 UZ#16 and USW SD-9 drill sites and for "background" eolian dusts, with an emphasis on the potential occurrence of

erionite. Results of this study are summarized in Guthrie et al. (in prep.). None of the dusts yet analyzed, including those induced by drilling operations, contained detectable erionite. Moreover, the results to date indicate that dusts generated by drilling operations do not contain appreciable amounts of fibrous particles. The natural dusts do contain particles with fibrous morphologies, but most of these fibrous particles appear to be biological in origin (silica phytoliths). The natural dusts also appear to be quite uniform in composition across the Yucca Mountain site, with mineralogies dominated by feldspars, quartz, and smectite. This study is ongoing, with the long-term objectives of (a) providing full characterization of the natural background dusts in the vicinity of Yucca Mountain, (b) determining the impact of Yucca Mountain site operations on these natural dusts, and (c) determining whether site operations (drilling and excavation) produce dusts representative of the soils and tuffs being disturbed, or whether certain minerals are concentrated in the dust created by these operations. Results of this study will be used in addressing the preclosure site suitability evaluation.

A paper describes improvements in the quantitative treatment of opal in x-ray diffraction analysis, with results that will improve the quantitative data for this thermally sensitive and silicon-activity-controlling phase at Yucca Mountain (Guthrie et al., in press[b]).

At the ESF, mineralogists and petrologists examined samples in situ, with geologists assigned to mapping the tunnel walls. They specifically looked at samples of calcite and of opal that provide markers of fluid transport through the Tiva Canyon Tuff and through the complex of nonwelded tuffs that form the extensive hanging wall of the Bow Ridge fault. Samples from the thin alteration zone that marks the Bow Ridge fault were collected for comparison with the very extensive near-surface calcite-silica alteration. These samples will provide data on the nature of fracture vs. fault transport, as recorded by past mineral deposition. Results of these studies will add information on fracture/fault parameters to the matrix mineralogy used for evaluating postclosure site performance.

An abstract was prepared for the Clay Minerals Society Annual Meeting (Vaniman et al., in prep.[a]). The abstract discusses the "dispersed" form of plutonium retention characteristic of smectites, contrasted with the point-concentration plutonium retention by oxides. The nature of plutonium retention by clays will be important in evaluating plutonium retention at Yucca Mountain, because clay distributions are more common and better constrained stratigraphically than other trace and minor minerals.

Microautoradiography studies, emphasizing the study of fracture samples and alteration features associated with fractures, will continue. Toward this end, petrologists reviewed samples at the Sample Management Facility from known transmissive intervals in the saturated zone. Samples that show promise for combined microautoradiography and intact-fracture sorption studies were identified from cores USW G-4 and UE-25 b#1. Manganese-oxide coated fractures, many with slickensides, were selected from USW G-4 for study. These fractures represent an important transmissive interval within the devitrified Tram Tuff. Open fractures, with liesegang-type oxide alteration outlining microchannels in the fractures, were selected from transmissive portions of the Prow Pass Tuff in UE-25 b#1. These samples will be used in experiments to determine radionuclide retardation under fracture-flow conditions; when coupled with microautoradiography to determine the mineral-specific sites of

waste retardation in the fracture walls, results can be obtained to address the integration of fracture transport into performance assessment models.

Project scientists collected x-ray diffraction data on 68 samples from UE-25 NRG#6. Project scientists were preparing samples from the upper portion of USW UZ-14. These data will provide part of the data base needed for several of the technical basis reports planned in evaluating site suitability.

Activity 8.3.1.3.2.1.3. - Fracture mineralogy. The objective of this activity is to determine the distribution of minerals within fractures at Yucca Mountain, within all significant rock masses that might provide transport pathways with some component of fracture flow.

Carlos (1994) contributes to the effort to establish uniform, streamlined sampling activities by Project scientists. The report provides descriptions, sketches, and color plates that can be used to identify fracture minerals in Yucca Mountain tuffs with the aid of a hand lens or binocular microscope. Five primary groups of fracture minerals are identified: (1) white or clear minerals with visible crystal form at <25x magnification, (2) white or clear minerals without visible crystal form, (3) colored minerals with visible crystal form, (4) colored minerals without visible crystal form, and (5) black minerals. These groups are subdivided into specific minerals within the report. Using this hierarchical classification, it is now possible for Project scientists examining core or ESF samples, either in the Sample Management Facility or in the field, to describe and select samples of fracture materials based on a better comprehension of what the fracture materials are.

Project scientists analyzed fracture samples from core UE-25 UZ#16 and incorporated this information into a report (Chipera et al., 1995). The appendix to this report summarizes the fracture data. Optical and x-ray diffraction methods were used to define fracture mineralogy in samples extending from the surface down to the saturated zone. The fracture-mineral distributions in UE-25 UZ#16 are in many respects similar to those observed in previously analyzed cores. For example, tuffs of the Paintbrush Group have a much greater variety of fracture minerals than do the deeper tuffs. The dominant fracture mineral in the Calico Hills Formation is mordenite, even though the zeolitic matrix of this unit consists of clinoptilolite. Calcite has a distribution similar to that previously seen, with a notable absence of this mineral in fractures within a zone about 100 m above the water table. There are, however, some significant differences in the fracture-mineral distributions of UE-25 UZ#16. As noted in the section on Activity 8.3.1.3.2.1.1, stellerite is exceptionally abundant and mordenite is absent in fractures of the potential repository horizon in the devitrified Topopah Spring Tuff. Within this interval there are several zones of shattered or brecciated rock, cemented with stellerite; in some instances, the stellerite content of the matrix increases greatly in the vicinity of the shattered zones. Relations revealed by mineral intergrowths between quartz and stellerite suggest that stellerite deposition may have occurred early, perhaps as part of the very latest stages of tuff cooling. Finally, the zeolite heulandite is conspicuously absent in the lower Topopah Spring Tuff in UE-25 UZ#16. If at least some of the heulandite in other drill cores was deposited relatively recently, then the distribution of heulandite in UE-25 UZ#16 suggests that recent fracture flow at this locality was limited to

intervals at the top of the drillhole (above 143 m depth). These data on fracture mineralogy from UE-25 UZ#16 add to the data base on fracture mineralogy that is needed for the evaluation of fracture transport.

Project scientists have been studying the intergrowths of calcite with zeolites to gain information on variabilities in geochemical conditions that have prevailed during fracture transport at Yucca Mountain. A paper on these intergrowths has been prepared for presentation at the 1995 High-Level Waste Conference (Carlos, in prep.).

A paper describing the thermodynamic constraints on heulandite versus stellerite deposition in fractures at Yucca Mountain is being prepared and will be submitted to the 8th International Symposium on Water/Rock Interaction (Carlos et al., in prep.[a]). The paper shows that stellerite is the stable phase under present geochemical conditions in unsaturated zone fractures. Heulandite may have been favored in the past, perhaps when fluids were poorer in calcium or richer in magnesium and strontium; these variabilities can be used to help define the variations in water chemistry that have occurred at the site.

Carlos et al. (in prep.[b]) is the first of several such studies that will begin to synthesize the distributions of fracture minerals for performance assessment.

Forecast: The chemistry of minerals lining faults and selected fractures and bulk-rock samples in the ESF will be identified. Core from the surface-based testing program and, as appropriate, samples from the ESF will be used to study minerals present at trace or minor levels that may influence or control the sorption behavior of the rocks at and below the potential repository horizon. Studies of the potential health risks associated with the inhalation of fibrous minerals will be performed. The mineralogy and chemistry of calcite in fractures at Yucca Mountain will be examined to determine the origin of calcite-depositing fluids and to identify paleo-transport pathways for these fluids. X-ray powder diffraction, x-ray fluorescence, electron microscopy, and petrography will be used to examine core from the surface-based testing program to determine the mineralogy of units above and below the potential repository horizon. The chemistry of fracture-lining minerals in drill core from Yucca Mountain will be identified and determined. Distribution of fracture minerals will be determined as a function of stratigraphic position, depth from surface, welding and crystallization of wall rocks, and position with respect to present-day and paleo-water tables. Lateral variability of fracture-lining minerals will be determined by comparing these minerals between drillholes. For both fracture and matrix samples, support will be provided for sorption studies through sample preparation, characterization, and petrographic/mineralogic analysis of radiography materials.

3.2.3 Study 8.3.1.3.2.2 - History of Mineralogic and Geochemical Alteration of Yucca Mountain

The objectives of this study are to determine the timing, temperatures, and hydrologic conditions of past alteration at Yucca Mountain; and to study experimentally the dehydration

of smectite, zeolite, and glass. Processes range from deep-seated past hydrothermal alteration to shallow mineral deposition along fractures and faults.

Activity 8.3.1.3.2.2.1 - History of mineralogic and geochemical alteration of Yucca Mountain. The objectives of this study are to constrain the timing of deep-seated alteration of a hydrothermal and epigenetic nature; to estimate the long-term thermal stabilities of important sorptive phases, such as clinoptilolite, and of the silica polymorphs that can influence water composition, precipitation, and the stabilities of other silicate minerals.

Project researchers of alteration history will provide input to the technical basis report on Geochemistry and Postclosure Rock Characteristics. The researchers evaluated geochemical processes that have affected the rock at Yucca Mountain in the context of the siting guidelines for Postclosure Qualifying Conditions for Geochemistry and Rock Characteristics.

A Technical Exchange on Rock Characteristics/Mineralogy/Petrology was held on February 28, 1995, to discuss various topics, including three-dimensional model, geologic framework model, breccia studies, and how such research areas might benefit from integration. Breccia studies were identified as a research area that would benefit from closer integration. Project scientists performing breccia studies as part of this activity have characterized the variations in mineralogy and textures of breccias around Yucca Mountain and searched for evidence of recent brecciation and mineralization, indicative of forceful upward injection or eruption of water from depth. Their expertise can now be applied to cooperative investigations mapping the distributions of fault breccias and other breccia occurrences. Studies of secondary silica were identified at the meeting as another topic deserving of continued cooperative research. The silica studies in the ESF described below are an example of alteration history research that will benefit the climatology program.

Project geologists designed K/Ar and Ar/Ar geochronology studies of mineralogic alteration products to constrain the timing of events in the alteration history of Yucca Mountain as quantitatively as possible and to the highest possible level of confidence. A detailed alteration chronology, which identifies geochemical processes as active or inactive during the last million years, is part of the basis for determining whether the site possesses the favorable geochemical condition.

Previously published results of the K/Ar dating activity included apparent ages as young as 1.5 million yr for clinoptilolites from the unsaturated zone at Yucca Mountain. Data collection was completed, and a report on this subject was published (WoldeGabriel, 1995). This report is part of ongoing research to test the hypothesis that young apparent ages of clinoptilolite from the unsaturated zone are the result of radiogenic argon loss rather than being indicators of recent and pervasive geochemical alteration. Preliminary experimental results suggested that water plays a vital role in stabilizing the clinoptilolite framework structure and in retaining argon. A regular decrease in radiogenic argon contents was noted in clinoptilolite heated at various temperatures under unsaturated conditions for 16 hours. Comparable losses were not observed in samples heated under saturated conditions at 100°C for more than five months. Cation exchange of zeolites with saturated salt solutions generally

had little effect on the argon content. Cesium- and sodium-exchanged samples experienced a gain and loss, respectively, of radiogenic argon for reasons that are not fully understood.

Project geologists continued to collect data on mineralogic alteration in ESF samples, with an emphasis on distinguishing pre-Quaternary geochemical processes from more recently active processes. Texturally and mineralogically complex secondary silica deposits in lithophysae and breccia zones of the Tiva Canyon Tuff were selected for study to help distinguish very old material from younger silica that will be used to help reconstruct the recent paleohydrologic and climatologic history of Yucca Mountain (Levy, in prep.). Silica separated from altered Tiva Canyon Tuff and the Paintbrush (nonwelded) unit at Harper Valley, Yucca Mountain, was characterized by x-ray diffraction and provided to researchers in the climatology program for isotopic analysis.

Activity 8.3.1.3.2.2.2 - Smectite, zeolite, manganese minerals, glass dehydration, and transformation. The objectives of this activity are to determine how minerals and glasses important in the rocks at Yucca Mountain will dehydrate and transform under expected thermal loads; and to investigate the ability of zeolites and smectites to rehydrate after the peak in temperature.

Project scientists continued to address repository effects on the radionuclide retardation properties of existing mineral assemblages and the contribution of hydrous minerals to the total pore water and to the modulation of temperature in a repository environment. They collected data on the equilibrium water content and the energetics of dehydration in clinoptilolite and made significant progress in understanding of the behavior of water in clinoptilolite as a function of temperature and pressure (Carey and Bish, in prep.[a]). In the paper, analytical expressions for the behavior of water were presented. Their calculations on simple models of zeolite-rich tuffaceous units demonstrated that clinoptilolite will make a substantial contribution to the total pore water and to the evolution of temperature.

Data collection on the enthalpy of hydration was completed, and an abstract was presented at the Fall Meeting of the American Geophysical Union and published in the conference proceedings (Carey and Bish, 1994). The enthalpy of hydration was determined using three different techniques: thermogravimetric analysis, differential scanning calorimetry, and immersion calorimetry. In the first method, the equilibrium water content of clinoptilolite was determined by thermogravimetric analysis as a function of temperature and water-vapor pressure. The data were fitted to an equation of state that allowed calculation of the enthalpy of hydration. In the second method, the enthalpy of hydration was measured by differential scanning calorimetry under isothermal conditions as a function of water-vapor pressure. Differential scanning calorimetry data were also collected in scanning mode in which heat capacity and enthalpy of hydration effects are superimposed. The water content of the zeolites during differential scanning calorimetry measurements was inferred from thermogravimetric analysis measurements under similar conditions. In the third technique, the samples were outgassed under vacuum and sealed in glass ampoules. The ampoules were broken under water in an immersion calorimeter and the heats of hydration were measured. Each method has advantages and disadvantages. The accuracy of the thermogravimetric analysis and differential scanning calorimetry determinations of the enthalpy of hydration was

compared with those obtained by immersion calorimetry. The molar enthalpies of hydration derived from thermogravimetric analysis measurements for cation-exchanged clinoptilolites were within 5 to 10 percent of results obtained by immersion calorimetry. Results of this research have also been incorporated in an abstract submitted to the Clay Minerals Society Annual Meeting (Carey and Bish, in prep.[b]).

The draft of a report was completed and submitted to *American Mineralogist* (Carey and Bish, in prep.[c]). A thermodynamic formulation of equilibrium in the clinoptilolite-water system was obtained from analyzing thermogravimetry data for calcium-, sodium-, and potassium-exchanged natural clinoptilolites.

Forecast: Existing alteration effects at Yucca Mountain will be examined to determine the approximate timing of alteration and the conditions under which the rocks were altered. An experimental approach will be used to determine the thermodynamics of water in zeolites and clays at Yucca Mountain and to determine the rates in which these minerals will dehydrate and rehydrate in a repository environment. Potassium-argon dating methods will be used to place bounds on the timing of mineral formation and alteration at Yucca Mountain. Samples from drillholes, the ESF, outcrops, and trenches will be examined to determine the relationships between mineralogic alteration history and hydrologic history.

3.2.4 Study 8.3.1.3.3.1 - Natural Analog of Hydrothermal Systems in Tuff

The objectives of the study are to improve the reliability of long-term predictions regarding hydro-thermal rock alteration in devitrified welded ash-flow tuff; to test the capabilities of the EQ3/6 geochemical code through modeling of alteration mineral assemblages in natural systems; and to provide a better understanding of the origin of alteration mineral assemblages currently found in Yucca Mountain.

As part of a work scope consolidation effort for study plans, this study plan will not be written. Much of the work is a compilation effort to select analog site(s) combined with testing and/or calibration of EQ3/6. This study is not site characterization work, would not substitute for site-specific data, and has utility only in reducing uncertainties in EQ3/6 applications. Some of the work overlaps with work being planned in Study 8.3.4.2.4.1 (Characterization of Chemical and Mineralogical Changes in the Post Emplacement Environment) and Study 8.3.1.20.1.1 (Altered Zone Characterization).

Related International Work

See Section 3.2.17 for related work (under the heading, Taupo Volcanic Zone Natural Analog) performed under the auspices of the OCRWM international program.

Forecast: When study plan revisions are completed, the Site Design and Test Requirements Document will be revised.

3.2.5 Study 8.3.1.3.3.2 - Kinetics and Thermodynamics of Mineral Evolution

The objectives of this study are to investigate the kinetics of glass and silica polymorph transitions and their relationship to aqueous silica activity; and to provide thermodynamic data for clinoptilolite/heulandite and albite and analcime.

Project scientists obtained a large quantity of analcime from Mont St. Hilaire, Canada, for solubility and kinetics experiments. The solubility of this analcime was measured during heating to 90°, 125°, 175°, 225°, and 275°C, yielding a measured solubility product consistent in trend with low- temperature flow-through measurements. The coupled low- and high-temperature measurements generally agree with literature data, although systematic departures exist. In general, the Project K_{sp} values are between 0.7 and 2.0 log units smaller than literature values. A sample of purified sedimentary analcime was prepared for use in further low- and high-temperature hydrothermal experiments. This sample of analcime is more representative of the analcime found at Yucca Mountain, although it is more difficult to obtain in pure form than the Canadian material. Comparison of the solubility of the two analcimes contributes to the understanding of the thermodynamics of the analcime solid solution. This information will allow extraction of the most accurate and applicable information on analcime to be used in modeling of mineral evolution. Preliminary modeling of such zeolite reactions at Yucca Mountain will be described in an abstract (Chipera and Bish, in prep.).

Project scientists reevaluated the solubility product for clinoptilolite and derived a corrected log K_{sp} of -188.4. Solubility runs were conducted in the high-temperature systems at 90°C, and the measured solubility product was found to be continuous with the 80°C value measured with the low-temperature flow-through systems. The resulting data will provide a basis from which rates of dissolution and precipitation can be determined as a function of reaction affinity. These data will allow proper formulation of upcoming kinetic experiments on clinoptilolite that should yield information to predict the behavior of clinoptilolite in a repository environment as a function of time and temperature. For example, the experiments will evaluate the possibility that clinoptilolite will become unstable in solutions with low silica concentrations, such as those saturated with respect to quartz.

Preliminary Na-exchange experiments on mordenite began this period in preparation for upcoming work next year.

Data collection was completed, and a paper (Renders et al., 1995) was being prepared that indicates that activation energies of dissolution and precipitation for cristobalite agree with those found for other silica polymorphs, and this agreement is consistent with the assumption that all silica polymorphs precipitate by the same rate-limiting elementary reaction. The results of this work show that cristobalite may precipitate from hydrothermal solutions if the concentration of $Si(OH)_4$ exceeds cristobalite saturation but is less than amorphous silica saturation, only if there are cristobalite nuclei present. In other words, the presence of cristobalite nuclei catalyzes the metastable precipitation of hydrothermal cristobalite.

Forecast: The rates of dissolution, precipitation, and reaction of clinoptilolite and analcime will continue to be measured, and experiments will begin on a natural sedimentary analcime. Experiments will be conducted from 50° to 250°C in flow-through hydrothermal systems to bracket the temperatures expected in a repository environment. Data will be obtained as a function of time, temperature, and water and mineral composition. Data will also be obtained from the literature for phases such as quartz. These data will be used in preparation of milestones on (a) solubility of Na-clinoptilolite and analcime; and (b) dissolution/precipitation kinetics of clinoptilolite as a function of H_2O_2 , SiO_2, Al_2O_3, and NaCl. Preliminary data will be obtained for mordenite in preparation for out-year milestones.

Using estimated and measured thermodynamic data, a preliminary model of the stability relations between analcime and clinoptilolite as a function of temperature, zeolite composition, and water chemistry will be prepared. This preliminary model will be discussed in a milestone on modeling of the clinoptilolite-to-analcime transition. Results from this milestone will feed into the upcoming milestone on producing a conceptual model of natural and repository-induced mineral evolution at Yucca Mountain. This conceptual model will summarize the potential geochemical and mineralogical effects of thermal loading and the possible impacts on radionuclide containment and rock properties, culminating in an overall model of the expected behavior of the secondary phases at Yucca Mountain as a function of time, temperature, water and mineral composition, and water-vapor pressure.

3.2.6 Study 8.3.1.3.3.3 - Conceptual Model of Mineral Evolution

The objective of this study is to explain observed distributions of minerals in Yucca Mountain. Emphasis will be placed on the evolution of frameworking silicates (feldspars, zeolites, and silica polymorphs). The model will address the general chemical evolution of vitric tuffs. This model will also be used to predict future mineral evolution in the mountain caused by natural processes and resulting from repository emplacement.

This study has been combined with Study 8.3.1.3.3.2, see Section 3.2.5.

3.2.7 Study 8.3.1.3.4.1 - Batch Sorption Studies

The objective of this study is to obtain sorption coefficients for key radionuclides as a function of important geochemical parameters. These studies will statistically evaluate the experimental results and will provide the data base that will be used to develop models to predict sorption coefficients under conditions not directly addressed by the experimental program.

This study is being revised to incorporate Study 8.3.1.3.4.3 (Development of Sorption Models). When the revised study plan is completed, this discussion will address the development of sorption models currently contained in Section 3.2.9.

Activity 8.3.1.3.4.1.1 - Batch sorption measurements as a function of solid phase composition. The objective of this activity is to determine sorption coefficients for radionuclides on tuffs of the Calico Hills zeolitic and vitric units, on devitrified tuffs, and on pure minerals representative of the minerals present in the rock and fractures of the repository block.

Because of the large number of experiments conducted during FY 1994, Project geochemists had to spend considerable time preparing new material for FY 1995 sorption experiments. Three types of tuff samples (devitrified, vitric, and zeolitic); batches of pure minerals, including quartz, albite, gibbsite, calcite, clinoptilolite, and montmorillonite; and actinide solutions (Np(V), U(VI), and Pu(V) in natural and synthetic ground waters) were prepared.

A meeting of ten scientists from across the Project was held on December 15, 1994, to evaluate the current approach of sorption research and to assess whether a change in sorption strategy was necessary. The participants identified plutonium, neptunium, uranium, selenium, and nickel as the radionuclides with the highest priority for study. Surface complexation was identified as the most promising theoretical approach to describing sorption of radionuclides onto minerals in the subsurface, and it was decided that a subset of Project geochemists will continue to pursue this approach, concentrating on developing surface complexation models for tuff surfaces rather than those of pure minerals. Project scientists initiated a study to determine the effect of naturally occurring organic materials on the sorption of plutonium onto tuff surfaces. A paper, described last reporting period, was completed on the effect of organic coatings on the sorption of neptunium (Kung and Triay, 1994). The approach used for this neptunium study will be used for the study of Pu.

A paper on neptunium sorption (Triay et al., in prep.[a]) provided a comprehensive neptunium data base that will be used in the next performance assessment calculations and will be submitted to the YMP data base during the next reporting period.

Activity 8.3.1.3.4.1.2 - Sorption as a function of sorbing element concentrations (isotherms). The objective of this activity is to characterize the dependence of sorption coefficients upon the concentration of the element being sorbed by developing isotherms for the radionuclide. This activity will develop isotherms for the radionuclides to be tested. These isotherm data will be incorporated into the sorption data base for use in determining element concentration levels at which precipitation begins to contribute to the measured sorption ratio, and in modeling sorption to predict retardation along flow paths.

The major focus of this activity is to collect data on U(VI), Pu(V), and Se sorption onto tuffs. This involves refining the sorption data already given to performance assessment for these elements, as well as providing probability distributions for sorption distribution coefficients as a function of major controlling parameters. To this end, Project geochemists began collecting isotherm data for sorption of Pu(V) and selenium onto tuff and pure mineral separates as a function of radionuclide concentration. Preliminary results for selenium indicated minimal sorption onto the solid phases; this is not surprising since selenium exists as an anion (selenite) in ground waters from Yucca Mountain. Preliminary results for Pu(V)

indicated that kinetics may be a major factor in the sorption of plutonium onto tuff; therefore, kinetic experiments to elucidate the time-dependence of the sorption and desorption Pu reactions were begun.

Activity 8.3.1.3.4.1.3 - Sorption as a function of ground water composition. The objective of this activity is to measure sorption coefficients as a function of ground-water compositions anticipated along potential travel paths. These data will contribute to the sorption data base and support the sorption model development and performance assessment calculations.

Data collection began on (a) neptunium sorption onto clinoptilolite as a function of pH and pCO_2, and (b) neptunium sorption onto calcite as a function of water chemistry.

Activity 8.3.1.3.4.1.4 - Sorption on particulates and colloids. The objective of this activity is to determine if sorption of important radionuclides occurs on particulates or colloids that may be present in ground waters along potential transport pathways. Batch techniques, modified to accommodate the much smaller sample sizes, will be used to measure sorption. If any sorption is measured, the use of sorption coefficients alone may not accurately predict the transport of sorbed radionuclides.

No progress was made during the reporting period; this was an out-year activity.

Activity 8.3.1.3.4.1.5 - Statistical analysis of sorption data. The objective of this activity is to produce statistical correlations and error estimates. Various statistical approaches will be used on the sorption data to determine those variables (e.g., mineralogy, ground-water composition, and atmosphere) having the most profound effect on the sorption coefficients; to predict sorption coefficients as a function of mineralogy and, perhaps, ground-water composition; to estimate errors associated with predicted sorption coefficients; and to identify gaps in the experimental data.

No progress was made during the reporting period; this was an out-year activity.

Forecast: Whether sorption of plutonium occurs on particulates or colloids that may be present in ground waters and along potential transport pathways will be determined. Experimental techniques will be developed and optimized for batch sorption experiments using whole rock material obtained by drilling and from the ESF at Yucca Mountain. Analytical artifacts and uncertainties will be resolved. Detailed procedures will be prepared and revised as necessary. Studies of sorption of plutonium, neptunium, uranium, and selenium onto tuff and iron oxides will be conducted. An Actinide Sorption Workshop will be conducted. Experiments will be conducted to obtain data on the dependence of the value of K_d on radionuclide concentration in UE-25 J#13 and UE-25 p#1 waters. The focus will be on key radionuclides (plutonium and neptunium) as developed from the sorption strategy and specific ground-water compositions. Sorption coefficients of plutonium and neptunium as a function of expected ground-water compositions will be measured along potential travel paths. Data will be contributed to sorption data base and will be used to support sorption model development. Sorption experiments on pure separates of the minerals found in Yucca

Mountain tuffs involving various solution compositions and the important radionuclides will be performed; the data resulting will be used to extrapolate whole-rock K_d data. The effects of organics on plutonium sorption will be investigated.

3.2.8 Study 8.3.1.3.4.2 - Biological Sorption and Transport

The objectives of this study are to determine what effects microorganisms have on the movement of radioactive waste (i.e., effects on sorption) and to determine if microbial activities play a role significant enough to be included in a performance calculation for Yucca Mountain; to identify the quantity, location, and characteristics of past and future organic materials used at the site and their susceptibility to microbiological degradation; and to determine the effect that these microorganisms will have on the movement of actinides through analysis of their effect on ground-water quality, colloid formation, effect on solubility, or by direct sorption of the actinides.

This study was reinitiated on October 1, 1994. Project scientists began collecting data on the effects of microbially produced iron-chelating ligands (siderophores) on the transport of radioactive wastes at laboratory-scale. Siderophores have very high binding constants for iron and the actinide elements in the oxidation state. Preliminary results indicate that siderophores can be induced by the presence of iron oxides as the sole source of iron and are presented in a paper by Hersman (in prep.[a]).

Project scientists began crushed-tuff column studies to calculate the effect of siderophores on the transport of radioactive wastes. Column conditions (percentage moisture, flux rate, siderophore concentrations) are being adjusted to achieve maximum results. This experiment is designed to provide background information for Hersman (in prep.[a]).

Project scientists began field studies at the ESF. They collected samples from Alcove #1 and from the Bow Ridge fault and forwarded them to four university laboratories for microbial analysis. The samples are being analyzed to determine total numbers, identity, metabolic activity, and diversity. Sample collection will continue at every major stratigraphic member and contact point along the ESF, until the tunnel boring machine reaches the depth of the proposed repository. The results of these studies will be used to predict the effects of microorganisms on transport of radionuclides (at laboratory scale), and they will be incorporated into a paper by Hersman (in prep.[b]).

Forecast: A report will be written describing sampling procedures and microbiologic analyses of ESF samples. Rock will be collected behind the tunnel boring machine to determine ambient microbe populations at Yucca Mountain. Once these populations are characterized, scientists will begin describing the importance of these microbes to radionuclide transport.

3.2.9 Study 8.3.1.3.4.3 - Development of Sorption Models

The objectives of this study are to model the sorption experiments on rocks and minerals representing the proposed repository block and to derive a capability to predict sorption coefficients for key radionuclides under water-rock conditions not included within the experimental program.

This study is being combined with Study 8.3.1.3.4.1 (Batch Sorption Studies) and when the revised study plan is completed, the discussion of this study will be included in Section 3.2.7.

The history of sorption modeling efforts using surface complexation models indicates the need to experimentally determine sorption site densities and/or binding energies to constrain such models. Otherwise, too many adjustable parameters exist in the models, and their use becomes simply a data-fitting exercise rather than an elucidation of the existence of particular sorption complexes. Atomic force microscopy was studied as a technique that could potentially determine sorption site densities, but it was determined that atomic force microscopy alone is not effective for this purpose because the surfaces of mineral samples from Yucca Mountain show roughened features (typical of previous reaction with water). This surface roughness makes it impossible to distinguish newly sorbed atoms from existing surface atoms without a concurrent method of elemental analysis. Unfortunately, even though an atomic force microscopy apparatus capable of supplying elemental composition analysis is being developed, it will be two or more years until such machines become commercially available.

To provide experimental data to constrain surface complexation sorption models, spectroscopic studies of the radionuclide complexes that form on mineral surfaces are recommended. Data on the chemical form of the observed complexes could then be used in sorption models and, when combined with sorption isotherm data, would serve to determine the average sorption site density as a fitting parameter. Surface sorption under other conditions could then be predicted using the sorption model, and this is the purpose of the sorption modeling studies.

A paper (Rogers, in press) on the studies of sorption as a function of sample grinding and water composition was in press. In addition, a paper (Hawley and Rogers, in press) on the studies of surface reactions of goethite in water was in press.

Related International Work

See Section 3.2.17 for related work (under the headings, Radionuclide Retardation Model Development and Mechanistic Approach to Sorption of Radionuclides) performed under the auspices of the OCRWM international program.

Forecast: Fundamental data on the impact of surface composition on sorption will be obtained. Experiments will be conducted using advanced surface science techniques to determine the composition and coverage of sorbing surfaces in Yucca Mountain tuffs.

Reactions of these coatings that might result from a change in water composition or pH also will be studied as they relate to changes in measured sorption density.

3.2.10 Study 8.3.1.3.5.1 - Dissolved Species Concentration Limits

The objective of this study is to provide solubility or concentration limits for dissolved species of important waste elements under conditions that are characteristic of the repository and along flow paths toward the accessible environment.

Activity 8.3.1.3.5.1.1 - Solubility measurements. The objective of this activity is to specify the conditions under which solubility experiments will be carried out and then measure solubilities or concentration limits of important waste elements under these conditions.

The equipment to perform radionuclide solubility experiments (between room temperature and 90°C) was installed and run in the nonradioactive mode to verify that there were no problems with the system. Neptunium and plutonium, the major actinide components of waste whose solubilities still require refinement, will be studied using this equipment. Of particular importance is the careful determination of the precipitated solids. Because the present data base predicts that the double carbonate neptunium(V) salts are metastable with respect to NpO_2, signs of NpO_2 formation will be carefully looked for. Because NpO_2 is several orders of magnitude less soluble than the double carbonates, such a find would be quite significant to the Project. Note that the x-ray diffraction pattern of NpO_2 could easily be subsumed under that of the double carbonates, and so additional techniques such as diffuse reflectance spectroscopy must be included in the analysis.

Two papers describing recent experiments were completed (Toretto et al., in prep.; Nitsche et al., in prep.). The first paper discusses the approach to solubility equilibrium from oversaturation, where true equilibrium requires approach from both undersaturation and from oversaturation. The results from this study generally agreed with previous results from oversaturation, thereby giving greater credibility to the bulk solubility results. The second paper discusses the comparison between bulk solubility experiments done from oversaturation vs. those done from undersaturation in more detail.

Project scientists began collecting data on selenium, a fission product that has appeared as a potential problem element in performance assessment calculations (Andrews et al., 1993) and whose solubility has not been well studied. Project scientists will use synthetic UE-25 J#13 well water, and most of the experiments will be performed with non-radioactive selenium (with some experiments run in duplicate with radioactive selenium to measure potential radiolysis effects). Results have not yet been determined.

Activity 8.3.1.3.5.1.2 - Speciation Measurements. The objective of this activity is to identify important aqueous species of waste elements under conditions described in Activity 8.3.1.3.5.1.1 and to determine their formation constants.

Project scientists purified laboratory stock solutions of Np-237 and Pu-242 in preparation for speciation experiments. Studies on the first hydrolysis constant of Pu(VI) using photoacoustic spectroscopy were initiated. The relevant equation is $PuO_2^{2+} + H_2O <=> PuO_2OH^+ + H^+$. Previous work by other workers attempted to measure the first hydrolysis constant at high plutonium concentrations by fitting electromotive force and pH titration curves to several competing reactions. Because these methods required high plutonium concentrations (>1 mM), the formation of dimers and higher nuclearity species made the analysis more difficult and less direct. Higher-order hydrolysis constants also added to the uncertainty in these measurements. Because of the indirect nature of these experiments and because competitive reactions were also involved, direct spectroscopic equilibrium constant determination at low concentration is needed. One previous study used photoacoustic spectroscopy at intermediate plutonium concentration ($\geq$ 70 mM). This study was able to measure directly an equilibrium constant only for the reaction $2PuO_2^{2+} + 2H_2O <=> [PuO_2OH]_2^{2+} + 2H^+$ (i.e., the formation of a hydrolyzed dimer), but was not able to find the more environmentally relevant monomer hydrolysis product. This problem was addressed by using the PuO_2^{2+} peaks in the 500 nm region rather than the 650 nm region (as used previously), thereby minimizing water interference to the spectra. Using this strategy, PuO_2^{2+} spectra down to 3 μM have been obtained, so work can now be performed in a lowered plutonium concentration regime where the dimer is less likely to form. In this spectral range, a sharp peak for PuO_2^{2+} was found at 505 nm (acidic solutions) and one for the dimeric $[PuO_2OH]_2^{2+}$ was found at 513 nm (pH=5.3, [Pu]=70 mM). Moreover, a sharp third peak, found only at low plutonium concentration (pH=5.3, [Pu]=5 mM), has been identified at 502 nm. This new peak is attributed to the monomeric hydrolysis product. This is the first direct experimental hydrolysis equilibrium product to be measured for PuO_2^{2+}.

A paper was published (Clark et al., 1995) that proves the utility of nuclear magnetic resonance measurements in determining radionuclide structural information and quantitative equilibrium formation constants. Uranyl trimer species, whose existence had been postulated but never proven, were shown conclusively to exist. Another paper (Tait et al., in prep) discusses the use of photoacoustic spectroscopy in determining the Pu(IV) species present in carbonate waters. Equilibrium formation constants were measured as a function of pH, carbonate concentration, and temperature.

Activity 8.3.1.3.5.1.3 - Solubility Modeling. The objective of this activity is to develop the thermodynamic models and data needed to calculate waste element solubilities over the range of conditions expected at the site.

Geochemical computer modeling studies have focused on evaluating the data base by modeling the solubility of neptunium, plutonium, and americium in UE-25 J#13 and UE-25 p#1 waters and comparing the results to published bulk solubility results. Evaluation of distribution of aqueous species with respect to redox state and controls on mineral saturation state is continuing.

The computer modeling studies have focused on evaluating three data bases by modeling the solubility of neptunium in UE-25 J-13 and UE-25 p#1 waters. The three data bases used are the composite data base (standard EQ3/6 data base DATA0.COM.R22a

supplied with the version 7.2aPC release of the EQ3/6 code package), a composite data base modified with hydrolysis and carbonate complexation constants determined last year, and the alternate data base of Silva and Palmer (DATA0.ALT.R1b). While the predicted solution speciation vs. pH was similar for the first two data bases, the speciation of the third was considerably different, with Np(IV) species appearing at higher concentrations. For the solubility-limiting solid, NpO_2 and $Np(OH)_4$ are predominant throughout the pH range. These solids were not found in previous bulk solubility experiments (the double carbonate salt was important here), suggesting that true equilibrium was not reached, and that the double salts are kinetically metastable (see bulk solubility measurement section above). Similar calculations, providing qualitatively the same result, were done by LLNL and reported as part of the work for developing the geochemical modeling code for the geochemical speciation and reaction model (see Subactivity 1.5.3.2.2).

Project scientists are currently evaluating the activity models built into the EQ3/6 codes with respect to extrapolation techniques for speciation constants from solubility and spectroscopic data (particularly the specific interaction theory model). These calculations include sodium-carbonate, perchlorate and chloride solutions of varying ionic strength (0-5 molal), with minor neptunium and carbonate concentrations, as appropriate. Sodium and carbonate ion activities are being compared between b-dot, Davies and Pitzer model results, while Np(V)-carbonate complex calculated beta constants are being compared with specific interaction theory model extrapolations. These efforts will provide a basis for evaluating model uncertainties, applicability limits, and consistency of the coupled experimental and modeling approach.

The paper by Tait et al. (in prep.) discusses the temperature dependence of the first hydrolysis reaction, as well as the first and second carbonate complexation reaction. This paper eliminates a number of literature sources by disproving the disparate equilibrium constants reported, and also discusses the consequences of these changes for solubility. Recommended equilibrium values are made for incorporation into GEMBOCHS.

A letter report by Janecky et al. (in prep.) discusses the application the EQ3/6 geochemical modeling program with its standard (GEMBOCHS) data base of equilibrium constants. Calculations were performed vs. water composition, pH, and temperature.

Clark (in prep.) discusses the present knowledge of actinide radiocolloid formation. While Pu(VI) is the best known actinide radiocolloid and hence dominates this letter report, other possibilities exist (e.g., Am(III)) and are discussed. Frontiers in this field include basic items such as the overall charge of a colloid and the chemical stability vs. ionic strength and temperature.

A letter report by Clark et al. (in prep.) was prepared, which discusses the present knowledge of aqueous technetium chemistry. Significant gaps in knowledge exist at low concentrations and elevated temperatures for redox potentials, as well as for hydrolysis and carbonate complexation reactions.

Forecast: Thermodynamic modeling of existing solubility and speciation data for neptunium and plutonium will be performed. Scoping calculations to test sensitivity of solubility data to solution conditions outside the bounds used in bulk solubility experiments will be initiated. Solubility measurements for neptunium and plutonium will be performed in water mimicking that from well UE-25 J#13 at three pH values and three temperatures from oversaturation conditions. Particular attention will be devoted to determining the solid that is formed, especially for the neptunium species. The solubility of other radionuclides of potential importance to the repository as a function of ground-water oxidation-reduction potential, pH, and temperature will be determined, starting with selenium and possibly extending to technetium under reducing conditions. This work involves preparation and characterization of solid compounds of the listed radionuclide, followed by dissolution to steady state concentration. Speciation and equilibrium stability constants of radionuclides will be determined by a combination of techniques, including photoacoustic, nuclear magnetic resonance, RAMAN, and luminescence measurements. Experiments will be conducted at both higher concentrations and at concentrations typical of radionuclides at near-neutral water conditions. Comparisons between both concentration regions will be conducted. Data from this study is needed to allow thermodynamically defensible solubility and sorption calculations to be performed by performance assessment at any general water composition. plutonium and technitium will be studied. A computer code data base for making model calculations of radionuclide speciation in solution will be identified, acquired, and modified. Both equilibrium and nonequilibrium (i.e., kinetic) phenomena will be incorporated. A data base will be identified and supplemented with data from solubility and speciation experiments conducted in this study.

3.2.11 Study 8.3.1.3.5.2 - Colloid Behavior

The objective of this study is to determine the stability of waste element colloids under expected site-specific conditions that might be encountered at the repository or along flow paths toward the accessible environment.

Activity 8.3.1.3.5.2.1 - Colloid formation characterization and stability. The objective of this activity is to determine formation and stability of waste element colloids.

No progress was made during the reporting period; this was an unfunded activity.

Activity 8.3.1.3.5.2.2 - Colloid modeling. The objective of this activity is to develop models and parameters to calculate natural colloid concentrations and stability and to describe the disposition of the waste element species as the colloids break up.

No progress was made during the reporting period; this was an unfunded activity.

Forecast: No activity is planned for FY 1995.

3.2.12 Study 8.3.1.3.6.1 - Dynamic Transport Column Experiments

The objective of this study is to measure the breakthrough or elution curve for tracers through tuff columns.

Activity 8.3.1.3.6.1.1 - Crushed tuff column experiments. The objective of this activity is to measure the rate of movement through crushed tuff columns of radionuclides relative to tritiated water and other well-defined chemical species or colloids.

The role of sorption in retarding radionuclides has been described using sorption distribution coefficients (K_d) in Project performance assessment calculations. The K_d values were obtained from batch sorption experiments, and it is necessary to validate the values of K_d under flowing conditions. To this end, Project scientists completed data collection on the retardation of Np(V) in devitrified, vitric, and zeolitic tuffs in ground waters from Well UE-25 J#13 and UE-25 p#1 (as a function of flow velocity) using crushed-rock columns.

Project geochemists initiated crushed-rock column experiments to study the retardation of Pu(V) in devitrified, vitric, and zeolitic tuffs in ground-waters from Wells UE-25 J#13 and UE-25 p#1 as a function of flow velocity.

Project geochemists analyzed data on neptunium crushed-rock column experiments completed in FY 1994 using transport codes (SORBEQ and FEHM), which are capable of describing retardation caused by sorption during flow. The major conclusions were (a) the K_d model conservatively predicts transport of neptunium, (b) the K_d model can correctly predict the appearance of neptunium but fails to describe the shape of the elution curves (experimentally measured) for neptunium transport through tuff, (c) nonlinear isotherms models cannot predict the experimentally determined shape of the elution curves, and (d) sorption kinetics are probably responsible for the shape of the elution curves (with the sorption reaction being fast and the desorption reaction being slow). The final conclusion is of great significance because this sorption model for neptunium retardation can significantly decrease the potential neptunium releases calculated by performance assessment investigators using a K_d model.

All results from this activity will be reported in a paper by Triay (in prep.).

Activity 8.3.1.3.6.1.2 - Mass transfer kinetics. The objective of this activity is to determine the elution rate of radionuclides as a function of water velocity for crushed tuff columns (homogeneous system), solid rock columns (heterogeneous system), and for pure mineral samples.

Project scientists completed collecting data on the transport of neptunium though Yucca Mountain solid tuff (under saturated conditions) as a function of flow velocity (from 14 to 27 m/yr). Columns of zeolitic solid tuff and water similar to that obtained from Well UE-25 p#1 were used. The results indicated that dispersion is significant in this zeolitic tuff. Previously conducted batch sorption experiments using zeolitic tuffs and high-carbonate waters (like UE-25 p#1) yielded minimal sorption of neptunium onto these tuffs. The

transport data for Np-237 indicates that a K_d model to describe retardation will correctly predict the appearance of the tracer and conservatively predict neptunium retardation. Future efforts will be focused on fitting the data obtained (with FEHM) to determine dispersion as a function of flow velocity for neptunium.

Activity 8.3.1.3.6.1.3 - Unsaturated tuff columns. The objective of this activity is to measure the relative migration rate of radionuclides through partially unsaturated rock columns.

Project scientists began collecting data on U(VI) transport through unsaturated solid tuff (devitrified and zeolitic) columns. These experiments (using Well UE-25 J#13 water) were designed to verify whether batch sorption coefficients can describe the radionuclide transport of uranium through unsaturated tuff. A paper by Conca and Triay (in prep.) describing selenium transport was completed. This work shows agreement between batch sorption procedures and the unsaturated flow apparatus approach to measuring sorption coefficients.

Activity 8.3.1.3.6.1.4 - Fractured tuff column studies. The objectives of this activity are to measure the transport and diffusion of radionuclides through naturally fractured tuff; and to examine the movement of tracers through naturally fractured Yucca Mountain cores to test the transport models.

The retardation of radionuclides by sorption in fractures is extremely important for radionuclide transport in fracture-flow scenarios. Three experiments have been initiated:

1. Study of the elution of Np(V) through saturated fractured-tuff columns. (The fractures were obtained from Yucca Mountain and have fracture coatings, including iron and manganese oxides, and zeolites.)

2. Study of the magnitude of colloid transport through unsaturated fractures. Fluorescent polystyrene spheres (with a negative surface charge) have been chosen for these experiments. These colloids experiments will be performed in Well UE-25 J#13 water using natural fractures from Yucca Mountain.

3. Assessment of the coupling between matrix and fracture flow using autoradiography to detect the transport of radionuclides (that are alpha emitters) from the fractures into the matrix.

To investigate plutonium exposure, Project scientists completed microautoradiography studies of plutonium exposure on five different bulk-rock tuff types (devitrified densely-welded Topopah Spring Tuff, devitrified poorly-welded Prow Pass Tuff, vitric nonwelded Calico Hills Formation, opal-rich zeolitized Calico Hills Formation, and opal-poor zeolitized Prow Pass Tuff). Additional plutonium exposure studies were completed on one fracture sample representing a calcite/opal fracture coating from the devitrified Topopah Spring Tuff. Project scientists have identified specific plutonium retention by clay-rich portions of zeolitized tuffs, by iron-oxides associated with altered pyroxenes of the devitrified Prow Pass Tuff, and with altered oxide microphenocrysts in the Topopah Spring Tuff. A draft paper

(Vaniman et al., in prep.[b]) summarizing these results was the subject of a performance-based audit conducted at Los Alamos. The audit resulted in no corrective action requests; one deficiency was found but was easily corrected during the audit. At the recommendation of the auditors, some supporting tests were being performed.

Activity 8.3.1.3.6.1.5 - Filtration. The objective of this activity is to quantify the filtration of colloids and particulates by the tuff as a function of particle or pore size using solid tuff cores and fractured cores.

Project scientists improved the collection system for sampling ground waters at Yucca Mountain for colloid concentration. Water samples are now obtained before filtration, after filtration through a 0.4 mm filter, after filtration through a 0.05 mm filter, and after filtration through a hollow fiber filter. The improved water collection apparatus allows pH determinations at any point, makes cleaning the apparatus easier, and minimizes contamination.

Two papers on colloid-facilitated transport were completed (Wistrom and Triay, in prep.; Triay et al., in prep.[b].). The concentration of naturally occurring colloids in UE-25 J#13 well water was determined to be identical when measured in 1984 and 1994. This result gives confidence in the low concentration of colloids found in Yucca Mountain water (1 x 10^6 particles per mL). At this small colloid loading, Project scientists conclude that facilitation of radionuclide transport by naturally-occurring colloids at Yucca Mountain will be minimal.

Forecast: Column experiments will be conducted using crushed material to verify the results of batch sorption measurements under flowing conditions. Columns are packed, tracers are injected into the columns, and tritiated water is used to determine the column parameters. Crushed material will include devitrified tuff, vitric tuff, and zeolitic tuff. Work on neptunium and plutonium will be completed and studies on uranium and selenium will begin. Experiments will be conducted on the transport of radionuclides (neptunium, uranium, and selenium) through intact tuff columns under varying degrees of saturation. Experiments will be conducted on fractured-tuff columns to investigate the transport of radionuclides (neptunium, selenium, and carbons) with transverse matrix diffusion and channeled flow in fractures. Tuff samples containing natural fractures exhibiting the major fracture coatings found at Yucca Mountain will be used. The study of stability of silica colloids in ground water as a function of ionic strength and temperature will be completed.

3.2.13 Study 8.3.1.3.6.2 - Diffusion

The objectives of this study are to measure the diffusivity and kinetics of adsorption in a purely diffusive system (i.e., no advection) from the uptake of radionuclides on intact tuff as a function of time; and to conduct scaling studies to determine up to what scale the matrix diffusion model can be applied with confidence.

Activity 8.3.1.3.6.2.1 - Uptake of radionuclides on rock beakers in a saturated system. The objective of this activity is to measure the uptake of radionuclides by rock beakers as a function of time. These results will provide a baseline for the following activities on diffusion through a saturated tuff slab and diffusion in an unsaturated tuff block.

Diffusion in fractured flow can retard the migration of radionuclides through the subsurface. Using a transport code (such as FEHM), Project scientists analyzed data from FY 1994 experiments on the uptake of neptunium by beakers fabricated from tuff from the Topopah Spring and zeolitic Calico Hills units.

The preliminary results presented in Triay et al. (in prep.[c]) indicate the following:

1. Radionuclide diffusion through saturated devitrified tuffs is slower than diffusion through zeolitic tuffs. Previous results indicate that tritiated water diffusion through saturated devitrified tuffs is on the order of 1×10^{-6} cm^2/s.

2. The uptake of neptunium by saturated devitrified tuff (in UE-25 J#13 and UE-25 p#1 waters) and zeolitic tuffs (in UE-25 p#1 water) is slower that the uptake of tritium in the same systems. The reason for this observation is that neptunium can exist as an anion (a neptunyl carbonate complex), which is excluded from tuff pores as a result of size and charge.

3. The uptake of neptunium by saturated zeolitic tuff in UE-25 J#13 water is faster than the uptake of tritium in the same system. This is because neptunium uptake by saturated zeolitic tuffs in UE-25 J#13 water is the result of sorption and diffusion.

Activity 8.3.1.3.6.2.2 - Diffusion through a saturated tuff slab. The objective of this activity is to measure the diffusion of radionuclides in a purely diffusive system (no advection) by varying the thickness of the slabs of Topopah Spring Tuff and Calico Hills zeolitic tuff.

Project scientists fabricated four diffusion cells for studying the diffusion of technetium, Np(V), U(VI), and Pu(V) through devitrified tuff (from the Topopah Spring Tuff) and zeolitic tuff (from the Calico Hills) using waters from the Wells UE-25 J#13 and UE-25 p#1. Tritiated water will be used as a nonsorbing tracer. Experiments to study the diffusion of technetium and tritiated water through devitrified and zeolitic tuffs in water from Wells UE-25 J#13 and UE-25 p#1 began. These data will be reported in Triay et al. (in prep.[d])

Activity 8.3.1.3.6.2.3 - Diffusion in an unsaturated tuff block. The objectives of this activity are to determine the distribution of radioactivity in the unsaturated tuff matrix, using an unsaturated tuff block of the Topopah Spring member of Calico Hills, and to fit the uptake of radionuclides as a function of time to a diffusion model with reactions (sorption) to determine the diffusivities and rate constants.

The manipulation of Yucca Mountain tuff to obtain blocks of tuff to study the diffusion of sorbing and non-sorbing radionuclides (under unsaturated conditions) was initiated during this reporting period. The techniques developed to study diffusion under unsaturated conditions will be reported in Triay et al. (in prep.[d]).

Forecast: Techniques will be developed and experiments conducted to study the diffusion behavior of radionuclides under unsaturated conditions using blocks of intact tuff. Diffusion cell tests, water diffusion tests, rock beaker tests, and unsaturated diffusion tests will be performed. Well-characterized radionuclide solutions and tuff samples representative of hydrologic units will be used.

3.2.14 Study 8.3.1.3.7.1 - Retardation Sensitivity Analysis

The objectives of this study are to develop a conceptual geochemical-geophysical description of Yucca Mountain based on the results, data, and information generated from the geochemistry, mineralogy-petrology, hydrology, and other pertinent Project tasks; and to determine what data may be inadequate or insufficient to make the cumulative, integrated transport calculations needed to meet the NRC and EPA regulations.

This work will be used in preparing a report on site-scale integrated transport; the report will support the radionuclide transport model.

Related International Work

See Section 3.2.17 for related work (under the headings, CHEMVAL, Natural Analog Studies at Cigar Lake, and Geochemical Modeling) performed under the auspices of the OCRWM international program.

Activity 8.3.1.3.7.1.1 - Analysis of physical/chemical processes affecting transport. The objectives of this activity are to analyze all the processes that may affect transport, geochemical, physical, particulate, heat-load effects, and coupled phenomena; to support and develop those laboratory experiments designed to examine the physical and geochemical processes affecting radionuclide transport and other experimental activities under this program and the ESF tests (i.e., diffusion experiments); to correlate and validate results obtained from laboratory, ESF, and field experimental results with transport calculations.

With regard to the assessment of the effects of repository heating on geochemistry and hydrologic behavior, initial results indicate that there is a strong coupling in the near-field between these three processes and that further modeling, in which all the processes are fully coupled, should be conducted (Robinson et al., 1995). Project scientists are now developing simplified rock-water interaction models that can be incorporated into large scale transport codes so that the coupled processes can be studied.

Activity 8.3.1.3.7.1.2 - Geochemical/geophysical model of Yucca Mountain and integrated geochemical transport calculations. The objective of this activity is to perform

calculations of radionuclide transport from the repository to the accessible environment using, as a basis, an integrated, conceptual geochemical-geophysical model of Yucca Mountain.

Project scientists are working to provide a technical basis that will ensure that performance assessment models contain the most important geochemical phenomena and interactions for radionuclide transport. Their activities include adapting a coupled reaction/transport simulator (LEHGC) to a massively parallel computing architecture. This simulator will then be used to model radionuclide transport with complex chemical behavior on the time and spatial scales required for regulatory compliance assessments.

The massively parallel version of LEHGC1.0 was compiled, and a sample problem was executed on the Intel Paragon (1800 nodes). Results indicate that the larger chemically complex problem, executed previously on the nCUBE and reported in FY 1994, can be analyzed an order-of-magnitude faster on the Paragon. Design of new sample problems to test the adsorption and transport capabilities of LEHGC1.1 continued in preparation for qualification of the code.

Using available hydrostratigraphic data, staff performed the first large-scale, three-dimensional transport simulations of radionuclide migration for Yucca Mountain (Zyvoloski and Gable, 1994). Although new hydrostratigraphic data are now available and these results must now be updated, the study proved the practicality of performing these calculations and identified code development efforts that needed to be undertaken to improve the efficiency of the calculations.

Project staff incorporated the most recent stratigraphy data and developed computational grids that can be used for flow and transport calculations. Before performing radionuclide transport calculations, the hydrologic results from the flow and transport code FEHM used in this activity must be determined to agree with the modeling results from other Project transport calculations. Calculations can then be made that are consistent with hydrologic modeling done elsewhere in the Project. At the same time, models and computational grids that are appropriate for transport calculations are being constructed from the most recent USGS data base.

The grid effort will support the accelerated site characterization effort by allowing rapid inclusion of the latest hydrogeologic information into the transport models. The development of the computer code GEOMESH has streamlined the mesh generation process, allowing more time to be spent on the computations and the interpretation of results. The flexibility of automated mesh generation also means the modeler is not confined to a single computational grid, and the gridding process is linked to the stratigraphic data base so new grids with different resolution are simple to generate.

Activity 8.3.1.3.7.1.3 - Transport models and related support. The objectives of this activity are to verify the computer codes and to validate the models used in this study and to identify important contributors to the uncertainties in retardation calculations (sensitivity analyses).

Numerical simulation efforts focused on Cl-36 simulations. The goal of the computational effort is to use the Cl-36 data to constrain hydrologic models. Because Cl-36 is a liquid-borne solute present in trace quantities, these data are among the only site-scale transport data available that provide information over the expected time scales of radionuclide migration. Thus, this field data and modeling effort significantly contribute toward providing the Project with reliable data on the suitability of the site for providing a geologic barrier to radionuclide migration. Modeling studies so far (summarized in a paper by Liu et al., 1995) have been mechanistic. Deterministic model calibration will be possible once more hydrologic and Cl-36 data have been collected. The studies to date show that high infiltration over portions of the surface of Yucca Mountain can give rise to lateral flow. This flow can, in turn, result in inversions of Cl-36 age with depth in a particular well bore (i.e., older fluid overlaying younger fluid).

The model results also demonstrate that for a heterogeneous flow system the apparent age of a fluid is actually a composite of fluids of different ages mixing to produce an isotopic age that reflects the mixing process. Recently developed particle tracking techniques allow the distribution of ages at a position to be computed for a computed flow field. This calculation provides support to the recent findings of Activity 8.3.1.2.2.2, which have shown that one explanation for the discrepancy between fluid ages measured using the Cl-36 and C-14 is that the ages determined from these isotopes are affected differently by mixing of fluids of different ages.

Project scientists begun studying the movement of C-14 in both the liquid and vapor phases. The studies focus both on transport of radionuclides from the potential repository and on the historic movement of background and C-14 from weapons testing within the Yucca Mountain environment. Chlorine-36 moves only in the liquid phase but C-14 resides in both liquid and vapor phases. Therefore, modeling tools are being developed to calculate the partitioning of C-14 (in CO_2) between the two phases during transport. The carbonate system is modeled as a series of kinetic and equilibrium reactions that result in a partitioning of C-14 between the phases.

Using this chemical approach in a simplified one-dimensional, gas phase transport simulation of C-14 movement, Project scientists were able to demonstrate agreement with results of other researchers taking an "apparent K_d" approach, thereby showing that the chemical model can be used with confidence in site-scale simulations. These scientists are now developing the site-scale liquid and gas flow models upon which to simulate the C-14 system at Yucca Mountain.

Code development efforts centered on improving the performance of the Finite Element Heat and Mass transfer (FEHM) code. The calculation of property values for unsaturated media require the use of correlations that must be extrapolated at both high and low saturation. The method of extrapolation was revised to significantly improve code performance on vadose zone problems.

Other code developments include the following:

1. Developing a particle tracking module for generating solute transport calculations that are free of numerical dispersion

2. Revising the methods for solving problems involving transport of heat, air, water, and water vapor and enhancing the boundary conditions for these problems

3. Developing improved solution techniques for solving dual permeability problems

4. Certifying the linear equation solver GZSOLVE for use in quality activities (Robinson and Zyvoloski, 1995).

Each of these code development efforts allow Project code developers to perform larger, more complex transport problems. Continuous improvements are required to enable site-scale transport calculations to be performed at the level of detail required to reliably predict radionuclide transport.

Related International Work

See Section 3.2.17 for related work (under the heading, Natural Analog Studies at Cigar Lake and Geochemical Modeling) performed under the auspices of the OCRWM international program.

Forecast: The qualification of LEHGC1.1 will be completed and the user's manuals for LEHGC1.0 and LEHGC1.1 published. Processes will be studied that affect the transport of radionuclides at Yucca Mountain to support simplifying assumptions made by performance assessment for transport models. To guide site characterization data gathering activities, important processes will be identified and data accuracy requirements will be specified. Sensitivity analysis will be performed to determine the effects that variations in parameters and/or processes have on transport from the repository. Key data from site characterization will be identified and a site scale model of neptunium produced. Coupled processes will be investigated and a near-field coupled-flow model will be produced; this model will be used in conjunction with testing the coupled flow geochemistry module. A cross validation of the LBL/USGS flow model will be produced using the computer code FEHM. Hydrogeologic and property data made available by LBL and USGS will be used to produce a flow model codes developed to simulate various transport processes that may occur at Yucca Mountain. A particle-tracking module for FEHM will be created that will allow evaluation of numerical errors associated with transport simulation. A flow/geochemistry module will be created that will allow flow parameters to change with geochemistry.

3.2.15 Study 8.3.1.3.7.2 - Demonstration of Applicability of Laboratory Data to Repository Transport Calculations

The objective of this study is to outline the strategy that will be used to demonstrate the validity of the laboratory generated geochemical data and the transport calculations using that data.

Activity 8.3.1.3.7.2.1 - Intermediate-scale experiments. The objective of this activity is to conduct experiments at a scale larger than a laboratory but with sufficient control on material and boundary conditions to test how increased spatial scale affects water flow and radionuclide transport in unsaturated porous media.

No progress was made during the reporting period; this was an out-year activity.

Activity 8.3.1.3.7.2.2 - Field-scale experiments to study radionuclide transport at Yucca Mountain. The objective of this activity is to evaluate the validity of laboratory-derived data and models for radionuclide transport at the Yucca Mountain site by conducting tests in the bedded tuffs of the Calico Hills unit underlying the Topopah Spring unit.

Project scientists began planning to investigate advective radionuclide transport using stable-isotope tracers, in the nonwelded tuff in P-tunnel at the Nevada Test Site. Field trips and sampling at P-tunnel were conducted for geological reconnaissance to select a site for the transport experiments. Project geologists examined existing samples from the tuff of Calico Hills originally collected for the Alteration History study. The purpose of the examination was to identify any thin-bedded, fine-grained ash layers for comparison with the Paintbrush Group section at P-tunnel. Fine-grained layers in the Calico Hills Tuff have been observed in outcrop along northeastern Yucca Mountain and in the G-2 core but are probably rare or absent below the exploration block. Current plans for the P-tunnel experiment are to avoid thin-bedded intervals as much as possible to facilitate interpretation of experimental results. This restriction should not compromise the applicability of P-tunnel results to the Yucca Mountain exploration block or the subsurface rocks down dip from the block.

A white paper on the need for testing and early entry into the Calico Hills geologic unit was prepared. Key issues considered in the paper included (a) the need for horizontal access to intersect potential vertical fast transport paths before extensive perturbations, (b) whether pristine conditions are necessary so that the ambient geologic record can be used to reduce uncertainty in long-term assessment, (c) whether limiting access to the Topopah Spring Tuff would jeopardize the opportunity to evaluate the suitability of Yucca Mountain to minimize radionuclide migration and serve as a permanent repository, and (d) the cost effectiveness of focusing transport studies on the Calico Hills. The uses of a horizontal access in the Calico Hills include testing and long-term monitoring.

Existing data, primarily from Defense Nuclear Agency and its contractors, have been reviewed to estimate the range of hydrological conditions and material properties that might be encountered in the test block in P-tunnel. This information has been used in designing the current fiscal year test planning package. This information is also being used to develop scoping calculations to explore the range of flow and transport behavior that may occur in the test block during experiments in the coming fiscal year.

Activity 8.3.1.3.7.2.3 - Natural analog studies of radionuclide transport. The objective of this activity is to use natural analog studies and data generated by natural analog studies to support long-term calculations of radionuclide transport using laboratory data and radionuclide transport models.

No progress was made during the reporting period; this was an unfunded activity.

Related International Work

See Section 3.2.17 for related work (under the heading, Natural Analog Studies at Cigar Lake) performed under the auspices of the OCRWM international program.

Activity 8.3.1.3.7.2.4 - Data on radionuclide transport from other U.S. Department of Energy sites (Anthropogenic Analogs). The objective of this activity is to evaluate the validity of laboratory-derived data and models for radionuclide transport at the Yucca Mountain site by obtaining data collected at other United States DOE sites on radionuclide distribution in geologic systems.

No progress was made during the reporting period; this was an unfunded activity.

Forecast: Design of the field tests for the Calico Hills geologic unit at Yucca Mountain will continue. These field tests will be used to evaluate new data available from the surface-based testing program. A study plan for Calico Hills work will be prepared. A test plan for P-Tunnel work that will address archive, simulation, and laboratory data needed to perform P-tunnel tests will be developed. Simulations to predict water and tracer behavior from packed zones in boreholes will be initiated. Field tests will be performed using boreholes with packers. The rock samples collected at P-tunnel will be analyzed to investigate the nature of the vitric-to-zeolitic transition in the exposed Paintbrush Group.

3.2.16 Study 8.3.1.3.8.1 - Gaseous Radionuclide Transport Calculations and Measurements

The objectives of this study are to calculate the rates of transport of gaseous radionuclide species between the repository and the accessible environment considering the various driving forces and retardation mechanisms that may exist; and to experimentally verify potential existing models of gaseous radionuclide transport and retardation that are used to assess radionuclide release to the environment.

As a result of the study plan work consolidation effort, no study plan is to be developed for this SCP section. Until the National Academy of Sciences completes its report pursuant to Section 801 of the Energy Policy Act of 1992, and subsequent rulemaking by the EPA takes place, there is ambiguity regarding the need for greater attention than already exists for gaseous transport calculations under Study 8.3.1.2.2.6. Modeling of C-14 gas-phase transport, conducted under Activity 8.3.1.3.7.1.3 demonstrated that the chemical model of C-14 reactions can be used with confidence in site-scale simulations. Modeling efforts as a part of Activity 8.3.1.3.7.1.3 will continue to investigate the movement of C-14 in the liquid and vapor phases.

Forecast: The need for further work on this activity will be evaluated after the National Academy of Sciences completes its report and the EPA promulgates its rules.

3.2.17 Related International Geochemical Work

Taupo Volcanic Zone Natural Analog

The following is work related to Study 8.3.1.3.3.1 (Section 3.2.4) conducted cooperatively with New Zealand under the auspices of the OCRWM international program.

The purpose of this investigation is to make accurate long term predictions of processes in hydrothermal systems resembling those likely to be produced at Yucca Mountain, if it becomes a repository. Specifically, the task aims to determine at a natural site whether the thermodynamic data base is adequate, to evaluate whether models of reaction rates are appropriate, and to develop strategies for rigorous confidence building in the codes used in the models.

During the previous reporting period, five hydrothermal sites (in the Taupo Volcanic Zone) were identified as suitable for this work. Most of the water data thought to be needed have been collected for water chemistry, as well as mineralogical data, including both the minerals present and their compositions. The study of precipitation kinetics for silica was started at one site. Particular needs for simulations have been identified. A strategy has been devised for testing the adequacy of the thermodynamic data base (Bruton et al., 1994)

During this reporting period, data obtained by the New Zealand collaborators on silica precipitation was synthesized. Rates have been measured in several different parts of the geothermal system, including cooling trenches, silencers, and other parts of the system. Comparison of these data with laboratory rate measurements will be reported during FY 1995. Comparison of simulated phase relationships, using various thermodynamic data, with observed mineral relationships is continuing and discrepancies between data sets were resolved. A large amount of time was spent dealing with new and evolving procurement requirements, before the contract with the New Zealand collaborators could be renewed, but work is now accelerating to address schedule impacts.

Forecast: Reports will be issued summarizing the silica precipitation kinetics work and the thermodynamic data analysis. These results will allow code testing strategies to be refined. Studies of uranium-series disequilibrium will be started to ascertain the role of colloids in transport in this system, and to address questions regarding transport mechanisms and precipitation kinetics.

Radionuclide Retardation Model Development

The following is work related to Study 8.3.1.3.4.3 (Section 3.2.9) conducted cooperatively with Canada under the auspices of the OCRWM international program.

The Large Block Tracer Test consists of a series of experiments to study the migration of radionuclides through fractures in rock at a scale of 1 m.

During the previous reporting period, migration experiments were conducted using conservative tracers in artificial fractures with near parallel plane and near wedge-shaped fractures. A comparison of experimental data with predictions of the transport code TRACR3D showed good agreement. There was also good correlation between the distribution of the dye tracer and the elution profiles. This suggests that the transport of a tracer through a fracture can be inferred from elution profiles.

The experiments led to new procedures for constructing and characterizing fractures of known geometry; for example, the use of acrylic blocks and digitized images of tracer profiles to fine tune the permeability of the outlet plenum and sampling ports. The block cut from welded tuff at Yucca Mountain was shipped to Atomic Energy of Canada Limited for testing in their laboratory, which is already equipped to perform relevant experiments. The experiments provide data with well-defined geometry and conditions for use in increasing confidence in codes and models needed for site characterization and performance assessment at Yucca Mountain.

During this reporting period, plotted results from the acrylic blocks show the effect of concavity of the fracture, delayed breakthroughs for the narrower part of the fracture, and increased dispersion as the fracture narrows. Again, results agreed well between experimental and imaged profiles and with predictions by TRACR3D.

Forecast: Separate effects to be considered include sorption onto minerals within the rock matrix, diffusion of radionuclide species through the rock matrix, diffusion and hydrodynamic dispersion within the fracture, and the effect of heterogeneity in the fluid flow field. The rock fractures to be used have natural fractures or artificial fractures with engineered heterogeneity.

Mechanistic Approach to Sorption of Radionuclides

The following is work related to Study 8.3.1.3.4.3 (Section 3.2.9) conducted cooperatively with Switzerland under the auspices of the OCRWM international program.

During the previous reporting period, the Swiss National Cooperative Society for the Storage of Radioactive Wastes/DOE collaboration resulted in the elucidation of the mechanism for sorption of neptunium onto zeolitic tuff. An experiment using the protocol developed at Paul Scherrer Institute showed that the adsorption mechanism had a cation exchange component and inner-sphere complexation component. The dominant mechanism at an electrolyte concentration equivalent to that in UE-25 J#13 well water is cation exchange. This observation resembles that observed at Paul Scherrer Institute for nickel sorption onto montmorillonite and mylonite. This result offers an explanation for the relative insensitivity of neptunium adsorption to pH changes that have been observed in the YMP geochemistry program. This two process mechanism illustrates how complexity can increase the robustness of sorption modeling. A further consequence of the two component mechanism is a lower limit to the distribution coefficient (K_d) as salt concentration increases, i.e. the inner-sphere surface complex (which does not depend on salt concentration) would prevent the K_d from going to zero. In anticipation of the need for a better adsorption model, a bidentate isotherm

(i.e., one in which a complex is attached on a surface at two positions) was developed; this contrasts with the commonly used Langmuir isotherm, which applies only to a monodentate mechanism. A paper by Rundberg et al., (1994) on the sorption of sodium onto goethite was published in *Radiochimica Acta.*

During this reporting period, developments showed that the bidentate mechanism fits the experimental data slightly better than the two-site model with only two parameters as opposed to four parameters. Note that the strong specific adsorption of iodate and other oxyanions have long been suspected to bind by a bidentate mechanism. A bidentate mechanism explains why the sorption capacity for fluoride on goethite is approximately twice that of iodate and phosphate.

The only mechanism that can be conceived of that would allow a bidentate adsorption of iodate without having an extreme dependence on pH is one that attaches at both a Lewis acid site and a Lewis base site. This is possible because iodate has trigonal bipyramid structure. The reaction that is postulated would put a negative charge on the surface, which is consistent with the following observations. The stability of a goethite suspension at pH 4 is destroyed when the iodate concentration is raised above 0.001M. The pH dependence of the iodate adsorption onto goethite is not linearly dependent on the hydrogen ion concentration.

The first hydrolysis constant for Np(V) has been measured at Los Alamos. The new value agrees with the value obtained by the group at the Technical University of Munich. When the Los Alamos neptunium adsorption data for goethite is interpreted using the Dzombak Morrell model, the "Strong site" interaction constant fits the correlation with first hydrolysis constant. This suggests that the Hard/Soft acid base theory can be applied to actinide adsorption onto metal oxides. The significance of this observation is the formation of a basis with which to predict actinide adsorption without extensive measurement programs. This correlation will also allow the selection of surface complexation analogs to the actinides.

Forecast: Surface complexation of neptunium onto goethite will be investigated. This will involve especially the capacity to adsorb neptunium and whether it adsorbs via a bidentate mechanism, such as is true for iodate. Thus, the thermodynamics of neptunium sorption onto goethite will be studied. In addition, investigations will continue on ion exchange in tuff. As part of this project, a literature search will be performed to see if a similar correlation can be established for surfaces containing octahedral aluminum.

CHEMVAL

The following is work related to Study 8.3.1.3.7.1 (Section 3.2.14) conducted cooperatively with international CHEMVAL participants under the auspices of the OCRWM international program.

During the previous reporting period, cooperative efforts in support of the international CHEMVAL 2 project continued, notably with the British Geological Survey. Discussions began with Russian scientists to obtain data from the Mayak site and to perform benchmark calculations. Progress was made in understanding how to use and modify (including

corrections and enhancements) the coupled hydrological and geochemical code, LEGHC (a derivative of HYDROGEOCHEM). Experiments on surface complexation and adsorption of trace metals were completed in collaboration with the British Geological Survey, specifically for nickel on natural and synthetic systems containing sands and sandstones. Preparation of letter reports on these topics was started.

During this reporting period, the development of the proposed CHEMVAL 3 test problem, based on the Mayak Site, continued. Efforts to solve the CHEMVAL 2 validation problems continued. Efforts focused on the test problem describing U transport in sandstone and diffusion in a clay barrier. The CHEMVAL 2 Final Plenary Meeting, in Grenoble, France (October 25-26,1994), provided an opportunity to compare results of benchmark calculations and to help plan CHEMVAL 3. In addition, a meeting was held with the British firm, W.S. Atkins, and their subcontractors (October 31-November 1, 1994), to discuss a collaborative study in massive parallel computing applications for transport codes.

Two letter reports were completed. The first report described the results of CHEMVAL 2 activities, including (a) comparison of batch adsorption techniques used by British Geological Survey and SNL to study sorption of trace metals (nickel) by geological material (natural sand and sandstones), and (b) SNL results for several CHEMVAL 2 test problems. The second letter report described proposed tests cases for CHEMVAL 3. These include (a) nickel transport in the DOE Caisson experiment to validate flow and transport models, (b) strontium and nitrate transport at the Mayak site (Chelyabinsk 65, Russia), and (c) transport of base metals at an abandoned solution mining site.

A coherent and internally consistent model of nickel adsorption on Wedron 510 sand was completed, and its important end members continued as part of efforts to design a CHEMVAL 3 problem based on the caisson experiment. As a results of collaboration with the British Geological Survey, a bug in the chemical speciation and adsorption program HYDRAQL was identified and fixed. Another modification to HYDRAQL included the addition of the ability to iterate on charge-balance as well as ionic strength and the use of additional methods to calculate activity coefficients for reactants and products in surface complexation reactions. Efforts to solve the CHEMVAL 2 validation problems (Winfreth column study and National Radioactive Waste Management Agency, France, clay barrier study) continued. The calculational effort led to design of uranium transport column experiments to validate the methods and models used by AEA Technology, United Kingdom, in the CHEMVAL 2 coupled process model test problems.

Other activities in support of international programs included meetings and discussions concerning collaboration with scientists from National Radioactive Waste Management Agency, France, on retardation sensitivity analysis using the LEHGC code and the development of a massively parallel version of the code.

Preparation for the final CHEMVAL 2 meeting (October 25-26, 1994) included completing test cases for the temperature effects section of CHEMVAL 2. Following the meeting, those simulations were refined and reported to the temperature effects coordinator. In preparation for CHEMVAL 3, design of coupled flow and reactive transport experiments

were monitored to ensure that data generated in those experiments would be available. Experiment design and execution is underway. Collaboration with CHEMVAL 3 participants in the design of comparisons of simulated coupled processes began.

Forecast: Effort will be devoted to completing the collaboration with the British Geological Survey and initiating similar work with Harwell Laboratory (United Kingdom). Collaboration with W.S. Atkins (United Kingdom) on applications of massively parallel computer processors for coupling transport codes is also expected. Model predictions will be compared with laboratory measurements. In addition, three test problems, for which data were collected during FY 1994, will be proposed for inclusion in the CHEMVAL 3 exercises; this also anticipates participation in CHEMVAL 3. The experiments and collaborations on temperature effects and on coupled flow and transport will begin. Sufficient results from the experiments may be available to initiate simulation runs.

Natural Analog Studies at Cigar Lake

The following is work related to Study 8.3.1.3.7.1 (Section 3.2.14) conducted cooperatively with Canada under the auspices of the OCRWM international program.

Field work for this study is completed.

During the previous reporting period, preliminary data reduction from the Cigar Lake studies, conducted in cooperation with Atomic Energy of Canada Limited, showed that technetium moved short distances under the very reducing conditions present at that locality. This was not expected. Reducing conditions appear to limit the migration of technetium to short distances, but may not stop it completely. This has possible relevance to the YMP inasmuch as reducing conditions will probably develop within and close to waste packages containing abundant iron. Data for plutonium at Cigar Lake are essentially as expected; a few samples show a slightly high disequilibrium ratio. This result provides confidence that the behavior of plutonium can be adequately modeled under reducing conditions; at least some aspects of the same model would apply under oxidizing conditions. The work will also assist in demonstrating how natural analog field studies can be incorporated directly into performance assessments. Some results appear in Curtis et al. (1994).

During this reporting period, continued analysis of ore samples, with technetium anomalies, from Cigar Lake proved to be controversial. The technetium appeared to be very heterogeneously distributed in these samples. A process of determining with what phase, or phases, the technetium is associated in these samples began. Ore samples that do not have excess technetium anomalies appear to have their technetium very homogeneously distributed. These results indicate there may be a phase or phases formed under reducing conditions that sequester technetium when it gets mobilized. Therefore, identifying these phases will be important for the Engineered Barrier System at Yucca Mountain.

Preliminary I-129 results from waters in the ore zone and surrounding rocks at Cigar Lake indicate the following:

1. Drastic reduction in the I-129 concentration of the ore zone waters over a three year sampling period is indicative of fresh water dilution through fracture into the once tight ore zone rocks.

2. The release rate for I-129 for the ore is five orders of magnitude greater than for uranium in the reducing ore zone waters.

3. Evidence indicates down gradient movement of I-129 in the local aquifer surrounding the Cigar Lake ore body.

Continued analysis of ore samples for plutonium indicated no disequilibria from model values calculated for the ores. Meetings were held to start the integration of natural analog data into performance assessment modeling. The meetings also outlined the future research steps that natural analogs studies will take for Yucca Mountain.

Forecast: Analyses of the samples taken will continue until early summer 1995. Modeling work will also continue. The annual technical exchange with the Canadians, as part of Subsidiary Agreement 2, will occur at White Shell laboratories in early May 1995. Rough drafts of papers will be completed during this technical exchange on analytical procedures for extracting technitium and plutonium from uranium ores; profiles at Cigar Lake for technitium, plutonium, iodine, and chlorine; and the radionuclides, technitium, iodine, and chlorine, in ground water at Cigar Lake. A study plan outlining the future research directions that natural analogs studies will take for Yucca Mountain will be produced. Expectations are to finish the task and write the final report during FY 1995 or early in FY 1996.

Geochemical Modeling

The following is work related to Study 8.3.1.3.7.1 (Section 3.2.14) conducted cooperatively with Sweden under the auspices of the OCRWM international program.

During the previous reporting period, a modeling study was performed for the Hard Rock Laboratory in Sweden. This study indicated that ion exchange may play a significant role in fractures. The various options tried all worked well, and provided more credence than previously thought for the efficacy of ion exchange in fractures as a viable retardation mechanism. A main objective of this cooperative effort is to increase confidence in geochemical models. The extensive data available at Äspö, and the terms of the agreement that allow United States scientists to steer the course of some of the analytical work, provide a unique opportunity to proceed expeditiously with this essential task. A significant question for the modeling of transport at Yucca Mountain has been the extent to which ion exchange and sorption along fractures would retard the migration of radionuclides; this work is expected to assist that evaluation.

During this reporting period, a comparison (Bruton, 1994) of the thermodynamic data bases for radionuclides used by the Swedish Nuclear Fuel and Waste Management Company and LLNL and corresponding predictions of radionuclide solubilities in representative fresh and saline Finnsjvwater, revealed that:

- Except for plutonium, the Swedish Nuclear Fuel and Waste Management Company and LLNL data bases are similar, or will be similar when both data bases incorporate Nuclear Energy Agency critical compilations of data for specific radionuclides. The plutonium data now differ significantly because the Swedish Nuclear Fuel and Waste Management Company has refined the LLNL data base.

- Despite similarities in the data bases, concentrations of radionuclides predicted by Bruno and Sellin (1992) to be in equilibrium with specific solid phases in fresh and saline Finnsjvwater differ significantly in many instances from calculations using EQ3. The differences have yet to be explained.

Geochemical calculations of mineral-fluid equilibria suggest that precipitation and dissolution of silicate minerals do not control fluid chemistry in the low temperature (<25°C) systems at Äspö (Bruno and Sellin, 1992). This finding is consistent with current models describing rates of mineral dissolution and precipitation and supports the hypothesis that the observed chemical composition of the ground water sampled, from the redox zone at the Hard Rock Laboratory, mainly results from the interaction with the fracture minerals via cation exchange.

A report (Viani and Bruton, 1994) was published as part of the Äspö Geochemistry Workshop detailing the results of modeling the mixing of fluids in fractures in the "redox zone" of the Hard Rock Laboratory. The mixing of fluids in the redox zone was simulated using EQ3/6 to address the hypothesis that cation exchange reactions control the observed major cation chemistry. Mixing and cation exchange were assumed to occur simultaneously. The conclusions include the following:

- An exchanger with the properties of smectite is consistent with the observed sodium, calcium, and magnesium fluid concentrations, when present in amounts on the order of 0.1 equivalents per kilogram of fluid.

- The quantity of exchanger necessary to explain fluid composition variation during mixing is physically reasonable.

- The "exchange" complex in the rocks at Äspö is predicted to become more sodium rich with depth.

- To test and verify the model and hypothesis more completely, compositions of the exchanger phases must be compared with model predictions.

- Cation exchange equilibria involving heterovalent exchange are sensitive to ionic strength.

- The effects of a small amount of exchanger would be most evident for mixing involving dilute waters and significant ionic strength changes.

- For dilute ground waters, the exchanger provides a relatively large source of "reactive" cations.

Forecast: Geochemical modeling simulations of the partitioning of trace metals between ground water and fracture-lining minerals, using two types of adsorption models, will be undertaken. The modeling exercises will comprise the following:

- Use of cation exchange to model the partitioning of trace elements such as cesium and strontium between fracture-lining minerals (especially layer silicates) and ground waters and compare simulation results with field data at the Hard Rock Laboratory.

- Use of surface complexation models to simulate the partitioning of trace elements such as uranium between fracture-lining minerals (especially iron oxides) and ground waters and compare simulation results with field data at the Hard Rock Laboratory.

3.3 ROCK CHARACTERISTICS (SCP SECTION 8.3.1.4)

3.3.1 Activity 8.3.1.4.1.1 - Development of an Integrated Drilling Program

The objectives of this activity are to ensure representativeness of data acquired during surface-based site characterization activities and that data represent the range of phenomena and structural characteristics needed for performance assessment, to integrate and prioritize surface-based testing activities to produce a schedule that addresses representativeness and efficacy, and to maintain a system of technical element baseline approval and control.

There will be no study plan developed for this activity.

The YMSCO uses a test planning package development process to integrate the site characterization drilling program. This process serves as an interface between the Technical Implementation Plans and the authorization of drilling-related surface-based testing activities involving multiple investigators. The goal is to identify requirements from primary and secondary studies, and to define a set of consolidated requirements that meet as many secondary needs as possible while not compromising the primary purpose of the activity. For example, in a borehole drilled in support of the systematic drilling program, the needs of other activities can be met through distribution of core or cutting samples or through testing in the borehole after it is completed. By maximizing the benefit of each activity, the overall cost-effectiveness of the program is increased. The Catalog of Planned Boreholes (CRWMS M&O, 1993) has resulted from this integration effort. The consolidation effort was revisited in the five-year planning effort and the re-evaluation of the surface-based testing effort under the Program Plan.

During the reporting period, test planning packages were developed for planned Borehole USW UZ-7A. This borehole is planned to be drilled in the Ghost Dance fault zone, near existing Well USW WT-2.

Forecast: In FY 1995, there may be a streamlining of the surface-based testing coordination planning effort, resulting in the combination of test planning packages and accompanying job packages into one field work package document.

3.3.2 Activity 8.3.1.4.1.2 - Integration of Geophysical Activities

The objective of this activity is to provide a mechanism for information exchange, an analysis of data and other technical information, and an overview of planned geophysical site characterization activities.

The Geophysics Integration Task Force continued to address geophysical testing issues to facilitate the efficient use of geophysical methods in site characterization. Geophysical tests proposed for FY 1995 were examined to determine whether they supported the program priorities. A program of geophysical logging in new and existing boreholes, vertical seismic profiling, high-resolution seismic reflection lines, and associated magnetic, electrical, and gravity surveys was planned, budgeted, and scheduled, and execution was nearly completed.

During the first half of FY 1995, standard geophysical logging suites were planned, budgeted, scheduled, and executed in Boreholes USW UZ-14, UE-25 UZ#16, USW SD-12, USW SD-9, and USW G-2.

A 96-geophone string of 3-component seismometers was emplaced and grouted into position in borehole UE-25 UZ#16 during the second quarter of FY 1995 for the collection of vertical seismic profile data (shear and compressional) later in FY 1995.

A key focus of this activity during the current reporting period was the facilitation of geophysical data collection on the 22-mi long regional east-west seismic reflection profiling lines crossing Crater Flat, Yucca Mountain, and Midway Valley. Planning, scheduling, and field data collection were completed for 14 shorter LBL seismic reflection profiling lines in the vicinity of Yucca Mountain, totalling over 25 mi of shallow high-resolution seismic data. Gravity data collection along both the USGS and LBL seismic lines was also planned, budgeted, scheduled, and executed to help corroborate the results.

A feasibility test for the magnetotelluric geophysical method was completed along one line. Field acquisition costs exceeded the cost of the reflection seismic profiling method by almost three times. As a result of this high cost, further data collection using the magnotelluric method has ceased until its usefulness to the Project can be reevaluated and the results of the feasibility test can be assessed.

Approximately 60 percent of a 22-mi long regional magnetic profile (coincident with the regional seismic reflection profiling lines discussed above) was planned, budgeted,

scheduled and performed. Additionally, approximately 150 km of magnetic profiling lines in the vicinity of proposed locations for V-holes 1, 2, and 3 for the volcanism program have been acquired. The magnetic profiles will aid in the selection of V-hole locations.

The Geophysics Integration Task Force is currently examining the regional magnetic and gravity geophysical data to determine if the data set needs to be upgraded to QA status for license application, or if the interpretation and analyses of existing data will suffice for license application as support information.

A geophysics integration meeting was held with YMSCO, the M&O, and key Principal Investigators (Unsaturated Zone Hydrology, Structural Features, Stratigraphy, Soil and Rock Properties, Systematic Drilling Program, and the Modeling Group) to facilitate geophysical borehole logging integration; needs were identified and addressed. In addition, the Geophysics Integration Task Force participated in several meetings addressing the development of an integrated three-dimensional geologic framework model.

Work continued on compilation and integration of existing and planned geophysical data and tests. In addition, work continued on developing a reference bibliography of known geophysical testing results related to the Project and general vicinity.

A bibliography of all relevant geophysical publications will be issued in draft form for review and comment. Monthly geophysical activity summaries will be issued to the Geophysics Integration Task Force and to YMSCO. Discussions will continue between the Geophysics Integration Task Force and YMSCO on the form and content of a Geophysics Integration Plan.

A first draft of the Stratigraphic Compendium was issued in the first quarter of FY 1995, with later updates to follow on an annual or semiannual basis.

Forecast: There will be no study plan developed for this activity, although Study Plan 8.3.1.4.2.1 (Characterization of the Vertical and Lateral Distribution of Stratigraphic Units Within the Site Area) has been revised to permit the application of geophysical methods in and adjacent to the site area. The Geophysics Integration Task Force will continue to meet periodically to discuss, determine the need for, plan, budget, prioritize, sequence, and schedule geophysical testing, as well as to ensure the appropriate application of geophysical test results within the site characterization program. Technological advances in geophysical methods will be considered as new and potentially useful geophysical test methods that could be incorporated into site characterization studies under this activity.

The Geophysics Integration Task Force will endeavor to ensure that objectives, scope, and methods for geophysical tests are well defined, geophysical and nongeophysical testing programs are integrated, test linkages and information needs are established, the technical need and adequacy for all proposed geophysical tests is well understood, the conduct of the geophysical tests is justified, and the implementation of a geophysical test will contribute to the development of models and assessments to be used for the determination of site suitability and for the license application.

During the second half of FY 1995, the Geophysics Integration Task Force will help plan, budget, and schedule the standard geophysical borehole logging suites in Boreholes UE-25 ONC-1, USW UZ-4, USW SD-7, USW SD-12, USW UZ-7a, UE-25 WT#24, and in at least 1 or 2 other WT holes. In addition, the task force is currently considering scheduling the geophysical logging of additional boreholes in the proposed repository block area in support of ESF Design.

The Geophysics Integration Task Force will assist in the planning, budgeting, scheduling, and data acquisition of the vertical seismic profiling walkaway survey to be performed at Borehole UE-25 UZ#16, which will aid in the analyses of the Ghost Dance Fault and will help determine fracture density in the area of UE-25 UZ#16.

The Geophysics Integration Task Force is currently planning the field acquisition of approximately 150 mi of regional shallow- to intermediate-depth reflection seismic data, from Death Valley Junction, California to Beatty, Nevada, thence to Skull Mountain, Nevada and to Timber Mountain, Nevada. Approximately 70 to 90 mi of these data are planned to be collected in FY 1996, with the remainder to be collected in FY 1997. In addition, the task force is currently planning the acquisition of data along two high-resolution shallow seismic reflection lines in the vicinity of Little Skull Mountain to examine the Rock Valley fault zone; these lines will be acquired by within the next quarter of the current fiscal year.

The Geophysics Integration Task Force will ensure that objectives, scope, and methods for geophysical tests are well defined, that geophysical and nongeophysical testing programs are integrated, that test linkages and information needs are established, that the technical need and adequacy for all proposed geophysical tests is well understood, that the conduct of the geophysical tests is justified, and that the implementation of a geophysical test will contribute to the development of models and assessments to be used for the determination of site suitability and on the license application.

A reference bibliography of all relevant geophysical publications is being compiled and will be issued in draft form for review and comment. Discussions will continue between the Geophysics Integration Task Force and YMSCO on the form and content of a Geophysics Integration Plan.

3.3.3 Study 8.3.1.4.2.1 - Characterization of the Vertical and Lateral Distribution of Stratigraphic Units Within the Site Area

The objective of this study is to determine the vertical and lateral variability and emplacement history of stratigraphic units and lithostratigraphic subunits within the Yucca Mountain site area.

Activity 8.3.1.4.2.1.1 - Surface and subsurface stratigraphic studies of the host rock and surrounding units. The objective of this activity is to determine the spatial distribution, history, and characteristics of stratigraphic units within the Paintbrush Tuff, tuffaceous beds of Calico Hills, Crater Flat Tuff, and possibly older volcanic rocks within the site area.

Project geologists conducted lithologic logging and made graphical lithologic logs during Phase I of this activity. Bit cuttings from Boreholes UE-25 NRG#4, UE-25 NRG#5, and UE-25 WT#18 were examined to determine depths to lithostratigraphic contacts in the intervals that were not cored.

Project geologists completed lithologic logging of Borehole USW SD-9 which was drilled to a total depth of 675.8 m (2,223.1 ft). Lithologic contacts were selected from the base of the Paintbrush Group to total depth and presented in a table of contacts that was transmitted to project personnel for review. In addition, detailed descriptions of rocks from 1,487 to about 2,000 ft were made, and a graphical lithologic log of this interval of the borehole was prepared. Lithologic logging of this borehole was completed. The lithologic log was reviewed, revised, and submitted for release.

Graphical lithologic logs for Boreholes USW UZ-N31 and UZ-N32 were prepared, reviewed, revised, and submitted for release. Detailed lithologic data were collected for borehole USW UZN-31 from surface to total depth and were compiled for the graphical lithologic log.

Three reports summarizing results to date were completed and approved and are currently in preparation: (1) Geslin and Moyer, in prep.; (2) Moyer and Geslin, in prep.; and (3) Geslin et al., in prep. Geslin and Moyer (in prep.), and Geslin et al., (in prep.), include descriptions of lithologies and stratigraphic contacts based on studies of cores from 20 boreholes at Yucca Mountain. The volcanic units penetrated are in the Miocene Paintbrush Group and Calico Hills Formation. As discussed in Moyer and Geslin (in prep.), an analysis of core samples, combined with outcrop studies, has resulted in the informal subdivision of the Calico Hills Formation and the Prow Pass Tuff (Crater Flat Group) into several lithostratigraphic units and subunits that can be traced throughout the Yucca Mountain area. Stratigraphic thicknesses indicate deposition in south-trending paleovalleys lying east of Yucca Mountain. This report includes detailed descriptions of all defined units.

To further help define rock properties in core, Project scientists continued to examine devitrification textures and vapor-phase mineralogy from the thin section suites collected from Drillholes USW NRG-2A and USW NRG-3 (in the Tiva Canyon Tuff). They compared subsurface petrographic features in the Tiva Canyon Tuff with those examined from the surface sample suites, including thin sections from samples collected from the vertical transects across Antler Ridge, Whale Back Ridge, and Solitario Canyon.

The collection of borehole lithologic data directly supports the development and updating of the three-dimensional geologic framework model. This work supports the development of the stratigraphic and structural setting at Yucca Mountain.

Lithology and Hydrologic Properties in the PTn

This activity consists of reoccupying and remeasuring previously measured sections where samples for hydrogeologic properties analysis have been collected, and measuring and sampling selected new sections. The results will be used to provide regional and local

stratigraphic framework for lateral continuity of beds and tephrostratigraphic correlations in this important hydrostratigraphic unit.

Project investigators examined variations in depositional features in the PTn in the headwaters of Sever Wash. They began processing hydrologic-properties data received from project scientists for comparison with current stratigraphic studies of the PTn. Project geologists completed new measured sections near Fortymile Wash, in Solitario Canyon, and at Isolation Ridge. Review copies were prepared and sent for field checking and technical review.

Project geologists began characterizing stratigraphic variations in the lower part of PTn hydrogeologic unit by examining the interval from the base of the Pah Canyon Tuff to the top of the crystal-rich vitrophyre of the Topopah Spring Tuff in Yucca Mountain boreholes. These data are being synthesized into generalized descriptions of the subunits and marker horizons. Units can be correlated throughout all boreholes despite variable amounts of alteration and locally poor core recovery.

Stratigraphic relations within units of pre-Tiva Canyon Tuff bedded tuffs and pre-Yucca Mountain Tuff bedded tuffs of the PTn hydrogeologic unit were characterized by examining, sampling, and describing these intervals in Yucca Mountain boreholes. These data were synthesized into generalized descriptions of the subunits and marker horizons. Some units can be correlated throughout all boreholes, while others are laterally discontinuous. Bed thickness and distribution data for stratigraphic units within PTn hydrogeologic unit are being compiled.

Project scientists reviewed thin sections in the Tiva Canyon Tuff from a measured section on the west flank of Yucca Mountain. Changes were noted in the (a) relative amounts of welding, as indicated by variations in porosity and the shapes of shards and pumice, (b) types of crystallization of the dust, shards, and pumice, and (c) possibly the characteristics of fractures.

A draft digital location map for all measured sections was compiled, and a draft digital topographic location map for measured sections on and near Yucca Mountain was prepared.

Synthesis of the stratigraphy of the pre-Pah Canyon Tuff bedded tuffs, the pre-Yucca Mountain Tuff bedded tuffs, and pre-Tiva Canyon Tuff bedded tuffs was begun by preparing unit descriptions, tables of contacts, and unit correlations, and assembling data packages. Descriptions of cores of the Yucca Mountain Tuff were completed, and existing information on lithologic variations observed within cores of the Pah Canyon Tuff was compiled.

Project geologists completed examination of pre-Yucca Mountain Tuff bedded tuffs and pre-Tiva Canyon Tuff bedded tuffs in core and compiled their observations into data packages. The correlation of marker horizons within these units between boreholes continued, as did the examination of the hydrologic properties of these units continued. Comparisons of paleosols within pre-Yucca Mountain Tuff bedded tuffs with the negative gamma ray

signatures found on digital geophysical logs were made and preliminary isochore maps of selected subunits of pre-Yucca Mountain Tuff bedded tuffs were drafted.

Project staff updated the data base and existing surfaces for the three-dimensional geologic framework model. New lithologic data acquired from Boreholes USW SD-9, USW SD-12, UE-25 NRG#4, and UE-25 NRG#5 were incorporated into and used to update the LYNX structure contour maps. Project geologists conducted limited geologic field mapping in the vicinity of Boreholes USW UZ-N31, N32, N53, N54, and N55 and on the west side of Exile Hill. The 11 existing surfaces in the model were updated, based on newly acquired borehole and outcrop data. The Bow Ridge fault surface was updated to reflect new information obtained from boreholes USW NRG-2 and UE-25 NRG#2b. Quaternary alluvium/colluvium data were obtained from the USGS unsaturated-zone investigators and added to the three-dimensional model data base. Project staff prepared and submitted to DOE for approval three administrative reports containing the documentation and reviews of the input data, a structure contour map, and 10 isochore maps for model version YMP.R1.1. Two new isopachs for the Calico Hills Formation and Prow Pass Tuff were incorporated into this model.

Technical reviews of input data were conducted by project scientists and a base map showing the location of measured sections within the study area was constructed. Export isopach maps from LYNX model YMP.R2 were constructed to check the performance of the model. A report on this work (USGS, in prep.) was prepared and submitted for review and approval to publish. The central part of the mountain consists of seven structural blocks composed of six formations and the interstratified bedded tuffaceous deposits. Rocks ranging from the 12.7 Ma Tiva Canyon Tuff to the 13.1 Ma Prow Pass Tuff are modeled with 13 surfaces. The model is based on data from 75 boreholes from which a structure contour map at the base of the Tiva Canyon Tuff and isochore maps for each unit are constructed to serve as primary input. The model is capable of producing structure contour maps on the base of each unit, and provides a useful site-scale lithostratigraphic and structural representation of the central block of Yucca Mountain. Such a representation can be used for (a) storing data from, and planning future, site characterization activities, (b) preliminary geometry of units for design of the ESF and the potential repository, and (c) performance assessment evaluations. Preliminary copies of the three-dimensional model were sent to users of the LYNX modeling system.

Work began on modeling new surfaces in the LYNX model. Various interpretations of the potentiometric surface were digitized and incorporated into the model. A regional water table map was obtained to further explain the high gradient area in the northern part of the modeled area. The vitric/zeolitic contact data in the tuffs beneath Yucca Mountain were prepared for incorporation into the model. New features that were being prepared to add to the model included the bedrock/alluvial contact and surfaces, structural data, and topography east of the Bow Ridge fault in order to obtain accurate offsets and elevations of units adjacent to the fault.

Project scientists began a review and field check of pre-1992 measured sections. Work on this task was started in early October, with the field check of several pre-1992 measured

sections near Yucca Wash and Isolation Ridge, in northern Yucca Mountain and in Solitario Canyon. Project geologists field-checked 19 pre-1992 measured sections (including SC#1 and #2, Tpt-10, Tpt-32, Tpt-32A, Tpt-31, Tpt-35, Tpt-12, H-1 and -2, Tpt-15, Tpt-2, Tpt-14, PTn#1 through PTn#6, PTn#2, and PTn#3), and prepared technical review forms for these measured sections. Mandatory and non-mandatory comments that resulted from the technical reviews were addressed by Project scientists.

Project geologists examined exposures in Yucca Wash, in the vicinity of several pre-1992 measured sections, from the top of the Topopah Spring Tuff to the base of the Yucca Mountain Tuff. This work provided additional control for the new lithostratigraphic units in the pre-1992 measured sections. The upper units of the Topopah Spring Tuff and the pre-Pah Canyon Tuff bedded tuffs were re-measured at SC#1, on the east side of Solitario Canyon. The locations of the measured sections were updated, and a list of the measured sections with their completion status was compiled.

The results of the reviews of the pre-1992 measured sections will provide input data to the three-dimensional geologic framework model. The field reviews will not only provide a technical review of the measured sections, but will also help convert the Scott and Bonk (1984) units to the new lithostratigraphic units (Buesch et al., in prep.).

Activity 8.3.1.4.2.1.2 - Surface-based geophysical surveys. The objective of this activity is to improve confidence in stratigraphic models of Yucca Mountain by incorporating geophysical constraints.

A draft of a Geophysical White Paper, Phase II (Oliver et al., in prep.) was submitted for DOE approval. This document includes ten chapters written by specialists in various fields of geophysics. Besides an introductory chapter, which describes the geologic setting of Yucca Mountain and presents an overview of geophysical methods, and a concluding summary chapter, there are separate chapters on gravity, magnetic, magnetotelluric, seismic refraction, seismic reflection, and teleseismic investigations as well as on heat flow and stress measurements. Each chapter summarizes the results and interpretations derived from the various surveys that have been conducted in the area to date, with suggestions as to the course of future geophysical activities. Because Yucca Mountain is structurally complex, and has other aspects that complicate geophysical exploration, such as high resistivity and low seismic velocity and density contrasts near the surface, the general conclusion is that a combination of methods is required to provide high quality subsurface data.

Project personnel acquired seismic-reflection data in Crater Flat and at Yucca Mountain. Station survey crews began locating source points, shotholes, and geophones in mid October 1994. Drilling of deep shotholes contract) was completed by the end of October. Seismic crews completed noise testing, and production data collection began on Line 2SW south of Highway 95 near Steve's Pass in Crater Flat. By the end of October 1994, data collection had proceeded to the approximate boundary of the Test and Waste Isolation Evaluation Zone southwest of Solitario Canyon. Minihole drilling was completed on Fran Ridge, and additional deep shotholes were loaded.

A total of 23 mi of reflection data were acquired. Multiple energy sources used for the survey include (a) vibrator, (b) Poulter (surface charges of 5 lbs mounted on stakes), (c) minihole (5 lb charges in 10-ft deep holes), and (d) explosive shot-hole (200 lb charges in 200-ft deep holes). The first three energy sources produced 8-second records and the fourth produced 20-second records. Thus, the survey resulted in two simultaneous investigations, one relatively shallow and the other deep. A 480-channel digital recording program was used, with geophone spacing of 25 m (82.5 ft) (group interval). Data collection was completed on November 11, 1994, and magnetic data tapes were delivered to Project staff in late November.

Preliminary data (in the form of a Brut stack that represents essentially unprocessed data) indicate that the rocks traversed provided reflections that promised definitive subsurface interpretations upon further processing. Work on processing the reflection data has begun, and project personnel met with the processing team to discuss the geology of the Yucca Mountain area and the specific objectives to be met in the processing program.

The results of the seismic reflection profile will support the further development of the three-dimensional geologic model. The geometry of faults in the subsurface (planar, listric, etc.) can be evaluated using the results of this activity. Additionally, the results will be used to help locate Borehole USW G-6, a deep corehole that is designed to penetrate the Tertiary/ Paleozoic contact.

Activity 8.3.1.4.2.1.3 - Borehole geophysical surveys. The objectives of this activity are to help define and refine the location and character of lithostratigraphic units and contacts between units and to determine the distribution of rock properties within lithostratigraphic units.

Project scientists assisted with geophysical modeling. The staff also discussed the seismic reflection and refraction lines that are in progress, and focused on a possible detailed study of the USW UZ-7A drill pad. Methods of integrating the quantitative mineralogy data into geophysical logs were considered.

Project scientists reviewed the methods for assembling borehole fracture data. Methods that can be used in the review of video tapes of fractures in pre-1990 boreholes were studied, and experiments were conducted with some of these methods on the borehole video tape of UE-25 UZ#16.

The integration of geology and geophysics will help interpret surface and borehole geophysical data. The results will be used as input data for the three-dimensional geologic model, especially in areas either where no boreholes exist or there is little of no core data.

The responsibility for collecting and interpreting borehole geophysical data has been delegated to SAIC-M&O, who will have the responsibility for reporting work conducted under this activity in the future.

Activity 8.3.1.4.2.1.4 - Petrophysical properties testing. The objective of this activity is to provide geophysical and rock property data to be used in the interpretation of surface-based and borehole geophysical surveys.

No progress was made during reporting period; this was an unfunded activity.

Activity 8.3.1.4.2.1.5 - Magnetic properties and stratigraphic correlations. The objective of this activity is to provide magnetic property data to aid in the interpretation of volcanic stratigraphy and structure of rock units, to use paleomagnetic directions to provide orientations for drill core segments, and to assess the rotation of rock units in relation to the geologic structures of Yucca Mountain from paleomagnetic indications.

Project scientists began the processing and reduction of gravity and magnetic data collected in FY 1994. The task will ultimately provide coordinated modeling and interpretation of the traverses conducted on Yucca Mountain and across the Solitario Canyon fault in the spring of 1994. Initial steps were taken to involve geologic staff in interpretations to guide advanced modeling, including generation of preliminary profiles and model solutions for the geologic staff. Processing, reduction, and modeling of these data were completed, and a report was completed and approved (Oliver and Sikora, in press). Preliminary gravity results show a distinct decrease of 0.1 to 0.2 mgal over a 182.4-m (600-ft)-wide zone to the east of and including the mapped location of the Ghost Dance fault. The gravity decrease probably marks a zone of brecciation. The ground magnetic data show a 60.8-m (200-ft)-wide magnetic low of about 400 nT centered about 30 m (100 ft) east of the fault. This low probably also indicates a zone of brecciation within the normally polarized Topopah Spring Tuff, the top of which is about 1,700 ft below the surface at the locality surveyed.

The results of this activity directly support the interpretation of the subsurface geologic setting at Yucca Mountain. Stratigraphic and structural information obtained from this work will be used as input data to the three-dimensional geologic framework model.

Project scientists began acquiring magnetic data along the seismic reflection line described under Activity 8.3.1.4.2.1.2. This task was initiated early to take advantage of survey flags still in place after reflection data was acquired. Geophone and sourcepoint locations provided stations for the magnetic data collection. Magnetic data were collected in a single 37-km pass along the entire seismic line. Collection of offset data on remaining parts of the line will be completed in later field sessions. Two offset and parallel lines were collected between Steve's Pass and Borehole VH-1 to complete the data acquisition phase of this task. The offset lines now extend from Ashton, the west end of the seismic line, to VH-1. Aeromagnetic data will be used for the offset lines for the remainder of the seismic traverses.

The results of this activity directly support the interpretation of the subsurface geologic setting at Yucca Mountain. The outlying profiles will be used to identify discontinuities oblique to the seismic reflection lines. Stratigraphic and structural information obtained from this work will be used as input data to the three-dimensional geologic framework model.

Project scientists began the initial planning of line locations based on existing data and interpretation of general geological/geophysical setting (some data have been collected at one of the proposed drill sites; other extensive regional data exist). The magnetic/gravity crew collecting the gravity and magnetic data conducted the surveying concurrent with the data collection. Collection of the gravity and magnetic data is 90 percent complete.

Data produced by this activity will be used to locate the volcanic boreholes in the Amargosa Desert.

Forecast: Lithostratigraphic studies of surface exposures in the Calico Hills Formation, and the Bullfrog Tuff and tram Tuff will be conducted in the last half of FY 1995. Field review and geochemical sampling, to define stratigraphy, of pre- and post-1992 measured sections will be completed. Provisional interpretations based on partial processing of the regional seismic-reflection data will be completed, and work will begin on the final report. Magnetic and gravity data collected during the first half of FY 1995 will be processed, analyzed, and interpreted. Collection of additional gravity and magnetic data will continue in the second half of FY 1995. Data collected under this study will be used in the construction of the three-dimensional geologic framework model.

3.3.4 Study 8.3.1.4.2.2 - Characterization of the Structural Features Within the Site Area

The objective of this study is to determine the frequency, distribution, characteristics, and relative chronology of structural features within the Yucca Mountain site area.

Activity 8.3.1.4.2.2.1 - Geologic mapping of zonal features in the Paintbrush Tuff. The objectives of this activity are to map zonal variations within exposed tuffs that will aid in the identification of structural displacement at a scale of 10 m or less; and to detect subtle changes in structural styles.

Project geologists began and completed a preliminary study of linear features on low sun-angle photos and have plotted results on 1:5000 topographic maps. A preliminary rough map showing significant photolineaments observed in the central block on 1:12000 and 1:6000 scale airphotos, including low sun-angle photos was completed. A preliminary map of lineaments has been produced. Lineaments appear to be mostly shadow alignments caused by topography but other causes are present also. Review of the photolineaments is complete. Project geologists completed a narrative description of photolineaments within the central block (essentially the site area). A detailed outline of the introduction and geologic setting sections of the final report was completed, and much of the draft stratigraphy, structural geometry, and fracture character sections were written. A map detailing significant photolineaments and other features of interest is near completion.

Work on the Solitario Canyon strip map was begun, and the staff met with project design engineers to discuss surveying of contacts on the west flank of Yucca Mountain and

what the engineers will need for spacing of locations. The lithologic contacts to be surveyed on the east side of Solitario Canyon (west flank of Yucca Crest) were identified and flagged.

Project geologists began to check the consistency of the Scott and Bonk (1984) map. Digital maps of local structure contours for subunits of the Tiva Canyon Tuff, based on the Scott and Bonk (1984) were prepared. These digital maps can be reproduced at any scale and used to compare subunit contacts with each other and with other structural data. Selected portions of the Scott and Bonk (1984) along the north and south sides of Yucca Wash were field checked. Structure contour coverage of the central block of Yucca Mountain on the Scott and Bonk (1984) map was increased by 100 percent, and expanded coverage north to Yucca Wash, east to Exile Hill, and south to drill hole USW H-3. The local strike line maps for the Tiva Canyon base and the Tiva "upper cliff" base were digitized for the consistency check of the Scott and Bonk (1984) map.

Mapping began of the extension of the Sundance fault to the northwest from Split Wash, and preliminary progress maps showing the major structures located within a 456 m. (1,500-ft) wide strip adjacent to the centerline of the fault have been completed.

Activity 8.3.1.4.2.2.2 - Surface-fracture network studies. The objective of this activity is to provide measurements and analyses of fracture networks to support modeling of hydrologic potential flowpaths, particularly in unsaturated zones. Applications are also expected to aid development of tectonic models and determination of the mechanical response of fractured rock to excavation and thermal loading.

Project geologists examined 1:2400 scale air photos of the west flank of Yucca Mountain to identify potential sections for study of the nonwelded unit of the Paintbrush Tuff (PTn). An existing measured section on the west flank of Yucca Mountain in Solitario Canyon was examined. The stratigraphic relationships within the PTn, Topopah Spring Tuff, and Tiva Canyon Tuff were investigated. Project geologists examined several sections in the PTn along a 2-km traverse on the west flank of Yucca Mountain in Solitario Canyon. Two study areas were selected and partially flagged for surveying. Potential locations for the third study area were noted and were examined in mid November.

The three PTn fracture study areas were selected using the following six criteria:

1. Completeness of exposure of the PTn section

2. Quality of exposure at the contacts with the overlying Tiva Canyon Tuff and underlying Topopah Spring Tuff

3. Inclusion of a variety of stratigraphic settings as the Pah Canyon and Yucca Mountain Tuffs pinch out southward

4. Location of one study area adjacent to a northwest-trending fault to evaluate changes in fracture density with proximity to faults within the PTn

5. Ties to Flint-sample traverses and available matrix porosity/permeability information

6. Overall N-S coverage along the western boundary of the proposed repository.

The three PTn fracture study areas have been flagged and await surveying; the surveying will be combined with the surveying of the geologic strip map along Solitario Canyon. Project geologists began studying and mapping fractures in these localities. Activities included observation of fracture orientations and terminations, photography of the study areas, and preparation of a base map of the northern study area through the surveying of location points by triangulation using tape and compass. Geologic maps have been completed, and the total fracture study in Solitario Canyon is over half done. Fracture attribute data remains to be collected from the three areas, as well as in other areas along Solitario Canyon where individual lithologic contacts are well exposed.

Survey information on the Fran Ridge pavement was obtained in paper and digital form. Brecciated material from three 2- to 3-in-wide fracture fillings in this pavement were collected for thin-section study, with the primary purpose of identifying lithic casts. Photo micrographs were also taken as an aid in the study of mineral parogenesis, fracture movement history, and breccia clast identification. Fracture attribute data (orientation, trace length, height, aperture, roughness, fracture filling, termination, and intersection and offset relationships) were collected from about 275 fractures and cooling joints. These data were tabulated and entered in a computer data base in a format suitable for use in a final report.

Field maps of the Fran Ridge pavement were completed, and comparisons made for consistency with the fracture attribute data. The field maps have been digitized and are being compiled and edited. Future work will include a synthesis of the mapped relationships, examination of fracture offsets, and statistical analysis of the fracture attribute data.

Activity 8.3.1.4.2.2.3 - Borehole evaluation of faults and fractures. The objectives of this activity are to assess the reliability and usefulness of available borehole techniques for identifying and characterizing the subsurface fracture distribution; to determine vertical and lateral variability and characteristics of subsurface fractures; and to identify subsurface characteristics of fault zones.

No progress was made during the reporting period; this was an unfunded activity.

Activity 8.3.1.4.2.2.4 - Geologic mapping of the Exploratory Studies Facility. The objectives of this activity are to determine the vertical and horizontal variability of fracture networks in the ESF ramps, drifts, and boreholes; to characterize major faults and fault zones in the subsurface; to map the lithostratigraphic features of the subunits and the abundance and character of lithophysal zones; and to assist in the evaluation of test locations in the ESF test facility.

Project staff monitored the progress of the tunnel boring machine near the end of October 1994, and prepared equipment for mapping. They also continued setting up an

AutoCAD station at the Field Operations Center and modified base maps to be used in the underground operation.

Initially, mapping in the North Ramp was limited to mapping from the trailing gear of the tunnel boring machine. A detailed line survey (DLS-94-1) was started on the right wall, springline at station 0+60.62 and continued to station 0+69.05, just behind the operator's cab. Locations of steel sets and lagging were placed on the full periphery map and full-periphery mapping was started from station 0+60.62 to 0+69.05. Ground support in this area is circular steel ribs, with lagging covering much of the crown. This has created some difficulty in mapping, as many of the fractures causing block fallout in the crown are not visible behind nearly solid lagging.

Project geologists developed a cross-section comparing stratigraphy and predicted geologic structure developed by Sandia/Agapito in cooperation with the USGS with actual geology encountered in the North Ramp.

Project geologists began mapping of the North Ramp on January 24, 1995. Full periphery mapping was divided into two operations, recording the locations of steel sets and lagging first, followed by mapping of geologic features. Detailed line surveys on the right wall springline began on January 26, 1995. Mapping was accomplished as follows:

- Full peripheral mapping completed to approximately station 1+80
- Detailed line survey completed to station 2+11
- Photogrammetry work completed to station 2+35.57
- Sixty-nine samples collected for submittal to the Sample Management Facility as part of the consolidated sampling program.

Mapping crews began gathering of geotechnical data behind the tunnel boring machine. Field data was entered into computers for use in the geotechnical report. Project geologists met with soil and rock support personnel to discuss rock quality designation, quality, and rock mass rating calculation techniques to standardize methods between the two groups.

Activity 8.3.1.4.2.2.5 - Seismic tomography/vertical seismic profiling. The objectives of this activity are to investigate, and if successful, provide a means for broadly detecting and characterizing the subsurface fracture network in regions between the surface, boreholes, and underground workings; and to calibrate and relate the seismic propagation characteristics of the host rock to the fracture patterns observed in boreholes and underground workings, and extrapolate the observed fracture patterns to the surrounding region.

No progress was made during the reporting period; this was an unfunded activity.

Related International Work

See Sections 3.1.17 (under the heading, Field Tracer Test Development) and 3.3.8 (under the heading, Seismic Tomographic Imaging) for related work performed under the auspices of the OCRWM international program.

Forecast: Mapping structural features at the surface of Yucca Mountain will continue. The field check of "significant" structural features, obtained from low-sun-angle aerial photographs, will be completed. Fracture, pavement, and vertical continuity studies will be completed. The ESF mapping will keep pace with the progress of the tunnel boring machine, producing detailed line surveys and full-periphery maps of the tunnel. Surface mapping will expand outside the "central" block area with verification and enhancement studies in the Jet Ridge and Midway Valley areas. Data collected under this study will be used in the construction of the three-dimensional geologic framework model.

3.3.5 Study 8.3.1.4.2.3 - Three-Dimensional Geologic Model

The objective of this study is to develop a three-dimensional geologic model of the site area. In doing so, much of the study will involve synthesis of the results of other studies in the investigation to develop a model that will be integrated into the three-dimensional rock characteristics model described in Study 8.3.1.4.3.2.

Activity 8.3.1.4.2.3.1 - Development of a Three-dimensional Geologic Model of the Site Area. The objective of the this activity is to develop a three-dimensional geologic model of the Yucca Mountain Site that incorporates stratigraphic, structural, geophysical, and rock properties information pertinent to site characterization, and design and performance activities.

An Extended Site Model is under development, using the lithostratigraphic model of the central block extended over a larger area. Additional inputs to the model include a high-resolution topographic surface, a directed-well data base containing boreholes corrected by deviation surveys and the true vertical depth of each lithostratigraphic markers, an extended three-dimensional fault model, and a model of an aeromagnetic map draped on the topographic surface. Development of the Numerical Model Warehouse continues. Several three-dimensional models are continuing to be configured under the Numerical Model Warehouse and will be used by the prototype system, which is currently under development. A comprehensive compilation of borehole lithostratigraphic information was completed in conjunction with the Draft Stratigraphic Compendium (Mattson et al., 1994). The draft Stratigraphic Compendium lists each borehole with available data sources. These data form the basis for the extended site model.

Forecast: The extended site model baseline is expected to be completed during the fourth quarter of 1995. Revisions will proceed on a controlled basis throughout site characterization. Development of the integrated model will begin as the framework model is reviewed and accepted. A major effort will be required to acquire and synthesize the site attributes developed by principal investigators. The scope of this effort will be difficult to

define until the data and descriptive attribute submodels are thoroughly reviewed. A synthesis report will be completed during the fourth quarter of 1995.

3.3.6 Study 8.3.1.4.3.1 - Systematic Acquisition of Site-Specific Subsurface Information

The objective of this study is to acquire physical rock samples, analytical data, and basic descriptions of the subsurface geology of the repository site on a systematic basis. These samples and information are important for characterizing the three-dimensional distribution of rock characteristics, and hydrologic and geochemical variables, for the unsaturated zone at Yucca Mountain. Only one activity is planned under this study.

Activity 8.3.1.4.3.1.1 - Systematic Drilling Program. The purpose of the Systematic Drilling Program is to acquire physical rock samples and analytical data and to develop basic descriptions of the subsurface geology of the potential repository block for characterizing and evaluating the three-dimensional distribution of rock characteristics, hydrologic and geochemical parameters. Core samples taken from selected drillholes provide information related to the design of the ESF Main Test Level and relevant geologic information required for understanding the deeper portions of the repository block.

Drilling of Borehole USW SD-7 commenced October 3, 1994, following relocation of the drill rig from the USW SD-9 drill pad. Borehole USW SD-7 is a combined ESF main drift/Systematic Drilling Program drillhole located approximately where the main test level drift and South Ramp meet. This drillhole, which is about halfway up the mountain on a ridge crest, will provide information regarding the lateral (re)distribution of moisture within what have been observed previously as high-saturation lithologic intervals (particularly at the base of the Tiva Canyon Tuff and Topopah Spring Tuff).

Laboratory measurement of framework hydrologic bulk properties from Drillhole USW SD-9 and from the completed portion of Drillhole USW SD-12 was completed. Scientists at the Hydrologic Research Facility began taking measurements of hydrologic flow properties (e.g., saturated hydraulic conductivity).

Data collected during surface outcrop studies was evaluated in terms of their implications for down-hole sampling strategy (McKenna and Rautman, in prep.); this evaluation is in review.

Geologic logging of core from the USW SD-9 drillhole was also completed.

Project scientists strived to develop a single geologic log format and procedure that would apply to all holes drilled for the Project. According to preliminary plans, geologic logs would no longer be products of the various participant organizations with primary responsibility for the several drilling programs on the Project. Instead, geologic logs would become formal products of the DOE, based on logging input from the several participants, and they would be issued by YMSCO. Current thinking calls for a graphical log format at a primary scale of 1:120 (1 in.=10 ft), with more detailed logging of selected intervals at larger

scales as indicated by the complexity of the geology. Various attributes of the rocks (i.e., degree of welding, devitrification, vapor-phase alteration, etc.) would be portrayed visually in a semiquantitative to quantitative manner on a ft-by-ft basis, together with measured core recoveries for each core run and rock quality designation values based on a standardized 10-ft. interval. Laboratory measurements of selected framework rock properties would be included as well. A preliminary version of the geologic log is likely to be issued virtually on a monthly basis for recently drilled intervals, and this preliminary version would undergo one or more updates as more information becomes available and quantitative measurements are received from the laboratory.

Forecast: While drilling of Borehole USW SD-12 remained suspended during the entire reporting period, resumption of drilling is currently scheduled for mid 1995, following receipt of new dual-wall drill pipe to replace the original drill string. Other field and laboratory activities associated with Drillholes SD-7 and SD-12 will continue. Geologic logging of these holes, including describing lithology, welding and alteration, and fracturing, will be completed. Laboratory measurement of framework material properties and hydrologic-state variables will be completed and compiled in association with the geologic logs. Data will be made available to the ESF designers and other users, including performance assessment analysts, through submittals to the technical data base. Geological logging support will also be provided in association with drilling of various UZ- and SRG-series drillholes.

3.3.7 Study 8.3.1.4.3.2 - Three-Dimensional Rock Characteristics Models

The objective of this study is to produce spatially variable numerical models of material properties for use in various ESF design evaluation and performance-assessment analyses, principally using geostatistical and other computer modeling methods. The study also will support development of new computer algorithms and computer software required to accomplish the modeling.

Activity 8.3.1.4.3.2.1 - Development of three-dimensional models of rock characteristics at the repository site. The objective of this activity is to develop computer-based three-dimensional models that integrate quantitative and semiquantitative data on rock characteristics in light of constraining information developed by studies of the geologic framework of the Yucca Mountain site.

Numerical experiments are being conducted to scale selected material properties from a core-like measurement scale to the scale of a reasonable flow-and-transport model. Software to compute advective ground-water flow paths through both the detailed and upscaled material properties models has been developed and tested. These numerical experiments will be incorporated into FY 1995 ground-water travel time calculations using two steps. First, core-scale measurements will be used to produce intermediate-scale values, using information from numerical and physical experimentation to control the scaling relationship. Scaling from this intermediate scale to the flow-model grid-block scale will use adaptive-gridding techniques developed several years ago under this activity. Adaptive gridding works to

minimize within-block heterogeneity of flow properties, which in turn reduces problems associated with orders-of-magnitude volumetric averaging. Work has begun to modify the adaptive-grid approach to minimize heterogeneity within polygons and triangles in addition to the currently used quadrilateral elements. Numerical flow codes, such as TOUGH and FEHM, require the use of these specific geometric forms for the calculational elements. A brief summary of the physical and numerical scaling experiments conducted to date is presented by McKenna and Tidwell (1995).

The geostatistically based, heterogeneous thermal property models developed previously in support of ongoing thermal-loading calculations were documented in Longenbaugh et al., (1994) and Rautman (in prep.). Two abstracts that summarized this work (Rautman, 1995); (Rautman et al., 1995) were accepted for presentation at the 1995 High-Level Waste Conference. Work in FY 1995 focuses on identifying how uncertainty in the spatial variability of thermal conductivity and bulk density propagate through heat-flow calculations to impact the temperature distribution within the mountain. Also being evaluated are some of the assumptions necessary in converting thermal conductivity, a very sparsely measured material property, from a surrogate framework property, porosity. Previous thermal modeling invoked very simplified assumptions regarding the in situ saturation of the rocks, and FY 1995 modeling will investigate more realistic saturation distributions for the models. Differences in temperature distributions that can be attributed to using different geostatistical modeling approaches will also be investigated. This latter impact is related to the fact that heat flow is being modeled in these exercises as a diffusive process, with the consequence that small-scale heterogeneity may not prove to be as important as in advective-type transport modeling. The effects of geologic uncertainty, as captured in the geostatistical modeling process, may be less significant under these conditions, leading to greater confidence in the overall conclusions of the thermal modeling studies.

Geometric and geostatistical modeling of rock-quality data for cross-sectional profiles along the ESF North Ramp and main test level drifts continues. The objective is to make location-specific predictions of rock quality along the ESF drifts and to quantify the uncertainty in those predictions. Preparation of deterministic (kriged) models of rock quality designation is summarized by Zelinski (in prep.). Cromer et al. (in prep.) discuss expanded modeling which emphasizes simulation and uncertainty assessment.

The Lynx-GSLIB integration module (GLINTMOD), which accesses a framework geologic model to provide soft information to constrain geostatistical simulation of rock material properties, was coded and tested successfully using a two-dimensional synthetic data set. The test problem consisted of simulating a 40 x 30 grid, conditioned by soft information representing a four-layer geologic model represented on an independent 20 x 15 grid. Sparse, additional hard conditioning data were present in the form of artificial drillholes. The configuration is identical to that frequently encountered in modeling Yucca Mountain, where some hard data exist, but in which portions of the modeled volume are beyond the range of influence of these data. Geologically unrealistic material properties have been simulated in such ill-constrained regions in previous modeling exercises. GLINTMOD refers to the geologic model whenever no conditioning data are located within the range of spatial correlation of a point being simulated. The prior expected value for the identified geologic

unit is then used to constrain stochastic simulation of the material property at that point. Testing of GLINTMOD continues in anticipation of implementation for FY 1995 ground-water travel time modeling.

A prototype three-dimensional geometric model has been created for the Yucca Mountain site area, extending away from the main repository block to and beyond the limits of the controlled area and the accessible environment, and from the topographic surface to the Paleozoic basement. The principal purpose of this model is to provide the geometric control and prior expectations of material property values necessary for the Lynx-GSLIB integration module (GLINTMOD). Accordingly, emphasis has been placed on the geometry of numerous, potentially distinct hydrogeologic or thermal/mechanical units; the exact modeling of faults has not been attempted. Instead, major faults are represented by abrupt folding of the offset units over approximately the width of several known fault zones at Yucca Mountain. The model honors all known drillhole stratigraphic intercepts. Surface outcrop mapping and published structural interpretations were also incorporated wherever possible. A significant observation from this modeling effort is that there appear to be several older faults or faults with differing amounts of older and younger movement that are largely obscured by the tuffs of the Paintbrush Group. The geometry of these early fault blocks, which are only partially related to the surface structure exhibited by the areally dominant exposures of the Tiva Canyon Tuff, will have greatest impact in studies of the saturated zone hydrologic system. The static water table has been incorporated into the prototype model, and the complete model is being used to support design of the saturated zone ground-water travel time modeling exercises for FY 1995. The modeled distribution of the lower Topopah Spring vitrophyre was provided to investigators working on thermal loading strategies.

Forecast: Geometric and geostatistical modeling of the Yucca Mountain site will continue with particular emphasis on specific ESF design and performance assessment problems. Development of models of thermal properties, probably using widely distributed measurements of porosity as a surrogate for thermal conductivity, will continue. Modeling to support ground-water travel time calculations will begin as part of technical site suitability. Modeling of both unsaturated and saturated zone flow paths will be conducted. Major emphasis will be placed on quantifying the uncertainty associated with ground-water travel time estimates.

Upscaling techniques and their applicability to upscaling hydrologic property measurements will be analyzed for their feasibility in producing accurate values of hydrologic properties at the geostatistical grid-block scale and at the flow/transport model grid-block scale. Ground-water travel time calculations depend on using upscaling algorithms beginning in April 1995.

Efforts will continue into FY 1995 to integrate soft information from geologic models into Gaussian-based geostatistical simulation algorithms. The linked Linx-GSLIB modeling software will be demonstrated through the construction and evaluation of prototype models. Successful implementation of this software will be used in support of ground-water travel time studies.

3.3.8 Related International Rock Characteristics Work

Seismic Tomographic Imaging

The following is work related to Study 8.3.1.4.2.2 (Section 3.3.4) conducted cooperatively with Switzerland under the auspices of the OCRWM international program.

During the previous reporting period, the activity focused on two separate efforts: refining software for improving seismic data processing methodology for application at Yucca Mountain and Swiss National Cooperative Society for the Storage of Radioactive Wastes sites, and evaluating cross-hole hardware for improving distance of penetration. With respect to enhancement of data processing codes, improved tomographic imaging methods for producing more reliable and robust interpretations were emphasized. Evaluations began on the utility of high dynamic range systems for data recording. By accurate predicting the location of geologic features (faults, lithology, structure), this work potentially could provide advance warning of "bad ground" ahead of the tunnel boring machine and reduce the number of required boreholes.

During this reporting period, Swiss National Cooperative Society for the Storage of Radioactive Wastes personnel generated a synthetic data set from a finite element code that will be used to test the waveform inversion codes. The data set was generated, travel times picked, and a tomographic inversion, using times only, was produced. An amplifier, using the integrated gate bipolar transistor technology, was fabricated and tested. The integrated gate bipolar transistor technology is an order of magnitude cheaper and potentially more powerful. For successful application to a multisource application, small, powerful, low-cost amplifiers must be available. The results of the initial tests indicated that the new amplifiers are more powerful than the present versions and produce equivalent waveforms.

Forecast: During the remainder of FY 1995, work will involve development and refinement of high resolution tunnel to surface, surface to tunnel, tunnel to tunnel, and surface to surface seismic imaging. The next step for tomographic inversion is to apply the waveform inversion to compare with the results of the travel time inversion. Testing and developing improved sources and receivers, for use in tunnels and underground boreholes, will continue.

3.4 CLIMATE (SCP SECTION 8.3.1.5)

3.4.1 Study 8.3.1.5.1.1 - Characterization of Modern Regional Climate

The objective of this study is to provide a baseline and a background for the interpretation of climatic variation. These data will be used to develop modern vegetation-climate calibration relationships, to assess lake-climate relationships, and to test global and regional climate circulation model relationships in regard to site performance.

Activity 8.3.1.5.1.1.1 - Synoptic characterization of regional climate. The objectives of this activity are to provide the basis for developing vegetation-climate relationships, lake-climate relationships, and climate-circulation models (meteorological data); to provide an understanding of spatial and temporal variation in climate (synoptic climate); and to determine the climate conditions (i.e., time, temperature, seasonality, and air masses) under which recharge occurs (isotopic data).

Precipitation samples continued to be collected from 7 sites on Yucca Mountain and 12 regional sites within 100 km of Yucca Mountain. Seven of the regional sites had snow collectors installed during the reporting period; these will be monitored in May and June. The unusually high amounts of precipitation during the present winter should provide some data defining the dominant weather patterns that prevail during wetter climate cycles.

To date, the $\delta^{18}O$ values of 55 precipitation samples have been determined, but a large backlog of samples await both δD and $\delta^{18}O$ determinations. Because of the recent unusually high amounts of precipitation, the backlog is increasing rapidly, but steps are being taken to provide analyses on a more timely basis.

Forecast: Rain collectors will be installed at the 7 sites where snow collectors were installed in the fall, and the accumulated water from the snow collectors will be recovered. A data base for precipitation stable-isotopic data is currently being developed. This data base will be the focal point of the preparation of charts and maps for a report due during the latter half of FY 1995. Strontium isotopic compositions will not be determined in FY 1995.

3.4.2 Study 8.3.1.5.1.2 - Paleoclimate Study: Lake, Playa, and Marsh Deposits

The objective of this study is to establish the nature, timing, duration, and amplitude of paleoclimate changes in the Yucca Mountain area, based on paleontologic, geochemical, stratigraphic, sedimentologic, and geochronological data obtained from lacustrine, playa, and marsh sediments in or near southern Nevada.

The studies Lake, Playas, and Marshes, and Terrestrial Paleoecology are closely related. During the last six months, data from these two studies were integrated, resulting in a preliminary interpretation of late Pleistocene climate change. The climate change interpretations and new data from past discharge have been compared and further study is in progress. The climate interpretations and their possible implications for climate induced discharge in the Yucca Mountain flow system are summarized below with specific accomplishments detailed under their activity numbers.

Activity 8.3.1.5.1.2.1 - Paleontologic analyses. The objective of this activity is to assemble and interpret, in paleoclimatic terms, detailed records of ostracodes, diatoms, and pollen, along with other types of fossils as warranted by specific paleoclimatic questions.

Ostracode analyses are nearing completion for sections collected in the Las Vegas Valley. That data likely spans the time from about 30 to 10 ka. Ostracode data also are

being collected from long lacustrine records from lakes in the general region. Those data from the lower Quaternary are now available for interpretation . Additional samples from the Pahranagat Marshes are available for analyses of ostracodes and diatoms.

Activity 8.3.1.5.1.2.2 - Analysis of the stratigraphy-sedimentology of marsh, lacustrine, and playa deposits. The objectives of this activity are to identify and characterize the general physical and chemical properties of sedimentary units from outcrops, shore deposits, and cores (providing a physical and relative temporal framework for various paleoenvironmental studies), and to determine the specific environment of deposition for the sedimentary units using the principles of clastic and chemical sedimentology.

A preliminary description of two sections collected in the Las Vegas Valley paleowetland sediments, which were also collected for paleontological analyses, suggests stratigraphic unit D, the unit associated with the maximum wet period, may be divided into two subunits. Those subunits representing changes in deposition may coincide with the paleontological evidence of climate change summarized above. Cores from the Pahranagat Marshes have been described.

Activity 8.3.1.5.1.2.3 - Geochemical analyses of lake, marsh, and playa deposits. The objective of this activity is to provide a detailed chemical and mineralogic characterization of lacustrine, marsh, and playa deposits to generate information about paleohydrology, sediment provenance, weathering rates, and sediment-water interface environments in ancient lakes.

Stable isotopic studies of biogenic carbonate from the upper part of the Pahranagat core have been completed. Results show changes in the isotopic stratigraphy that appear to coincide with those observed in the ostracode and pollen stratigraphy. These collective changes indicate that climate during the last 2,000 yr has undergone changes from wetter to drier episodes.

Activity 8.3.1.5.1.2.4 - Chronologic analyses of lake, playa, and marsh deposits. The objective of this activity is to obtain an accurate chronologic framework for the paleoclimatic information acquired in this study. All age information should, whenever possible, be tested with other techniques to reduce uncertainties.

Brenner and Quade (in prep.) completed a study to determine how various kinds of mollusks store radiocarbon information. They have discovered significant differences between taxa and have determined which species are likely to provide reliable age information.

Forecast: Ostracode valves counts will be made on an additional suite of sediment samples that were collected during December 1994. Further valve counts will be made on available ostracode material from the Pahranagat Marshes, Owens Lake, California, and the Sevier Basin, Utah. Ostracode and mollusc material will be extracted from some of the samples for stable isotope analyses.

The younger (late Pleistocene) sections will be dated using terrestrial gastropods found in the spring and wetland sediments as was suggested by the study by Brenner and Quade (in prep).

Additional diatom samples from the Owens Lake record will be counted and added to the existing data base. The diatom and ostracode data from the long cores (Owens Lake, California, Death Valley, and Sevier Basin) provide the Quaternary history of climate change in the region. Current data, which includes at least one sample from most 10,000-yr intervals ranging from modern to over 2 million yr, seem to suggest that the modern style climate common to Yucca Mountain is very atypical. It is critical that the Project is able to verify that modern dry periods are indeed very rare or determine if the data is biased in some way toward wet records.

3.4.3 Study 8.3.1.5.1.3 - Climatic Implications of Terrestrial Paleoecology

The objective of this study is to provide quantitative estimates of changes in climatic variables (precipitation, temperature, seasonality, etc.) for late Quaternary time in the southern Great Basin. This study will collect and analyze data on plant macrofossils from pack rat middens; fossil pollen assemblages from lake, marsh, and playa deposits; radiocarbon age determinations on paleovegetational assemblages; vegetation-climate and/or pollen-climate response surfaces; and pollen climate transfer functions.

The DOE has committed grant monies to the Desert Research Institute, University of Nevada, Reno, to support independent research that includes paleoclimatic tasks specified in parts of the SCP. Desert Research Institute has agreed to follow USGS quality-assurance techniques in its studies, enabling USGS to use data collected by Desert Research Institute in its own studies.

Activity 8.3.1.5.1.3.1 - Analysis of pack rat middens. The objective of this activity is to determine nature, timing, duration, and magnitude of past vegetation changes as recorded in plant macrofossil assemblages preserved in pack rat middens.

A large data base that includes data from about 800 fossil pack rat middens has been assembled. Several new collections of middens from the area around Yucca Mountain has been made and that data together with existing data in the midden data base provide the primary structure to our understanding of late Pleistocene climate summarized above.

Activity 8.3.1.5.1.3.2 - Analysis of pollen samples. The objective of this activity is to determine the nature, timing, duration, and magnitude of past vegetation change as recorded in the stratigraphic record of fossil pollen grains.

Pollen studies and sampling of the new cores from the Pahranagat Marshes within the interval from about 2 ka to nearly 6 ka are in progress. Those data, together with the completed analyses for the last 2 ka, are expected to provide the information about middle Holocene to present day climate variability.

Activity 8.3.1.5.1.3.3 - Determination of vegetation-climate relationships. The objective of this activity is to translate vegetational records provided by pack rat midden and palynological activities and available dendroclimatological data into quantitative estimates of past climatic variables.

Initial findings of the activities in Study 8.3.1.5.1.3 (Terrestrial Paleoecology) have been integrated with those of Study 8.3.1.5.1.2 (Lake, Playa, and Marshes) to form preliminary interpretations of Pleistocene climate changes. They are discussed under Study 8.3.1.5.1.2.

Forecast: The pollen data base from the Pahranagat Marshes will be extended back in time. Pollen data presently exist for the last 2,000 radiocarbon yr and core exists to at least 5,600 radiocarbon yr ago. Similarly selected samples from the core will be radiocarbon dated to refine the existing chronology. A detailed tree record of climate exists for the last 9,000 yr. The study of the Pahranagat Marshes provides a way for the climate program to turn climate expressed as tree ring variations into climate expressed as surface- and near-surface-water change during the Holocene.

Wood samples from packrat midden samples collected in southern Nevada will be radiocarbon dated by the accelerator mass spectrometry technique. Presently over 60 samples are ready to be dated.

3.4.4 Study 8.3.1.5.1.4 - Analysis of the Paleoenvironmental History of the Yucca Mountain Region

The objectives of this study are to evaluate the paleoenvironmental record at Yucca Mountain and surroundings in light of inferred paleoclimate history of the southern Great Basin; to provide information to distinguish the effects of surficial processes from those of tectonic activity, based on the character and distribution of surficial deposits; and to evaluate the age of tectonic events.

Because of the need for defensible numerical ages for Quaternary deposits, a proposal to provide a comprehensive and integrated geochronological investigation of surficial deposits was submitted to DOE. The lack of calibrated materials and the application of nonstandard dating techniques in the past is a distinct problem in evaluating the existing ages used to estimate erosion rates, faulting kinetics, and climate-influenced sedimentation and soil-forming processes. The proposal was developed as a collaborative effort between USGS and LBL geochronologists, and USGS Quaternary geologists with input from DOE as to the Program needs.

A primary goal of this work is to apply a broader range of geochronological techniques most likely to provide useful data (uranium-series disequilibrium, luminescence, cosmogenic nuclide, tephrochronology, and radiocarbon methods) to several well-characterized Quaternary deposit profiles. The numerical dating results will be evaluated on the basis of both internal consistency checks using stratigraphic and geologic controls, and on external consistency

checks between different independent chronometers applied to the same deposits. Sites will be chosen on the basis of representing important surface deposits and considering the materials available for dating at each site. Data on the physical properties of the soils at each of the sites will also be collected. A longer-term goal of this investigation is to evaluate the reliability of assuming an age for a surficial deposit based solely on its physical morphology.

Activity 8.3.1.5.1.4.1 - Modeling of soil properties in the Yucca Mountain region. The objectives of this activity are (a) to determine the relations among properties of late Holocene soils and climatic parameters; (b) to compare properties of selected soils at Pahute Mesa and near Tonopah that formed under conditions similar to those that may have existed at Yucca Mountain during Pleistocene pluvial conditions; (c) to compare postulated past climates based on properties of early Holocene and Pleistocene soils to paleoclimatic models that are reconstructed from other lines of evidence, such as paleolimnology and terrestrial paleocology, as a check on these models; (d) to postulate past climates based on the depth, distribution, and quantity of pedogenic carbonate and other soil parameters; and (e) to quantify rates of soil development in specific climates for use as a dating tool for Quaternary deposits and ages of fault movements.

No progress was made during the reporting period; this was an out-year activity.

Activity 8.3.1.5.1.4.2 - Surficial deposits mapping of the Yucca Mountain area. The objectives of this activity are to determine the distribution, age, genesis, soil properties, and physical properties of surficial deposits in the Yucca Mountain area; to evaluate the influences of climate and tectonics on the genesis of surficial deposits; to provide a map of surficial deposits for facility placement planning, geomorphic studies, tectonics studies, engineering property studies, and surface infiltration studies; and to determine the distribution of major concentrations of calcite-silica deposits at or near the ground surface at Yucca Mountain.

Preliminary maps of the surficial deposits of the northwest quarter of the Busted Butte Quadrangle (Lundstrom et al., in prep.[a]) and the southern half of the Topopah Springs NW Quadrangle were approved in February 1995 after response to technical review. After digitization, these maps and an earlier map (Lundstrom et al., in prep.[b]) provided the basis for a 1:24,000 color composite map (Hayes, 1995) of surficial deposits that includes northern and central Yucca Mountain, all of Yucca Wash and Midway Valley, upper areas of Solitario Canyon and Fatigue Wash, and lower Fortymile Canyon. Mapping of southern Yucca Mountain is in progress; a preliminary map of the southern half of the Busted Butte Quadrangle was submitted for technical review in February 1995.

Mapping of surficial deposits is significant to several aspects of the Program Plan. The above composite map (Hayes, 1995) was compiled to be used to answer questions raised by the NRC in their review of the Extreme Erosion Topical Report, as was a report on a debris flow event in 1984 (Coe et al., 1995). Information about the alluvial, colluvial, and eolian deposits depicted on the map is also being used in preparation of the Technical Basis Report for Surface Characteristics, Preclosure Hydrology, and Erosion (DOE, in prep.[a]). The distribution of surficial soils indicated by these maps are being further characterized for hydrologic properties relating to infiltration, and so the surficial deposits mapping is an

important input to the site-scale hydrologic model. Moreover, the surficial deposits of this area provide a record of episodes of alluviation relating to past climate and paleohydrology that provide a basis for considering future climate and hydrology.

A planned three-year accelerated Quaternary dating program to support the Tectonics and Climate programs was started at the beginning of FY 1995 with the objective of building a credible and defensible foundation for applied numerical dating. The dating program entails a comprehensive, multiple-method approach for developing, testing, and applying new analytical and sampling techniques. Specific goals include (a) establishing an age-framework for soil chronosequences, (b) evaluating the reliability of using the dated chronosequences to date surface deposits by correlation, and (c) rigorously assessing the reliability of Quaternary dating techniques. Applied dating at specific trenches and other sites continued as a parallel effort to the developmental studies while recognizing the risk that some of the sampling and analytical approaches might subsequently prove to be inferior as information from the developmental studies accrued.

Techniques used in the developmental studies included mass spectrometric U-series, thermoluminescence, Cl-36, and C-14 methods. The cosmogenic dating studies (Cl-36 and C-14) are being conducted by the Center for Isotope Geochemistry at LBL in collaboration with the USGS. Developmental work during this reporting period emphasized testing and evaluating materials used for dating, including detailed sample examination with a scanning electron microscope, and reduction in sample size to allow higher resolution sampling. The applied geochronology effort was largely conducted by U-series and thermoluminescence methods to (a) constrain the timing of deposit of alluvial units on the east side of Yucca Mountain, (b) establish the rupture history at numerous fault trenches on both the east and west side of Yucca Mountain, and (c) establish the timing of spring activity at paleodischarge sites downgradient from Yucca Mountain. A limited effort was expended on tephro-chronology using both basaltic and rhyolitic ash trapped in fault zones and in alluvial stratigraphy.

Major advances in the developmental phase of the geochronology effort resulted from the transition from alpha-counting to thermal ionization mass spectrometry in the U-series work. This has allowed sample sizes to be reduced by one to two orders of magnitude and sampling at a much finer scale. The second major advance resulted from investigations of high-uranium and/or low-thorium pedogenic opaline silica and calcified plant remains. It was demonstrated that stratigraphically coherent ages could be obtained from opaline silica deposits. The generally high-uranium contents of opal also allows for sample-size reduction and higher resolution sampling. With these materials, an age can be determined from a single analysis in contrast to the previously used technique involving the leach-residue approach.

In thermoluminescence dating, new sampling techniques have been successfully applied to materials that could not be sampled by conventional methods. Anomalous fading and sunlight sensitivity experiments have been refined to assess the reliability of data, and a suite of zero-age samples from both eolian and fluvial depositional environments were collected and analyzed to assess the rate of the natural resetting process. In addition to these zero-age tests, several suites of replicate samples have been collected to test reproducibility of the total

and partial bleach methods. Thermoluminescence dating continues to provide internally consistent data on fine-grained detrital materials and ages that are consistent with U-series ages.

On the east side of Yucca Mountain (Coyote Wash, Midway Valley, and Fortymile Wash), samples for thermoluminescence and U-series dating were collected from surface and buried soils to constrain the timing of deposition of the youngest major alluvial map unit, as well as to constrain the age of alluvium associated with the highest terrace of lower Fortymile Wash, a major geomorphic datum in the region. Soils from these sites have also been sampled for particle size and carbonate content to understand rates and processes of soil development calibrated by geochronologic results. Trenches (CF-1, CF-2, and CF-3) on the west side of Yucca Mountain in Crater Flat were sampled for thermoluminescence, U-series, and cosmogenic dating to establish the timing of rupture events.

Activity 8.3.1.5.1.4.3 - Eolian history of the Yucca Mountain region. The objectives of this activity are to document eolian erosion and deposition in the Yucca Mountain area during the last 750,000 yr; to determine paleoenvironmental conditions during times of eolian deposition and intervening times of surface stability and soil formation; and to determine source areas of sand and silt.

No progress was made during the reporting period; this was an out-year activity.

Forecast: Mapping will continue in the adjoining central and southern map area, and reports for individual 1:12,000 quadrangles will be submitted for review as mapping is completed. Geochronological and pedological investigations of mapped deposits will continue as necessary to provide critical constraints on geomorphic and tectonic rates and on the responses of the Yucca Mountain landscape to Quaternary climatic changes. A report of a debris flow event in July 1984 will be prepared, and additional age dates obtained, to address NRC questions on the Extreme Erosion Topical Report.

Geochronological work will continue to focus on alluvial and eolian deposits on both the east (Midway Valley and Fortymile Wash) and west (Fatigue Wash fault and Solitario Canyon fault) sides of Yucca Mountain in FY 1995 and explore their hydrologic relation and timing to ground-water discharge sites in the Amargosa Desert to the south. Work planned for the first year will involve experimentation with available materials to establish the most reliable analytical techniques applicable to each of the dating methods. Data collected in this period will be evaluated to determine which of these dating methods provides useful information and whether each method is worth pursuing in the future. Dating results and soil property data for a limited number of sites will be compiled in the year-end report. The second stage of data collection (FY 1996) will broaden the study to additional sites in the southern Yucca Mountain area. This work will focus on testing the reliability of correlating soil morphology and depositional age at different sites influenced by a variety of soil-forming factors.

3.4.5 Study 8.3.1.5.1.5 - Paleoclimate-Paleoenvironmental Synthesis

The objectives of this study are to compare paleoclimatic estimates from the various proxy data sets and to provide data syntheses in the formats required for future climate and paleohydrology investigations.

Activity 8.3.1.5.1.5.1 - Paleoclimate-paleoenvironmental synthesis. The objective of this activity is to provide summaries of the paleoclimatic data in formats that can be used by investigations of future climatic changes and paleohydrology.

No progress was made during the reporting period; this was an out-year study.

Forecast: The synthesis will be started and preliminary synthesis is scheduled to be completed in the second half of FY 1995.

3.4.6 Study 8.3.1.5.1.6 - Characterization of the Future Regional Climate and Environments

The objective of this study is to estimate key climate parameters, including precipitation, temperature, and evapotranspiration, for the Yucca Mountain area over the next 100,000 yr with special emphasis on the next 10,000 yr.

Activity 8.3.1.5.1.6.1 - Global climate modeling. The objective of this activity is to provide boundary-condition data for regional climate models for a selected set of climate scenarios that may occur during the next 100,000 yr.

The life cycle plan for the GENESIS Atmospheric General Circulation Model was prepared and approved. Efforts may now begin on establishing a QA software baseline for the code.

Activity 8.3.1.5.1.6.2 - Nested global-regional climate modeling. The objective of this activity is to embed higher-resolution regional climate modeling within global climate modeling and couple with soil-physics-hydrology model to develop capability to predict future climatic-induced conditions and net infiltration in the Yucca Mountain area.

Detailed analysis of the preliminary validation run of the regional climate modeling code, RegCM2, indicated a few problems needing correction before continuing. The software baseline was modified as specified in Software Change Requests. After making modifications and minor enhancements, the model was ported to an SGI Power Challenge work station, enabling the longer runs needed to establish a climatology scenario.

After the new current-climate analysis is completed with the modified RegCM2 code, the software baseline for the GENESIS Atmospheric General Circulation Model will be established. At that point, nested runs of the GENESIS - RegCM2 package can proceed.

Activity 8.3.1.5.1.6.3 - Site-specific model output adjustment. The objective of this activity is to predict climatic parameters such as precipitation, soil moisture, and net-infiltration rates for several possible future-climate scenarios at Yucca Mountain.

A summary of techniques for transforming regional climate model outputs was in YMSCO review (Church et al., in prep.). The results indicate that the technique known as Climatological Projection by Model Statistics appears to be the most promising semi-empirical approach for transforming regional-scale model output to the local scale of Yucca Mountain.

Activity 8.3.1.5.1.6.4 - Future climate synthesis. The objective of this activity is to analyze time-series data of climatic variability based on the paleoclimatic record to identify possible future scenarios of concern that may occur during the next 100,000 yr.

No progress was made during the reporting period; this was an out-year activity.

Forecast: The follow-up analysis of the current-climate RegCM2 will be completed. Baselining the GENESIS code will be completed, then validated, and nesting runs of the two codes will be performed for current- and paleo-climate conditions in preparation for developing reference local climate scenarios. Documentation reports on these activities and their results and analyses will be produced. Other reports identifying bounding future climate conditions, and detail of approach to synthesizing future climate scenarios are also forthcoming.

3.4.7 Study 8.3.1.5.2.1 - Characterization of the Quaternary Regional Hydrology

The objective of this study is to characterize the distribution of surface water, the unsaturated zone infiltration and percolation rates, and the ground-water potentiometric levels during the Quaternary Period in the vicinity of Yucca Mountain.

Activity 8.3.1.5.2.1.1 - Regional paleoflood evaluation. The objectives of this activity are to identify the locations and investigate the hydraulic characteristics of paleoflood events and compare this evidence with the locations and characteristics of modern flooding and geomorphic processes; and to assess the character and severity of paleoflood and debris hazards and the potential of flood and debris hazards for the repository during the preclosure period.

No progress was made during the reporting period; this was an out-year activity.

Activity 8.3.1.5.2.1.2 - Quaternary unsaturated zone hydrochemical analysis. The objectives of this activity are to determine the past and infiltration percolation history at Yucca Mountain by analyzing the isotopic and chemical characteristics of water from the unsaturated zone; and to understand the past unsaturated-zone hydrologic system by modeling vadose-water hydrochemistry to help predict the future hydrologic system.

No progress was made during the reporting period; this was an out-year activity.

Activity 8.3.1.5.2.1.3 - Evaluation of past discharge areas. The objectives of this activity are to determine the location, type, and extent of hydrogeologic units in the ground-water discharge areas of the Amargosa Desert and Death Valley; to understand the past quantity and quality of water in the discharge areas of Franklin Lake, Amargosa Desert River, and Peter's Playa and to determine the paleohydrologic significance of Peter's Playa and Franklin Lake as discharge areas; to determine the location and hydrogeologic characteristics of paleospring deposits in the discharge area; to determine the location and amount of discharge by evapotranspiration that has occurred at past discharge sites; to understand the past and present discharge areas of the regional hydrologic system to predict the future saturated zone hydrologic system at Yucca Mountain; and to determine past ground-water levels in carbonate caverns as evidence of past hydrologic conditions.

Studies of past discharge areas are important to constraining the possible changes in the hydrodynamics of the saturated zone at Yucca Mountain in the future. These studies indicate higher water-table altitudes by over 100 m throughout the late Pleistocene to as recently as 10,000 to 15,000 yr ago. They also play a role in assessing the contribution of local recharge and associated flow through the repository block, and ultimately may provide a means of assessing travel times to the accessible environment under wetter climate conditions.

A reconnaissance investigation of previously unexamined spring deposits in the Amargosa Desert near the terminus of the Fortymile Wash alluvial fan was accomplished. Two-dimensional hydrologic models have predicted this area as the site of ground-water discharge under conditions of increased recharge in the upper portions of Fortymile Wash that are approximately two times that of the present day. Work done in the present reporting period was oriented toward initially understanding the age and source water for the hydrogenic deposits. In addition, new samples were analyzed from spring-discharge sites near the southern end of Crater Flat to further constrain ages and ground-water sources.

Two sample-collection field trips to the Amargosa Desert, near Stateline, Nevada, and to the Crater Flat sites were made in the first quarter of the fiscal year. The Stateline deposits consist of fine-grained eolian sediments (clays, silts, and sands) with interbedded carbonate-rich materials typical of paleodischarge deposits throughout the region. Two areas of interest were examined, including an incised higher terrace north of the present-day Amargosa River capped with dense limestone (informally named Mesquite Arroyo), and a lower terrace near the level of the Amargosa River consisting of gastropod-bearing unconsolidated brown clays and silts. Samples were collected for geochronology (U-series disequilibrium, thermoluminescence, radiocarbon), isotope geochemistry (strontium, oxygen, carbon), and paleontology (ostracods). Stable carbon and oxygen isotopic compositions from green and gray silts are similar to paleo marsh and pond deposits found elsewhere in the region. Oxygen and carbon isotopic compositions from carbonates within these high terrace deposits are intermediate between values observed in paleo marsh and pond deposits and pedogenic calcrete. In contrast, uranium and strontium isotopic compositions of these carbonates are uniquely diagnostic of a discharging ground-water source similar to isotopic compositions measured from present-day ground waters sampled immediately north in the

Amargosa Farms area. Strontium concentrations and isotopic compositions also are distinct from the Tertiary bedded lacustrine limestones cropping out in the immediate vicinity. Uranium-series disequilibrium ages of opaline silica and carbonate deposits in the high terrace indicate that discharge spanned a time-period from at least 100 ka to 30 ka although a detailed history is not currently known. Terrestrial snail shells from the brown silt deposits near the Amargosa River have radiocarbon ages of about 9,100 ka. Uranium-series disequilibrium data from aquatic snail shells from the same deposit yields an analytically identical age and an initial U-234/U-238 indicative of a regional ground-water source. In addition to isotopic data, the abundance of opaline silica in the high terrace deposits suggests that silica-rich waters in the Fortymile Wash ground-water system draining the volcanic rocks to the north were responsible for paleodischarge. Thermoluminescence age-dating from the same deposits is in progress.

Deposits near the southern end of Crater Flat were also sampled and analyzed for stable and radiogenic isotopes. Stable carbon and oxygen isotope compositions are similar to marsh and pond deposits having a ground-water source. Uranium-series isotopes provide additional support of previously reported latest late Pleistocene ages, including the first date from a deposit containing root casts and other fossil plant material (informally referred to as "root cast deposit") of 15 ka. Initial uranium ratios for these young rhizoliths is higher than most values measured from the regional Paleozoic aquifers, and is more consistent with values observed in the shallow parts of the volcanic aquifers. These results may imply that recharge through Yucca Mountain may have provided a component of the discharge. The presence of abundant anthropogenic artifacts associated with the higher, older-appearing mounds, and the lack of artifacts in the lower, younger-appearing mounds may be related to the possibility of wet ground occurring into the early Holocene. These sites are critical to establishing fluctuations in the water-table altitudes throughout the late Pleistocene. They may also help constrain paleo ground-water flow paths which may be very different under wetter conditions than those at present, especially if Yucca Mountain represents a local recharge source.

A carbonate mound located immediately north of Highway 95 in Rock Valley, along with bedded limestone just south of the highway, yield stable carbon and oxygen isotopes that are consistent with ground-water discharge. They are currently mapped as Tertiary lacustrine limestone. Calcite $\delta^{13}C$ and $\delta^{18}O$ values describe a trend of compositions nearly identical to those observed at Nevares Spring in Death Valley. Petrographic textures between the Rock Valley and Nevares deposits are also strikingly similar. The Rock Valley carbonate mound deposits have not yet been dated.

Carbonate deposits from Pahroc Spring also were analyzed for stable carbon and oxygen isotopes. The active spring probably represents discharge from a perched-water zone within the southwestern portion of the Pahroc Range. Lithologies are dominated by volcanic tuffs, and the annual precipitation is about twice that observed at Yucca Mountain. Therefore, this system may serve to approximate an analog for Yucca Mountain hydrology during wetter climate episodes. Measured $\delta^{13}C$ and $\delta^{18}O$ values of carbonate crusts on fractures near the spring are consistent with dissolution of pedogenic carbonate during highland recharge and transport through the tuffs to the spring site.

Activity 8.3.1.5.2.1.4 - Analog recharge studies. The objective of this activity is to estimate the conditions and rates of ground-water recharge (infiltration) during the Quaternary Period in the vicinity of Yucca Mountain.

No progress was made during this reporting period; this was an unfunded activity.

Activity 8.3.1.5.2.1.5 - Studies of calcite and opaline silica vein deposits. The objective of this activity is to determine the ages, distribution, origin, and paleohydrologic significance of calcite and opaline silica deposits along faults and fractures in the vicinity of Yucca Mountain.

Cathodluminescence petrographic capabilities are now in place. Cathodluminescence provides a valuable tool for determining the petrogenesis of secondary minerals and is being heavily used in studies of the growth-banding and depositional history of secondary calcite and opal within the unsaturated zone of Yucca Mountain. Secondary calcite and opal record the $\delta^{13}C$ and $\delta^{18}O$ of unsaturated zone fluids, and as such provide a record of the hydrologic response of the unsaturated zone to climate changes in the past. Cathodluminescence is also being used in studies of past discharge.

About a dozen samples collected from the ESF show some promise for climate reconstruction, although their depositional ages have not been determined. The much larger volumes of secondary opal and calcite obtainable from fracture mineralization exposed in the ESF will facilitate U/Th geochronologic studies and will provide adequate material for detailed stable isotope analysis for climatic/hydrologic reconstructions.

Preliminary studies of silica minerals (opal, quartz, and chalcedony) within Yucca Mountain were presented at the Fall Meeting of the Geological Society of America (Moscati and Whelan, 1994). Several important inferences from this data follow:

1. Pedogenic (soil) opal $\delta^{18}O$ values from Trench 14 indicate that opal precipitated at ambient temperatures, but from soil-zone meteoric waters of somewhat variable $\delta^{18}O$ values, perhaps reflecting ^{18}O-enrichment during evaporation.

2. Calcite and opal $\delta^{18}O$ values from both pedogenic and unsaturated zone settings indicate they formed from similar but not identical fluids. Probably different climate/plant community settings controlled the chemistry of the soil zone fluids, and, as a result, the chemistry of fluids infiltrating into the unsaturated zone.

3. Petrographic evidence suggests that most (but not all) of the calcite and opal precipitated independently of each other (i.e., they did not generally coprecipitate) and are, therefore, not suitable for mineral-mineral O-isotope paleotemperature determinations.

These findings are discussed more fully in Moscati and Whelan (in prep.). The conclusions drawn are that the different fluid chemistries of pedogenic calcite and opal likely reflect different climate states, and consequently, that opal may provide an easily datable (by

the uranium/thorium method) secondary phase in paleosols and in the unsaturated zone that records major climate transitions.

Monitoring of soil gas arrays and collection of soil moisture samples at the Amargosa Desert, Breakbone Ridge, Fortymile Wash, Fran Ridge, Holmes Road, and top of Rainier Mesa sites took place during the months of October, December, January, February, and March. The unusually heavy amounts of precipitation during December and January will provide an important "end-member" for the study (McConnaughey et al., 1994).

Investigation of existing computer codes for the modeling of soil fluid and gas chemistry indicates that the codes provide excellent starting points, but will require modification. This modeling will seek to define the "transfer functions" between climate processes and the resulting responses of soil zone geochemistry/mineralogy and plant ecology that control the chemistry (Eh, pH, salinity, etc.) of waters infiltrating the unsaturated zone of Yucca Mountain. Geochronologic studies tying discrete soil zone and unsaturated zone mineral assemblages to defined climate states should provide the compositional bounds for modeling the relationships between climate and unsaturated zone hydrochemistry.

Secondary calcite and opaline silica in veins and fractures represent a record of past water movement within Yucca Mountain and a proxy record of past climate variations at the mountain. Twenty secondary mineral occurrences sampled from depths of 30 to 122 m (100 to 4,400 ft) in Boreholes UE-25 a#1, UE-25 a#5, UE-25 a#6, and UE-25 a#7, and UE-25 UZ#16, USW G-1, USW G-2, USW G-3/GU-3, and USW G-4 resulted in 35 analyses. Acid leaching experiments were performed to test the suitability of opal as a uranium-series geochronometer. These experiments indicated that the fracture-coating opals have behaved as closed systems for at least the past 500 ka. High uranium concentrations in the opals (ranging from 10 to 350 ppm) permit analysis of opal samples as small as several milligrams. This greatly increases the number of datable occurrences from the boreholes and permits detailed geochronologic study of the thicker occurrences. The ages obtained range from 170 ka to more than 500 ka, with an average value of 300 ±60 ka. Published data from both radiocarbon and uranium-series studies suggest that Yucca Mountain hosts younger secondary mineralization.

Forecast: Reconnaissance investigations prove the relevance of further study of these deposits to issues of site suitability under wetter climate conditions. Higher water-table levels are apparent, but a detailed discharge history that links the timing of discharge to surface-water records is still needed. Ultimately, it will be necessary to understand what specific conditions are required to prompt water table fluctuations, how long these conditions must be maintained, and how rapidly the hydrologic system responds to climate variations. Additional knowledge of present ground-water altitudes and compositions are needed for comparisons with paleo spring data.

To construct a more elaborate discharge history, detailed stratigraphic and sediment data are needed in the form of small-scale maps for the most exposed portions of the deposits near Crater Flat and Stateline, Nevada. These maps will allow the identification of the areas of greatest potential for elaborating the history of discharge so that further concentrated

geochronological, geochemical, and paleontological studies are possible. Mapping activities should commence as soon as possible (late spring, early summer) so that maps, archaeological surveys and surface-disturbing permits can be obtained in FY 1996. These geological surveys will identify a minimum of two surface trenches at each of four sites (Crater Flat, Horse Tooth, Root Cast, and Stateline) required for further detailed studies. In addition, the paucity of hydrochemical data in Crater Flat does not allow accurate modeling of water-table altitudes or flow-path identification.

Reports will be prepared detailing the progress of studies of (a) the responses of soil fluids and gases to varying climate conditions, (b) the hydrologic record of the unsaturated zone from secondary minerals, and (c) uranium/thorium and C-14 dating of unsaturated zone calcite and opaline silica.

Collection of stable carbon and oxygen compositions from unsaturated zone calcite will continue on samples from the drilling program and from the ESF. Comprehensive studies will be undertaken on those occurrences that uranium/thorium disequilibria and/or C-14 dating indicate formed largely within the past 100 ka.

Thirty to fifty samples of silica occurrences have been collected or requested from drill core or the ESF. These samples will be used to better define the hydrogeologic environments of silica formation, from the soil zone to the deep saturated zone, through determination of their oxygen-isotopic compositions. In collaboration with Project mineralogists, the postulated formation of quartz from trydimite during saturated conditions (i.e., below the water table) will be tested. Should this theory be verified, it may provide a further tool for reconstructing past water-table altitudes.

Soil-gas arrays and moisture contents will continue to be monitored, probably through FY 1996. Computer codes for modeling of soil gas/fluid geochemistry will be tested and desired modifications defined. This modeling exercise is not specifically funded for FY 1995; however, efforts will be made to begin this fiscal year, hopefully providing some meaningful results during FY 1996.

Uranium/thorium and C-14 dating of vein calcite and opal will continue on samples from both the consolidated drilling program and from the ESF, and on pedogenic calcite and opal from paleosols and trench materials. The dating will focus on reconnaissance sampling to establish a chronology of secondary mineralization and to provide a space-time framework of fracture flow within the unsaturated zone at Yucca Mountain. Provisional data from dating of mammillary calcite draping open fractures at the Sterling Mine (Bare Mountain) indicates that some of this material is young (~5 to 10 ka). As time permits, this potentially valuable paleoclimate proxy will be pursued by further sampling and analysis.

3.4.8 Study 8.3.1.5.2.2 - Characterization of the Future Regional Hydrology Due to Climate Changes

The objective of this study is to characterize impacts of potential future climate changes on site unsaturated zone hydrology and regional and site surface-water system and saturated-zone hydrology.

Activity 8.3.1.5.2.2.1 - Analysis of future surface-water hydrology due to climate changes. The objectives of this activity are to simulate past changes in runoff and surface-water storage (lakes) resulting from past climatic change; and to use the relationship between paleoclimate and paleosurface-water conditions to predict the impact of future climatic conditions on the surface-water hydrology at the site.

No progress was made during the reporting period; this was an out-year activity.

Activity 8.3.1.5.2.2.2 - Analysis of future unsaturated zone hydrology due to climate changes. As reported in Site Characterization Program Baseline, Revision 9, this activity has been deleted; the scope of work for this activity will be performed in Activity 8.3.1.2.2.9.5.

No progress was made during the reporting period; this was an out-year activity.

Activity 8.3.1.5.2.2.3 - Evaluation of possible future changes of the climate and regional geologic framework on the regional saturated zone hydrology. The objectives of this activity are to reconstruct paleohydrologic conditions at Yucca Mountain and use these conditions together with the paleoclimatic conditions reconstructed as a basis to predict the impact of future climatic conditions on the saturated-zone hydrologic system; to synthesize the existing paleohydrologic data through the use of numerical simulation techniques to determine effects that greater recharge would have on water-table altitude, ground-water flow paths, and hydraulic gradients between Yucca Mountain and the accessible environment; and to evaluate possible regional tectonic and thermal events that may produce prolonged or transient effects on the regional water level.

No progress was made during the reporting period; this was an out-year activity.

Forecast: No activity is planned for FY 1995.

3.5 EROSION (SCP SECTION 8.3.1.6)

The objective of this program is to obtain the site-specific data needed to calculate average Quaternary hillslope erosion rates and accurate average short-term erosion rates associated with episodic erosion; estimate the potential effects of future climate on locations and rates of erosion; estimate the potential effects of future tectonic activity on locations and rates of erosion; and produce a topical report to address the possibility that erosional processes at Yucca Mountain could adversely affect the potential for radionuclide releases to the accessible environment.

This work is completed. As a result of the study plan work scope consolidation effort, no study plans will be developed in this program. A topical report was submitted to NRC for comment; nine comments were received. A plan, involving minimal new work, has been developed to provide supplemental responses to the NRC comments. Any additional work needed to provide the supplemental responses will be performed under Study Plan 8.3.1.5.1.4, "Analysis of the Paleoenvironmental History of the Yucca Mountain Region," under its existing work scope.

Forecast: Supplemental responses to the NRC comments are planned for the second half of FY 1995. The Site Design and Test Requirements Document will be revised to delete this program.

3.6 POSTCLOSURE TECTONICS (SCP SECTION 8.3.1.8)

3.6.1 Study 8.3.1.8.1.1 - Probability of Magmatic Disruption of the Repository

The objective of this study is to assess the probability of future magmatic activity with respect to siting of a potential repository for the storage of high-level radioactive waste at Yucca Mountain.

Activity 8.3.1.8.1.1.1 - Location and timing of volcanic events. The objective of this activity is to synthesize the data collected by other activities on the dating, location, and volume of late Cenozoic volcanic events in the region surrounding the site.

A procedure on locating volcanic features using the Garmin global positioning survey instrument was completed. The instrument is being used to obtain latitude, longitude, and altitude data for volcanic features in the Yucca Mountain Region. These data will be compiled and used in revised probability assessments. This activity is not funded in FY 1995. The procedure was prepared in anticipation of funding of the activity in FY 1996.

Activity 8.3.1.8.1.1.2 - Evaluation of the structural controls of basaltic volcanic activity. The objective of this activity is to investigate the time-space patterns of past volcanic activity in the Yucca Mountain region and the possible structural controls of volcanic centers and potential future centers at and adjacent to Yucca Mountain.

A review of tectonic models and geophysical data for the Yucca Mountain region was published (Crowe et al., 1995). Chapter 7 of Crowe et al. (1995) contains tables of 42 spatial and structural models for the distribution of basaltic volcanic activity in the Yucca Mountain region. These tables provided the basis for a revised probabilistic assessment of magmatic disruption of the potential repository, the controlled area, and the Yucca Mountain region. A contract was established for simulation modeling of "disruption of the potential repository" using multiple sets of spatial and structural models.

Activity 8.3.1.8.1.1.3 - Presence of magma bodies in the vicinity of the site. The objective of this activity is to review geophysical and geochemical data collected in the

vicinity of the site to assess whether there are any indications of the presence of crustal magma bodies that could be the source of future volcanic activity.

Paleomagnetic data were collected for the older basalt of Crater Flat and the basalt dike of Solitario Canyon. Data from these samples will be used to test the detectability of basalt intrusions using magnetic methods. Data collection was completed and results regarding the interpretation of geophysical data with respect to the presence of a low velocity teleseismic zone that could represent partial melt were published (Crowe et al., 1995). The authors concluded that further assessment of the significance of the low-velocity zone will depend on the interpreted results of the deep seismic reflection/refraction experiment and acquired data from the upgraded seismic net.

Activity 8.3.1.8.1.1.4 - Probability calculations and assessment. The objective of this activity is to revise the estimates of the probability of volcanic disruption of a repository site at Yucca Mountain incorporating newly acquired data on the age, location, and volume of volcanic centers in the Nevada Test Site region and the results from activities investigating the possibility of structural controls of sites of volcanic activity and the presence of magma bodies in the Yucca Mountain area. These data may result in modifications of the area ratio and the rate of volcanic activity used in the probability formula.

The first formal revision of probabilistic volcanic hazard assessment using the methodology presented in Study Plan 8.3.1.8.1.1, "Probability of Magmatic Disruption of the Repository," was published (Crowe et al., 1995). Project volcanologists presented several talks at the first meeting of the Expert Judgment Panel on Volcanism in Phoenix, Arizona, February 22-23, 1995. The purpose of this panel is to independently estimate the recurrence and intersection probability of volcanism at the Yucca Mountain site.

Forecast: Alternative structural models for the distribution of past basaltic centers will be developed. These models will be used to constrain probability ranges of E2 and stochastic and simulation modeling of spatial and structural models of E2 will be performed at the Yucca Mountain site. Data from field geologic studies and from aspects of the tectonics programs (seismicity, geophysical studies, studies of Quaternary faulting and fault systems, and the evaluation of tectonic models) will be used. Review of the geophysical data for the Yucca Mountain region will continue, as will evaluation to determine if it is sufficiently comprehensive to allow adequate evaluation of the presence of magma bodies in the region. If there is evidence of the presence of significant subsurface magma in the Yucca Mountain region, detailed plans will be developed for evaluating the existence and location of magma using geophysical data. Modeling of aeromagnetic data will be implemented to assess the issue of detectability of igneous intrusions. Refined methods and calculations of the first two parameters of the three-part probability calculation will be developed. An iterative approach using multiple alternative models for establishing the recurrence rate of volcanic events (El), similar to the approach used for establishing E2 will be used. The first iteration of a data matrix of recurrence calculations has been completed (April 1992) using homogeneous and nonhomogeneous Poisson recurrence models, and refinement of these calculations has continued since then. Data will continue to be gathered for the final report on the probability of magmatic disruption of the repository, which is due in FY 1997. The probability of

magmatic disruption at the repository will be calculated assuming a polygenetic model for volcanism. Work in this study will also be evaluated in the Expert Judgment Report, due in late FY 1996.

3.6.2 Study 8.3.1.8.1.2 - Physical Processes of Magmatism and Effects on the Repository

The objective of this study is to gather data on the potential effects of magmatic activity on the proposed repository. The data will be used to assess the consequences of such an eruption on repository performance.

Activity 8.3.1.8.1.2.1 - Eruptive effects. The objective of this activity is to summarize the effects of hydrovolcanic and Strombolian eruptions of basaltic magma on a repository. The summary will be available for use in consequence analyses of possible radiological releases.

This activity will quantify the abundance and depth of derivation of lithic fragments in basaltic centers that are similar to the centers at Crater Flat. The lithic data serve as a first order approximation of the amount of repository debris that could be ejected if a basaltic eruption were to penetrate the repository. Project scientists made significant progress during this period. Upper-crustal xenoliths erupted from small-volume basaltic volcanoes of the Lucero volcanic field (west-central New Mexico) were studied to assess the relative importance of various wall-rock entrainment mechanisms during a wide range of eruptive processes, including strongly hydrovolcanic, Strombolian, and effusive processes. These results were presented in Valentine and Groves (in prep.). It was found that the volcanoes erupted through a thick, well-characterized sequence of Paleozoic and lower Mesozoic sedimentary rocks, so that erupted xenoliths can be correlated with sedimentary units and hence depth ranges. It was also found that the abundance of xenoliths from a given subvolcanic unit can be divided by the thickness of the unit to obtain an average entrainment rate (xenolith volume fraction derived per unit depth in the conduit). Shallow (< 510 m) entrainment rates were found to be very sensitive to the degree of hydrovolcanic activity, while deeper entrainment rates were not. Deep entrainment is very sensitive to the mechanical properties of the wallrocks, and in the cases studied here appears to depend mainly on brittle failure related to offshoot dikes and thermal stresses. These results have direct implications for the entrainment of waste packages should the potential repository be intersected during a volcanic eruption. Reconnaissance studies were performed in the San Francisco volcanic field, central Arizona, where the next suite of lithic studies will be performed at four or five selected basaltic centers. Detailed field studies there are scheduled to begin in April 1995.

Activity 8.3.1.8.1.2.2 - Subsurface effects of magmatic activity. The objective of this activity is to evaluate the subsurface effects of emplacement of basalt dikes and intrusive bodies through and adjacent to a potential repository. This study will assess mechanisms of incorporation of waste in magma, the geometry of basalt intrusions, and coupled effects on waste isolation of basalt intrusions through or near a repository.

The purpose of this activity is to assess subsurface processes accompanying small basaltic intrusions and their potential effects on a repository. Both theoretical modeling approaches and field studies at analog intrusive sites are being used. Theoretical considerations of subsurface effects during the reporting period have focused on quantifying the spatial and temporal extent of convective processes resulting from intrusion of magma. This information is used directly in determining the probability of a magmatic event affecting the repository, because it defines the maximum distance an intrusion can be from a repository and still significantly perturb its performance.

Because the potential repository resides in a thick vadose zone where the spatial extent of hydrothermal water circulation is limited, Project scientists initially focused work on convection of pore air that can circulate over much larger scales. Preliminary results will be presented in Auer and Rosenberg (in prep.). The authors began the studies by rederiving the basic equations for convection of dry (no water vapor) air in a porous medium, and reexamining the linear stability analysis for the onset of convection in a porous medium heated from below. The results indicate that the definition of the Rayleigh numbers for air and for water are very similar, although not identical, and that the two critical Rayleigh numbers are numerically the same. The values of the quantities that appear in the Rayleigh number, however, dominate the difference in the temperature gradient needed to cause subsurface air convection and not the magnitude of the critical Rayleigh number. For reasonable values of air and water properties, the critical temperature gradient for the onset of convection in air is ~3000 times greater than for water. While it is easy to convect large volumes of air (air viscosity is orders of magnitude lower than that of water), those volumes of air carry very little energy that is rapidly dissipated by the conduction through the matrix, damping the convective motion.

Project scientists are now conducting finite amplitude numerical studies of air convection in porous media using the flow and transport code FEHM. They are simulating air convection in response to dikes and sills intruded into a homogeneous box of material assumed to have the properties of the potential repository horizon at Yucca Mountain. Complexity in the modeled physics will gradually be increased so that eventually modeling can be combined with field studies at analog sites.

One of the analog sites at which Project scientists are conducting field studies is Paiute Ridge, located about 40 km northeast of Yucca Mountain. Paiute Ridge is characterized by dikes, small sills, and conduit plugs, representing the shallow (100 to 200 m depth) intrusive plumbing for a small volume volcanic center. Because of erosion and faulting, only a small part of the eruptive lavas and scoria remain. The intrusions are alkali basalts in composition, about 8.6 Ma old, and were emplaced into country rocks consisting of bedded, variably zeolitized silicic tuffs. Although these tuffs are mapped as belonging to the same formation as the tuffs that may actually host the potential repository, they are most analogous in their characteristics to units such as the Calico Hills Formation, one of the main geochemically retarding units beneath the potential repository horizon at Yucca Mountain. Project scientists are performing geologic, mineralogical, and geochemical investigations to characterize the nature and extent of alteration of tuffs around the basaltic intrusions. Zeolite-rich tuffs are characterized by low-temperature alteration minerals. For example, the upper stability limit

for alteration minerals such as clinoptilolite, smectite, and opal that are common in zeolite-rich altered tuffs is generally about 100°C. The effect of the dike and sill intrusions on the zeolite-rich tuffs will be investigated using petrographic, mineralogical, and geochemical studies.

The second analog site is Grants Ridge, in western New Mexico. Here a basaltic cinder cone erupted through a thick sequence of unaltered rhyolite tuffs and some volcaniclastic sediments. Since formation of the cinder cone, at 2.6 Ma, erosion processes have dissected the cone so that a natural cross section is now exposed in a canyon wall. The exposure not only includes the interior of the cone itself, but the lava plug that formed in the feeder conduit, from the original (pre-basalt) land surface down to about 100 m depth. Scientists are characterizing the rhyolite tuff sequence by sampling at regular distances away from the intrusive plug. Thermal and degassing effects are generally more pronounced along the contact zone. Alteration minerals will be described and identified using petrographic methods and x-ray diffraction. Thermal and degassing effects on the host rock at proximal and distal points will be compared and contrasted to determine the degree of geochemical mobilization during hydrothermal processes related to the basaltic intrusion.

Activity 8.3.1.8.1.2.3 - Magma system dynamics. The objectives of this activity are to evaluate the dynamics of basaltic magmatism including tracing the processes of formation of basalt magma through generation in the mantle, ascent through the mantle and crust, potential storage in the mantle and crust, and eruption at the earth's surface. Physically and mathematically based models of basaltic processes will be developed as a framework for a process-based assessment of the effects of basaltic magmatic activity on a repository.

Project scientists developed conceptual models for the melting process in the magma source region and the migration of melt into deep magma chambers. This has involved literature surveys on such topics as the spatial scale of mineralogical heterogeneities in the mantle.

Forecast: Studies of xenolith entrainment (as an analog for repository waste entrainment) at small basaltic centers will continue. Data will be gathered at the volcanoes of the Crater Flat volcanic field near Yucca Mountain, and scoria cones, maars, and lava flows from selected centers in the San Francisco volcanic field (Arizona). Results will be incorporated into probabilistic risk calculations. Work will continue on the subsurface effects of intrusion of magma at or near a potential repository. Modeling studies will focus on determining the maximum spatial and temporal extent of hydrothermal (including vapor phase) circulation. This will include three-dimensional calculations with Yucca Mountain geometry and hydrologic properties, and a range of intrusion geometries. Modeling studies directed at understanding field data from analog sites will continue. Field studies will concentrate on intrusion-induced variations in mechanical and mineralogical properties of tuff host rocks. Work will continue on tying geochemical, isotopic, petrologic, geophysical, and geochronological data for Pliocene-Quaternary magmatism in the Yucca Mountain region with existing theoretical models of melt segregation, ascent, storage, and eruption.

3.6.3 Study 8.3.1.8.2.1 - Tectonic Effects: Evaluations of Changes in the Natural and Engineered Barrier Systems Resulting from Tectonic Processes and Events

The objective of this study is to assess the probability and effects of tectonic processes and events that could result in adverse effects on waste package lifetime, average percolation flux rate over the repository, elevation of the water table, local fracture permeability, effective porosity, and rock geochemical properties.

The study plan and Site Characterization Program Baseline were revised to combine Investigations 8.3.1.8.2, 8.3.1.8.3, and 8.3.1.8.4 into one investigation (8.3.1.8.2), one study (8.3.1.8.2.1), and five activities (listed below, corresponding to the five studies formerly included in the three investigations). This work was consolidated because much of the work assigned in the SCP to these investigations duplicated work in other studies. The remaining work was sufficiently closely related and limited in scope that the planned work elements and the designated objectives and parameters could logically and appropriately be integrated.

As part of the study plan consolidation effort, work scope associated with Study 8.3.1.8.5.3, "Investigation of Folds in Miocene and Younger Rocks of Region," will be transferred to this study. The work will contribute to assessing the tectonic processes affecting Yucca Mountain.

Activity 8.3.1.8.2.1.1 - Analysis of waste package rupture due to tectonic processes and events. The objective of this activity is to collect and synthesize data that can be used to assess the probability and effects of tectonic processes and events that could result in adverse impacts on waste package lifetime and performance.

No progress was made during the reporting period; this was an unfunded activity.

Activity 8.3.1.8.2.1.2 - Analysis of the effects of tectonic processes and events on average percolation flux rates over the repository. The objective of this activity is to analyze and assess the probability and effects of tectonic initiating events that may result in changes in the average percolation flux rate at the top of the Topopah Spring welded unit.

No progress was made during the reporting period; this was an unfunded activity.

Activity 8.3.1.8.2.1.3 - Analysis of the effect of tectonic processes and events on changes in water-table elevation. The objective of this activity is to produce analyses and assessments of the probability that tectonic initiating events could result in significant changes in the elevation of the water table, changes in the hydraulic gradient, the creation of discharge points in the controlled area, or the creation of perched aquifers in the controlled area.

Technical staff for the computer modeling part of this activity were hired, and scoping studies were initiated to evaluate potential tectonic effects. Preliminary (scoping) computer modeling was started.

Activity 8.3.1.8.2.1.4 - Analysis of the effects of tectonic processes and events on local fracture permeability and effective porosity. The objective of this activity is to address possible changes in fracture permeability and effective porosity caused by tectonic events and processes.

No progress was made during the reporting period; this was an unfunded activity.

Activity 8.3.1.8.2.1.5 - Analysis of the effects of tectonic processes and events on rock geochemical properties. The objective of this activity is to provide assessments of the initiating events related to local changes in distribution coefficients resulting from tectonic processes and events.

No progress was made during the reporting period; this was an unfunded activity.

Forecast: Computer modeling of the effects of tectonic processes on the hydrologic system at Yucca Mountain will be conducted.

3.6.4 Study 8.3.1.8.3.1 - Analysis of the Effects of Tectonic Processes and Events on Average Percolation Flux Rates Over the Repository

This study has been combined with Study 8.3.1.8.2.1.

3.6.5 Study 8.3.1.8.3.2 - Analysis of the Effects of Tectonic Processes and Events on Changes in Water-Table Elevation

This study has been combined with Study 8.3.1.8.2.1.

3.6.6 Study 8.3.1.8.3.3 - Analysis of the Effects of Tectonic Processes and Events on Local Fracture Permeability and Effective Porosity

This study has been combined with Study 8.3.1.8.2.1.

3.6.7 Study 8.3.1.8.4.1 - Analysis of the Effects of Tectonic Processes and Events on Rock Geochemical Properties

This study has been combined with Study 8.3.1.8.2.1.

3.6.8 Study 8.3.1.8.5.1 - Characterization of Volcanic Features

The objective of this study is to provide refined data on the age, location, eruptive models, and volume of young volcanic rocks in the vicinity of the site. These data will be

used to refine the calculations on the probability of igneous or volcanic events occurring in the controlled area and penetrating the repository.

Activity 8.3.1.8.5.1.1 - Volcanism drillholes. The objective of this activity is to investigate the origin of four or five aeromagnetic anomalies found in Crater Flat and the Amargosa Valley. Data from this work will be used to refine probability calculations, to evaluate the tectonic setting of volcanic centers, and to test concepts of the temporal and geochemical patterns of basalts in the Nevada Test Site region.

No progress was made during the reporting period; this was an unfunded activity.

Activity 8.3.1.8.5.1.2 - Geochronology studies. The objective of this activity is to establish the chronology of basaltic volcanism and the youngest silicic volcanic activity in the Yucca Mountain region. These data will be used to revise the recurrence rate of the volcanic probability calculations and to determine the age of cessation of silicic volcanic activity. Further studies are required for three topics: the age of the Quaternary volcanic events in the Yucca Mountain region; the age and eruption chronology of the youngest (<0.5 ma) volcanic event in the Yucca Mountain area; and the age of the youngest silicic volcanic activity in the region with emphasis on the Black Mountain caldera or young silicic rocks that may be encountered in shallow volcanic drillholes.

Data collection on the geochronology of all post-Miocene eruptive centers continued. These data will be compiled into a final geochronology milestone, "Geochronology of Basaltic Volcanic Centers of the Yucca Mountain Region," due in FY 1996, which will form the geochronology framework for final volcanism probability calculations.

Six samples were collected from the Little Black Peak and Hidden Cone centers at Sleeping Butte for Ar-40/Ar-39 dating. The Ar-40/Ar-39 dates were determined for two whole-rock samples at Buckboard Mesa, three samples at Red Cone, two samples at Little Cones, two samples at Makani Cone, one sample at Black Cone, one sample from Little Black Peak, and one sample from the Pliocene episode in southeast Crater Flat.

Uranium-thorium disequilibria mineral isochrons were finalized for one sample from Little Black Peak and three samples from Lathrop Wells. The uranium-thorium data from Lathrop Wells support the conclusion of significant age differences between eruptive units. The uranium-thorium results are reported in Murrell et al. (in prep.). Results presented in the abstract indicate that lava flows at Lathrop Wells have ages ranging from approximately 130 to 50 ka.

The Ar-40/Ar-39 ages were completed for 6 samples from flow Ql_2 at Lathrop Wells. These results suggest that the flow erupted between ~100 and 60 ka, with the younger age range being the preferred interpretation. Samples were collected from three sites at Lathrop Wells for thermoluminescence dating. These dates will be integrated with thermoluminescence dating in trenched fault exposures near Yucca Mountain.

Geochronology data gathered before May 1994 were published (Crowe et al., 1995).

Activity 8.3.1.8.5.1.3 - Field geologic studies. The objective of this activity is to establish the field geologic relations and the eruptive history of basaltic volcanic centers in the Yucca Mountain region.

Geologic mapping and map compilation continued for the 3.7-million-yr-old basalts of Crater Flat and the 1-million-yr-old basalts of Little Cones and Makani Cone. These data will be combined with geochemical data to constrain the number of magma pulses involved in the formation of each volcanic center. A geologic map of the Lathrop Wells Volcanic Center, showing the distribution of eruptive units from four main eruptive episodes, was published (Figure 2.33 in Crowe et al. 1995).

Activity 8.3.1.8.5.1.4 - Geochemistry of scoria sequences. The objective of this activity is to determine the geochemistry of scoria sequences of different ages at the Lathrop Wells center and older centers in the Crater Flat area. The models will be used to test geologic assumptions made for the probability calculations and the time-space tectonic model for the distribution of basaltic volcanism. In addition, the data on the geochemistry of the scoria sequences will also be used to correlate basaltic ash interbedded in trenches with their correct eruptive source.

Project scientists completed 15 instrumental neutron activation analyses of basaltic ash from Solitario Canyon Fault Trench 8 and Lathrop Wells. These analyses will be used to constrain the identity of basaltic ash found in numerous trenched fault exposures near Yucca Mountain. Identification of the ashes will place constraints on their age and the timing of coupled seismic/volcanism episodes near Yucca Mountain. Sixty three x-ray fluorescence analyses of basalt samples from Sleeping Butte, Black Cone, Red Cone, Little Cones, southeast Crater Flat, Thirsty Mesa, Buckboard Mesa and the Cima volcanic field were completed. These data will be used to model the evolution of basaltic volcanism in the Yucca Mountain region during the last 5 Ma to determine whether volcanism is waxing or waning. A discussion of geochemical data from the Lathrop Wells volcanic center was published in Chapter 4 of Crowe et al. (1995). These data indicate that multiple magma batches were involved in the formation of the Lathrop Wells center (polygenetic volcanism), each representing a discrete episode of dike intrusion into the upper crust.

Activity 8.3.1.8.5.1.5 - Geochemical cycles of basaltic volcanic fields. The objective of this activity is to determine the time-space geochemical variations of the volcanic fields of the southern Great Basin.

Strontium, neodymium, and lead isotopic analyses continued to be gathered for post-Miocene eruptive centers in the Yucca Mountain region. These data, along with major and trace-element data, will be used to constrain the magmatic evolution of the Crater Flat Volcanic Zone, with particular emphasis on determining whether magmatic processes are waxing or waning in the Yucca Mountain region.

Forecast: Ar-40/Ar-39 dating of basalt will be completed for all post-Miocene volcanic centers. Paleomagnetic, geomorphic, and soils analysis will be completed at selected volcanic centers. Trenching of volcanic units will be completed at the Sleeping Butte Centers

and selected volcanic centers in Crater Flat. Maps of all post-Miocene (<5 million yr) centers will be finalized.

Geochemical studies will focus on petrological and isotopic studies of the basalt of Sleeping Butte and the 1 Ma and 3.7 Ma basalt of Crater Flat. Isotopic analyses of strontium, neodymium, and lead will be obtained for these units. Instrumental neutron activation analysis data for a selected suite of trace elements will also be obtained. Major element data will be obtained by x-ray fluorescence. Petrological modeling of the isotopic and geochemical data will be conducted to examine alternative models of basalt petrogenesis. The results of the modeling will be used to test assumptions used in probability calculations. Basaltic ash exposed in fault trenches east and west of Yucca Mountain will be sampled and analyzed for major and trace-element chemistry to correlate these ashes with eruptive episodes at the Lathrop Wells volcanic center. Correlation of these ashes will constrain the timing of major paleoseismic activity near Yucca Mountain.

Integration of geochemical and isotopic data for all post-Miocene volcanic centers in the Yucca Mountain region will continue. Evaluation of evolution of analog volcanic fields in the southwestern United States will continue to determine whether characteristic time-volume-geochemical patterns can be used to predict patterns of future volcanic activity.

3.6.9 Study 8.3.1.8.5.2 - Characterization of Igneous Intrusive Features

The objective of this study is to gather data concerning the presence of thermal anomalies in the area and data on the geochemical and physical effects of intrusions on the surrounding rock. The evidence for the presence or absence of thermal anomalies will be used as part of the evaluation of the presence of significant magma bodies in the area and their relation to the probability of future volcanic events.

Activity 8.3.1.8.5.2.1 - Evaluation of depth of curie temperature isotherm. The objective of this activity was intentionally omitted. The most current evaluation of curie temperature data shows that the technique yields results that are too ambiguous and are at a scale of detection too general to be useful for application at Yucca Mountain.

Activity 8.3.1.8.5.2.2 - Chemical and physical changes around dikes. The objective of this activity was intentionally omitted. Data on the nature and extent of physical changes that may occur in the surrounding tuffs as a result of the intrusion of dikes or sills will be collected under Study 8.3.1.8.1.2 (see Section 3.6.2).

Activity 8.3.1.8.5.2.3 - Heat flow at Yucca Mountain and evaluation of regional ambient heat flow anomalies. The objectives of this activity are to compile and evaluate available heat flow data at and near Yucca Mountain, to assess the need for additional heat flow determinations, to collect additional thermal data from existing and planned drillholes, and to identify and evaluate thermal anomalies.

All sondes, meters, balances, and related logging and laboratory equipment were maintained in a ready state pending opportunities to log existing holes. A horizontal temperature log was carried out in drillhole RBT2 in Alcove #1 of the ESF. The primary purpose of this log was to make a final test of the equipment before logging holes in the Bow Ridge Fault alcove, and to familiarize personnel with working in the ESF. A temperature log in the accessible section of the saturated zone of USW G-2 indicated a continued change in the thermal regime with time, indicating that possibly perched water in the area is being drained from one permeable zone into another, but at a rate that is declining with time. Sass et al. (in prep.) review previously published data and discuss additional insights into the hydrologic implications of thermal data. The report is included as Chapter 8 in the Geophysics White Paper Phase II; see description under Activity 8.3.1.4.2.1.2 in Section 3.3.3.

Forecast: Additional continuous high-resolution temperature logs are planned for the unsaturated zone and for the saturated zone below the present bridge in corehole USW-G2 before pumping tests are made. Horizontal temperature logs in the Bow Ridge fault zone in the ESF will test the null hypothesis that water is not flowing vertically at rates of more than a few centimeters per year. High-resolution, continuous-temperature logs in reconfigured WT holes will test the null hypothesis that there is no infiltration of water in the unsaturated zone outside of identified areas having high-angle faults and fractures. Input will be sought to the engineering plans for USW G-5 and/or USW G-6 to ensure that the nature of the hydrologic boundary between the tuffs and the Paleozoic carbonate aquifers can be characterized with sufficient resolution to identify any potential flow paths.

All work on Activity 8.3.1.8.5.2.3 will continue to be funded and performed within the closely-related Activity 8.3.1.15.2.2.1, "Surface-based Evaluation of Ambient Thermal Conditions."

3.6.10 Study 8.3.1.8.5.3 - Investigation of Folds in Miocene and Younger Rocks of Region

The objective of this study is to establish the regional pattern and rate of Neogene folding.

This SCP section contains one activity that relies on available data; no unique data are to be acquired.

Activity 8.3.1.8.5.3.1 - Evaluation of folds in Neogene rocks of the region. The objective of this activity is to establish the pattern, rate, amplitude, and wavelength of post-middle Miocene folding in the region.

No progress was made during the reporting period; this was an unfunded activity.

Forecast: Aspects of this work scope will be transferred to Study Plan 8.3.1.8.2.1.

3.7 HUMAN INTERFERENCE (SCP SECTION 8.3.1.9)

3.7.1 Study 8.3.1.9.1.1 - An Evaluation of Natural Processes that Could Affect the Long-Term Survivability of the Surface Marker System at Yucca Mountain

The objective of this study is to provide information on the currently or potentially active natural processes at Yucca Mountain capable of adversely affecting the long-term survivability of the surface marker system. This study will synthesize data obtained from other activities to be undertaken in support of several investigations. The data will then be evaluated to determine the most suitable locations of the monuments for the surface marker system.

There will be no study plan developed for this SCP section. This study is to identify candidate sites free of tectonic, seismic, volcanic, erosion, or depositional influences that would mitigate against survivability of surface markers. The two activities in this SCP section draw upon data collected from other studies. There are no unique data to be collected. Activity 8.3.1.9.1.1.1 will extract available data from Studies 8.3.1.8.1.2 and 8.3.1.8.2.1 to perform the assessment for marker siting. Activity 8.3.1.9.1.1.2 will use data reported in the Extreme Erosion Topical Report and related work such as surficial mapping and Study 8.3.1.5.1.4 (Paleoenvironmental History).

Activity 8.3.1.9.1.1.1 - Synthesis of tectonic, seismic, and volcanic hazards data from other site characterization activities. The objective of this activity is to identify the potential locations of faulting and volcanic eruption or intrusion that could occur where they could affect the marker system.

A proposal for this study was approved and work was begun. No results or progress have yet been submitted.

Activity 8.3.1.9.1.1.2 - Synthesis evaluation of the effects of future erosion and deposition on the survivability of the marker system at Yucca Mountain. The objective of this activity is to determine the effects of future erosion and deposition on the topographic elements of the controlled area boundary at Yucca Mountain. This information will be evaluated to identify the optimum locations for the markers.

A proposal for this study was approved and work was begun. No results or progress have yet been submitted.

Forecast: A report is being developed to recommend candidate locations for surface markers and other components of the surface marker system; this report should be available in September of 1995.

3.7.2 Study 8.3.1.9.2.1 - Natural Resource Assessment of Yucca Mountain, Nye County, Nevada

The objective of this study is to identify and assess the natural resource potential at the proposed repository site at Yucca Mountain. The information and data obtained in this study will provide the basis for probabilistic calculations for evaluating the potential for inadvertent human interference.

Activity 8.3.1.9.2.1.1 - Geochemical assessment of Yucca Mountain in relation to the potential for mineralization. The objective of this activity is to conduct a geochemical sampling program to evaluate the potential for precious, base, and strategic metals; energy resources; and industrial mineral resources in the vicinity of Yucca Mountain. Specific objectives include (a) selecting a suite of elements for analysis in a geochemical sampling program based upon known commodities that occur in silicic tuffs and/or trace elements indicative of commodities that occur in the tuffs, (b) developing a field program to include a systematic and biased sampling of surface materials, (c) generating a first-order geochemical data base for selected elements obtained from surface and subsurface sampling within the vicinity of Yucca Mountain, (d) evaluating the data base in conjunction with geological and geophysical data obtained from other site characterization activities to determine if additional data are needed for an evaluation of natural resources, and (e) evaluating the potential for the occurrence of natural resources in the vicinity of Yucca Mountain based on an analysis of the geochemical data.

A geotechnical sampling program is being implemented by the Nevada Bureau of Mines & Geology to provide the basis for the analysis described above. This sampling initiative includes surface and subsurface sampling and may use multiple analytical techniques. All sampling, field work, laboratory analyses, and the metallic resource assessment work is the responsibility of the Nevada Bureau of Mines & Geology and is being accomplished in this activity and as a part of Activities 8.3.1.9.2.1.2 and 8.3.1.9.2.1.5.

The Mineral Resources and Isotope Hydrology Team developed and implemented innovative procedures for assessing the potential for mineralization of the Miocene volcanic rock mass and its basement of Paleozoic limestones at Yucca Mountain. These procedures combined stable and radiogenic isotope geochemistry with more traditional trace-element geochemical analyses to search for evidence of mineralizing fluids that may have pervaded the rock mass in the past. The isotopic approaches were based upon principles established by researchers working in the Great Basin since the early 1970s and are much more sensitive to detecting subtle indications of mineralizing fluids than the more conventional or industry standard approaches to prospecting. These numerous studies have shown that epithermal hydrothermal systems in igneous terrains are targeted by bulls-eye zones of $^{18}0$ depletion that formed by interaction between the host rocks and hydrothermal fluids (Criss and Taylor, 1986). Additionally, hydrothermal fluids commonly carry the strontium and lead isotopic signatures of the Precambrian basement rocks through which the fluids ascended (Peterman et al., 1994; Peterman and Aleinikoff, 1994). These isotopic signatures are indelibly imprinted on the mineralized zones of the host rocks and on surrounding haloes.

Two studies using the principles and approaches outlined above were completed during this reporting period by the Mineral Resources and Isotope Hydrology Team. Neither study detected any evidence of the past involvement of the volcanic rocks with mineralizing fluids. The first study entailed a geochemical and oxygen-isotope study of outcrop samples of the Tiva Canyon Tuff collected within the conceptual controlled area (Marshall et al., in prep). The study was designed to detect any subtle indications of past interactions of the Tiva Canyon Tuff with hydrothermal solutions. Such evidence of intermediate- to high-temperature water-rock interaction would indicate the possibility of epithermal mineralization within the volcanic rock mass at and below the stratigraphic level of the Tiva Canyon Tuff. Unaltered volcanic rocks have primary $\delta^{18}O$ values between +5.5 and +11.0 permil (Taylor and Sheppard, 1986). Mineralizing fluids would have had $\delta^{18}O$ values between -14 and -13 permil based on modern meteoric water in the region (Benson and McKinley, 1985); thus, any interaction with hydrothermal fluids would have substantially lowered the $\delta^{18}O$ rock values as shown by O'Neil and Silberman (1974).

For this investigation, 159 samples were systematically collected from the upper cliff and caprock zones of the Tiva Canyon Tuff at spacings of 500 m where possible. For control, 36 samples were collected from a reference section of the Tiva Canyon Tuff in Solitario Canyon. All these samples were analyzed for ^{18}O and for selected major and trace elements including precious metals (gold, silver) and elements considered to be pathfinders for epithermal mineralization (e.g. arsenic, selenium, and mercury). $\delta^{18}O$ in the samples from the upper cliff and caprock zones of the Tiva Canyon ranged from +6.9 to +11.9 permil, with no indications of ^{18}O depletion that would have derived from interaction with hydrothermal fluids. Similarly, none of the trace metals indicative of epithermal mineralization were elevated in the Tiva Canyon samples. Some of the pathfinder elements were below detection limits, and both arsenic and gold are only marginally higher than typical magmatic levels in siliceous volcanic rocks (Connors et al., 1993).

The second study focused on potential fluid pathways in the Tiva Canyon Tuff and the Topopah Spring Tuff (Neymark et al., in press). Strontium, lead, and oxygen isotope analyses, and x-ray fluorescence analyses for selected major and trace elements were conducted on brecciated and altered samples within fault zones at Trench 14 and Busted Butte. Hydrothermal fluids ascending along fault zones would have modified the oxygen isotopic compositions of the rocks as described above and added or exchanged strontium and lead with isotopic compositions reflecting a source in older rocks. Isotopic and geochemical data for the altered rocks in the fault zones were compared with data obtained on unaltered samples of the Tiva Canyon Tuff from Antler Ridge and of the Topopah Spring Tuff from core in bore hole UE-25 a#1. Calcite and opaline silica have been introduced into the breccias resulting in the increase of calcium, strontium, uranium, and barium concentrations and $\delta^{18}O$ to values between +12.1 and +20.4 permil. The data do not indicate any introduction of radiogenic isotopes or oxygen isotope exchange by hydrothermal fluids, and it was concluded that the fault zones have not been pathways for epithermal mineralizing solutions.

Activity 8.3.1.9.2.1.2 - Geophysical/geological appraisal of the site relative to mineral resources. The objective of this activity is to qualitatively evaluate the available geophysical

data base as it relates to Study Plan 8.3.1.9.2.1. Geologic models derived from geophysical data will be evaluated for their impact on mineral resources.

This work is being conducted and will be reported in FY 1996 as part of Activity 8.3.1.9.2.1.5.

Activity 8.3.1.9.2.1.3 - Assessment of the potential for geothermal energy at Yucca Mountain, Nevada. The objective of this activity is to evaluate regional ambient heat flow and local heat flow anomalies. This activity assesses the geothermal regime in terms of its energy resource potential for either hydrothermal or conductive reservoir thermal systems.

A report on the work is due in September of 1995. Temperature, thermal conductivity, and heat flow data were compiled and transmitted to the Technical Data Base on March 15.

Activity 8.3.1.9.2.1.4 - Assessment of hydrocarbon resources at and near the site. The objectives of this activity are to determine the potential for the presence or absence of suitable source rocks, reservoir rocks, and traps and seals at or near the site; to determine the potential for occurrence of conventional hydrocarbon resources (crude oil and natural gas) at and near the site; and to provide necessary data for the overall mineral and energy resource assessment to be performed.

No progress was made during the reporting period; this was an unfunded activity.

Activity 8.3.1.9.2.1.5 - Mineral and energy assessment of the site, comparison to known mineralized areas, and the potential for undiscovered resources and future exploration. The objective of this activity is to integrate the data and information collected from the geochemical assessment, geophysical/geologic assessment, geothermal energy assessment, and hydrocarbon assessment. Integrating these activities and the data acquired from them will allow (a) the identification of mineral resources with current markets, as well as the calculation of gross and net values for identified resources or reserves; (b) the physical description of mineral resources with potential future markets relative to "tonnage, or other amount, grade, and quality," as described in 10 CFR 60.21(c)(13); (c) the physical description of energy resources using appropriate parameters that describe the extent and magnitude of those resources; (d) the evaluation of the resource potential of any identified or undiscovered mineral and energy resources based on a "representative" area of "similar size" and a comparison to the Yucca Mountain site as prescribed in 10 CFR 60.122(c)(17); and (e) an estimation of the potential for undiscovered deposits of those resources described in 10 CFR 60.21(c)(13).

Data are being collected as the result of activity in many studies. These data and information are being integrated and a report is due in FY 1996.

Forecast: Previously collected downhole temperature data and geochemical data including sample locations, sample descriptions, and elemental abundance data will be submitted to the Yucca Mountain Technical Data Base. These data will then be available for the assessment of natural resources within the controlled area of Yucca Mountain.

Reports are expected in early FY 1996 except for the assessment of metallic resources which is expected in mid- to late FY 1996.

3.7.3 Study 8.3.1.9.2.2 - Water Resource Assessment of Yucca Mountain, Nevada

The objective of this study is to use available data to estimate the future supply, demand, and value of the ground-water resource proximal to Yucca Mountain.

Activity 8.3.1.9.2.2.1 - Projected trends in local and regional ground-water development and estimated withdrawal rates in southern Nevada, proximal to Yucca Mountain. The objectives of this activity are to assess the current and projected supply and demand situation in the foreseeable future for ground water in the geohydrologic study area and to estimate the value of the ground-water resource.

No progress was made during the reporting period; this was an unfunded study.

Forecast: A milestone is being established to report on the availability, quality, potential uses, and demand for water resources in the area of the Yucca Mountain site. This work is expected to be completed in FY 1996

3.7.4 Study 8.3.1.9.3.1 - Evaluation of Data Needed to Support an Assessment of the Likelihood of Future Inadvertent Human Intrusion at Yucca Mountain as a Result of Exploration and/or Extraction of Natural Resources

The objective of this study is to compile and analyze data to assess the likelihood of inadvertent human interference in the Yucca Mountain vicinity.

No unique data are to be acquired by this study. As a result, there will be no study plan developed forthis SCP section. The results of Study 8.3.1.9.2.1 will be a major, direct input to this study. Other inputs will be acquired from existing study plans or available data.

Activity 8.3.1.9.3.1.1 - Compilation of data to support the assessment calculation of the potential for inadvertent human intrusion at Yucca Mountain. The objectives of this activity are to determine the maximum drilling density and frequency (drillholes per square kilometer per 10,000 yr) that can be reasonably assumed for a repository at Yucca Mountain; and to determine the extent to which future ground-water withdrawals will modify the expected ground-water flow paths.

Forecast: A DOE working paper will be developed to document and discuss input parameters for inadvertent intrusion performance modeling using direct inputs from Study 8.3.1.9.2.1 and other studies.

3.7.5 Study 8.3.1.9.3.2 - An Evaluation of the Potential Effects of Exploration for, or Extraction of, Natural Resources on the Hydrologic Characteristics at Yucca Mountain

The objective of this study is to assess, in qualitative or quantitative terms, the effects of exploiting natural resources known or believed to be present at Yucca Mountain. Consideration of the effects of resource exploitation or extraction are limited to changes in the hydrologic, geochemical, and rock characteristics.

There will be no study plan developed for this SCP section. No unique data are to be acquired by this study. The inputs to computer modeling for varying water withdrawal assumptions and input bounds for sensitivity analysis of the code will be supplied directly from Study Plan 8.3.1.9.2.2.

Forecast: No activity is planned for FY 1995.

3.8 METEOROLOGY (SCP SECTION 8.3.1.12)

3.8.1 Study 8.3.1.12.1.1 - Characterization of the Regional Meteorological Conditions

The objective of this study is to gather and analyze meteorological data from various locations to characterize the regional meteorology and assimilate that information into a regional summary report. This characterization will provide a regional overview of wind flow patterns and other meteorological parameters (related to atmospheric dispersion) associated with those patterns in and around Yucca Mountain.

There will be no further study plans developed for this SCP program. Three SCP studies and one investigation in the Meteorology Program (8.3.1.12) include work to describe current regional meteorological conditions: Study 8.3.1.12.1.1, "Characterization of the Regional Meteorological Conditions," Study 8.3.1.12.1.2, "Plan for Synthesis of Yucca Mountain Site Characterization Project Meteorological Monitoring," Investigation 8.3.1.12.3, "Studies to Provide Data on the Location of Population Centers Relative to Wind Patterns in the General Region of the Site," and Study 8.3.1.12.4.1, "Characterize the Potential Extreme Weather Phenomena and their Recurrence Intervals." These studies (and the investigation) were identified as suitable for control through means other than study plans. The planning material intended for inclusion in Study Plan 8.3.1.12.1.1 was written as a Scientific Investigation Implementation Package and was completed in January 1995. The next step is the preparation of one or more Work Instructions, initiated this reporting period.

Forecast: The Work Instruction(s) controlling the regional meteorology work will be completed during the next reporting period. The literature and data search portion of the investigation will be initiated. Information collected for this search will probably be applied to a technical basis report to support the Technical Site Suitability determination.

3.8.2 Study 8.3.1.12.1.2 - Plan for Synthesis of Yucca Mountain Site Characterization Project Meteorological Monitoring

The objective of this study is to develop a plan that provides for coordination of meteorological monitoring efforts prepared during site characterization by various Project participants.

The work in this study was combined with other studies into the Scientific Investigation Implementation Package. See Section 3.8.1 of this Progress Report.

3.8.3 Study 8.3.1.12.2.1 - Meteorological Data Collection at the Yucca Mountain Site

The objective of this study is to provide data to resolve design and performance issues associated with preclosure radiological safety.

Activity 8.3.1.12.2.1.1 - Site meteorological monitoring program. The objective of this activity is to collect meteorological data at potential locations of surface facilities and at a sufficient number of additional locations deemed necessary to characterize the wind flow patterns in the vicinity of Yucca Mountain.

The ongoing meteorological monitoring program continued at the nine active sites. This program is currently focused on data collection, though results from the monitoring program are being used in some current site characterization activities. The primary use of the data is for future site suitability and licensing work in preclosure radiological safety issues to estimate potential radiological dosage related to repository operations.

Data from the network were included in two quarterly Ambient Air Monitoring Reports submitted to the State of Nevada during this reporting period. These reports fulfill requirements of State Air Quality Permit No. AP9999-0076 (previously identified by the State as No. 2693), which covers site characterization surface-disturbing activities. No significant increase in the concentrations of inhalable particulate matter has been noted, despite increased surface-disturbing activity at the site.

Data from this program were used to prepare a study report on nocturnal airflow discussed in Section 3.8.4 of this report. Data from this routine monitoring program are also being supplied to other Project participants in support of other characterization activities. These requests are being completed in a timely manner.

Activity 8.3.1.12.2.1.2 - Data summary for input to dose assessments. The objective of this activity is to process the collected meteorological data into a format and content that will be useful in assessing radiological impacts, as required by design and performance issues.

No progress was made during the reporting period; this was an out-year activity.

Forecast: Data collection will continue at the nine sites during FY 1995 and beyond.

3.8.4 Study 8.3.1.12.3 - Studies to Provide Data on the Location of Population Centers Relative to Wind Patterns in the General Region of the Site

The objective of this study is to provide data on wind flow patterns in the general region of Yucca Mountain. These data will then be used in estimating doses to the public and in doing so ensure that wind flow patterns would not preferentially transport material towards population centers.

The work in this study was combined with other studies in the Scientific Investigation Implementation Package. See Section 3.8.1 of this Progress Report.

A report was issued that describes the special intensive field study program performed during late autumn 1993 with participation by the National Oceanic and Atmospheric Administration, Air Resources Laboratory, Atmospheric Turbulence and Diffusion Division in Oak Ridge, Tennessee, and the National Oceanic and Atmospheric Administration, Air Resources Laboratory, Special Operations and Research Division in Las Vegas and Mercury, Nevada. The purpose of the study was to characterize nighttime downslope airflow related to the west and east sides of the main Yucca Mountain ridge. These conditions may be the "worst-case" atmospheric dispersion relative to possible releases of airborne radioactive material in terms of impacts to the public. The results showed complex airflow patterns occurring, which appear to be influenced by local topography and large scale meteorological patterns.

Forecast: Future work on this study will be controlled and tracked through Study 8.3.1.12.1.1, discussed in Section 3.8.1 of this Progress Report.

3.8.5 Study 8.3.1.12.4.1 - Characterize the Potential Extreme Weather Phenomena and Their Recurrence Intervals

The objective of this study is to evaluate existing historical meteorological and climatological records, technical publications, and other relevant information to quantify the extreme weather phenomena that may be expected at the Yucca Mountain site and determine their recurrence interval.

The work in this study was combined with other studies in the Scientific Investigation Implementation Package. See Section 3.8.1 of this Progress Report.

3.9 OFFSITE INSTALLATIONS AND OPERATIONS (SCP SECTION 8.3.1.13)

The radiological environmental monitoring program is designed to provide, among other things, the data necessary to fulfill the objectives of SCP Section 8.3.1.13. Data from this program will form the basis of all future radiological monitoring programs and will be used to identify any possible future radiological impacts on the environs of Yucca Mountain.

The data generated by this program are reported for each calendar year. Soil and air samples are collected and analyzed for radionuclide concentrations. Ambient gamma exposure and environmental radon concentrations are also measured. The process of validating data continued during the reporting period. Collection and analysis of small mammal and vegetation samples has been suspended.

Data from the previous calendar year is presented in DOE (1994p) and DOE (in prep.).

Forecast: The collection of soil and airborne particulates will continue through FY 1995, as will measurements of ambient gamma exposure rates and environmental radon concentrations. The collection of vegetation samples, suspended in FY 1994, is scheduled to resume in FY 1995. Data validation of backlog data will continue through FY 1995.

3.10 SURFACE CHARACTERISTICS (SCP SECTION 8.3.1.14)

3.10.1 Study 8.3.1.14.2.1 - Exploration Program

The objective of this study is to conduct an exploration program for characterization of the soil and rock conditions that will influence or be influenced by the construction of the surface and subsurface facilities. The exploration program study will consist of site reconnaissance, and preliminary and detailed exploration.

Activity 8.3.1.14.2.1.1 - Site reconnaissance. The objective of this activity is to review existing site information and conduct a field reconnaissance to establish a preliminary exploration program to include further topographic and geologic mapping, subsurface drilling, test pits, trenching, and geophysical methods.

A team was formed to develop a uniform method for geologic and structural core logging and to develop a computer-based core logging process. This effort is supported by activities conducted under SCP Section 8.3.1.4, Rock Characteristics, and the log format was developed to include selected framework rock properties. A preliminary computer-based core logging procedure was developed and was provided to the Lithostratigraphy Working Group during its meeting on March 10, 1995.

Preliminary reconnaissance for locating boreholes to support design of the South Ramp was completed. Preliminary surface mapping of the South Portal area was completed, and a preliminary geologic cross section was developed.

Activity 8.3.1.14.2.1.2 - Preliminary and detailed exploration. The objective of this activity is to obtain sufficient surface and subsurface data to prepare a preliminary design for the ESF surface and subsurface access facilities. Preliminary designs based on these explorations will be suitable for economic and technical feasibility reports and Project planning reports.

A report was issued to present the results of the engineering characterization of the pre-Rainier Mesa and Rainier Mesa tuffs that were encountered by the Exploratory Studies Facility North Ramp (Kessel et al., 1994). This report provided the basis for determining whether these nonlithified tuffs could be mined through by the tunnel boring machine, and provided the geoengineering data for the North Ramp through station 6 +00 m.

Three specific objectives of the investigations were met:

- Develop a detailed cross section showing the extent and continuity of the nonlithified tuffs
- Determine if the nonlithified tuffs had sufficient bearing capacity to allow the TBM to maintain grade and alignment
- Determine if the nonlithified tuffs had sufficient cohesion to prevent material from running in on the tunnel boring machine.

The geotechnical investigation for the North Ramp was completed, and all data were submitted to the technical data base. The report documenting this work is in review (Brechtel, in prep.).

Various geological cross sections along the ESF tunnel alignment continue to evolve:

- The North Ramp cross section was revised to include additional borehole data.
- The Exile Hill cross section was revised to include additional data based on refined lithostratigraphic interpretation and surface mapping.
- A preliminary cross section was developed for the main drift.

Forecast: An administrative procedure will be developed to define the process for geologic core logging and the computer software to support logging and the generation of the uniform core log will be completed. Locations and requirements for South Ramp exploratory boreholes will be submitted.

A final cross section for the main drift will be issued and a geoengineering report on rock properties for the main drift will be issued.

3.10.2 Study 8.3.1.14.2.2 - Laboratory Tests and Material Property Measurements

The objective of this study is to conduct laboratory tests and material property measurements on representative samples of soil and rock. These tests and measurements are intended to determine physical, mechanical, and dynamic properties. Additional tests and measurements will be conducted on soils to determine index properties and moisture-density compaction curves for potential fill material.

Activity 8.3.1.14.2.2.1 - Physical property and index laboratory tests. The objective of this activity is to measure the soil or rock weight and volume components using physical property tests.

The results of laboratory tests on samples from the Rainier Mesa nonlithified tuffs were analyzed. The results were used to assess several factors important for constructing the North Ramp through the nonlithified tuffs. These included the following:

- Groutability of the nonlithified tuffs
- Identification of potential weak zones resulting from possible saturation conditions
- Strength parameters.

Activity 8.3.1.14.2.2.2 - Mechanical and dynamic laboratory property tests. The objective of this activity is to measure in the laboratory the static and dynamic deformation and strength characteristics of soil and rock samples obtained from the exploratory program. The results of this testing will be used to evaluate bearing capacity, earth pressures, shear strength parameters, slope stability, settlement and swelling potentials, and the dynamic characteristics of the soil and rock.

No progress was made during the reporting period; this was an out-year activity.

Forecast: Laboratory tests on samples from the Rainier Mesa nonlithified tuffs to determine detailed strength parameters will be completed. The results of these tests will support modeling of long-term stability of the North Ramp.

3.10.3 Study 8.3.1.14.2.3 - Field Tests and Characterization Measurements

The objective of this study is to conduct field tests and characterization measurements. These field tests are intended to determine the in situ physical, mechanical, and dynamic properties of the soil and rock.

Activity 8.3.1.14.2.3.1 - Physical property field tests and characterization measurements. The objectives of this activity are to classify and describe the soil and rock conditions in the field and to determine their physical properties. The results of these tests and measurements will be used to develop estimates of the engineering characteristics of the soil and rock. In addition, these properties and measurements will aid in the grouping of soil and rock into stratigraphic units and the extrapolation of results from a restricted number of mechanical and dynamic properties tests to zones of soil and rock with similar material properties.

The geology and rock structure log for NRG-7A was completed. Core rock mass quality indices and rock mass mechanical properties estimates for the NRG holes were revised to include additional borehole data. Geology and rock structure logs for the NRG boreholes

were revised to provide improved estimates of percent lithophysae and incorporate the USGS stratigraphic nomenclature. These data were transmitted to the design team in support of design of the North Ramp.

Activity 8.3.1.14.2.3.2 - Mechanical property field tests. The objective of this activity is to measure the deformation and strength characteristics of in situ soil and rock conditions. The results of this testing will be used to evaluate bearing capacity, earth pressures, settlement and swelling potentials, slope stability, and the dynamic response of soil and rock for the design of foundations, retaining walls, backfills, roads, slopes, ramps, and shafts.

Tests were completed to support the design of the water storage tanks for the ESF and a geotechnical report was transmitted to the design team. Tests were completed to support the design of the Muck Conveyor System and preliminary results were prepared and transmitted to the design team.

Activity 8.3.1.14.2.3.3 - Geophysical field measurements. The objectives of this activity are to obtain measurements of the compressional and shear wave velocities and to determine the velocity structure in the area of the ESF surface facilities and subsurface ramps and shafts. These methods may also be used to profile the alluvium-bedrock contact, locate discontinuities or other structural abnormalities, and to determine the depth, thickness, and lateral extent of soil and rock stratigraphic units.

Preliminary results from surface seismic studies in Daylight Valley indicated that additional intervals of the nonwelded "Tuff X" unit could be encountered in the North Ramp. These data were made available to the design team to support construction of the North Ramp.

Forecast: Geology and rock structure logs will be issued for USW SD-7, SD-9, and SD-12. Rock properties data will be developed from these holes.

A final geotechnical report for the muck conveyor system will be issued.

A report documenting results from the surface seismic studies in Daylight Valley will be issued.

3.11 THERMAL AND MECHANICAL ROCK PROPERTIES (SCP SECTION 8.3.1.15)

3.11.1 Study 8.3.1.15.1.1 - Laboratory Thermal Properties

The objective of this study is to provide laboratory characterization of thermal conductivity and heat capacity and the spatial variability thereof. To accomplish this, porosity, grain density, and the heat capacity and thermal conductivity of zero-porosity material must also be characterized.

Activity 8.3.1.15.1.1.1 - Density and porosity characterization. The objective of this activity is to obtain data on density and porosity and to evaluate its spatial variability. Data will contribute to determination of in situ thermal properties (porosity and grain density), to vertical in situ stress (bulk density), and radiation-shielding properties (bulk density).

Potential correlations between thermal properties and sample characteristics (bulk properties, grain densities, mineralogical and petrologic characterizations, and whole-rock chemistry) are being examined, for samples obtained from USW NRG-6. The existence of correlations have the potential to extrapolate measured thermal properties from specific drillholes to the three dimensional model of the site.

Activity 8.3.1.15.1.1.2 - Volumetric heat capacity characterization. The objective of this activity is to obtain data for volumetric heat capacity and to evaluate its spatial variability. The data will be used in calculations of the thermal response to the presence of heat-producing waste in unit TSw2.

Development of equipment to measure heat capacity of tuff continued.

Activity 8.3.1.15.1.1.3 - Thermal conductivity characterization. The objective of this activity is to obtain data for thermal conductivity and to evaluate its spatial variability. The data will be used in calculations of the thermal response to the presence of heat-producing waste in unit TSw2.

Measurements of thermal conductivity were made on samples of the TSw2 and TSw1 thermomechanical units from Drillholes UE-25 NRG#4, UE-25 NRG#5, and USW NRG-7A, to obtain an indication of the lateral and vertical variability of these units.

Forecast: Measurement of thermal conductivity will continue for samples from NRG, SD, and SRG holes. A data report, summarizing the data from samples from UE-25 NRG#4, UE-25 NRG#5, USW NRG-6, and USW NRG-7A drillholes will be submitted. In addition, this report will report any correlations between thermal conductivity and sample characteristics from samples from USW NRG-6.

3.11.2 Study 8.3.1.15.1.2 - Laboratory Thermal Expansion Testing

The objective of this study is to provide laboratory characterization of thermal-expansion behavior and the spatial variability thereof. Testing frequency at the main test level in the ESF will depend on spatial variability.

The coefficient of thermal expansion is a basic physical parameter that is required to determine the mechanical response of the repository to applied heat. The coefficient is required to predict thermal stresses in underground openings during operation and closure of the potential repository, and to predict thermohydrologic flow.

Project scientists are measuring thermal expansion on samples of tuff from the NRG and SD drillholes. These measurements will produce values for thermal expansion and indicate the lateral and vertical variability of thermal expansion. Testing this year is emphasizing the TSw2 thermomechanical unit.

Activity 8.3.1.15.1.2.1 - Thermal expansion characterization. The objective of this activity is to obtain data for thermal-expansion behavior and to evaluate the spatial variability thereof. The data will be used in calculations of thermal stress and deformation associated with the temperature field produced by the presence of heat-producing waste in unit TSw2.

Measurements of thermal expansion were made on samples of the TSw2 and TSw1 thermomechanical units from drillholes UE-25 NRG#4, UE-25 NRG#5, and USW NRG-7A, to obtain an indication of the lateral and vertical variability of these units.

A study of the effects of confining pressure on thermal expansion is ongoing. Past experiments on unconfined samples have resulted in values for thermal expansion that were higher than expected. These high values have been associated with silica phase transformations. This study is designed to determine if confining pressure will suppress the high values of thermal expansion. Equipment to conduct these experiments was assembled. Laboratory measurements were made of the amount of cristobalite and tridymite (the silica phases thought to be associated with the high values for thermal expansion) in the samples.

Forecast: Measurement of thermal conductivity will continue for samples from NRG, SD, and SRG holes. A data report summarizing the data from samples from UE-25 NRG#4, UE-25 NRG#5, USW NRG-6, and USW NRG-7A drillholes will be submitted. A second report, summarizing the results of the study on the effects of confining pressure on thermal expansion, will be also be submitted.

3.11.3 Study 8.3.1.15.1.3 - Laboratory Determination of Mechanical Properties of Intact Rock

The objective of this study is to provide laboratory characterization of the mechanical properties of intact rock and its spatial variability. Testing frequency at the main test level in the ESF will depend on spatial variability.

Activity 8.3.1.15.1.3.1 - Compressive mechanical properties of intact rock at baseline experiment conditions. The objective of this activity is to obtain data for the comprehensive mechanical properties of intact rock and the spatial variability thereof for baseline experiment conditions. These data will be used in mechanical and thermomechanical calculations of stresses and deformations induced by the presence of underground openings in unit TSw2 and overlying units and by the presence of heat-producing waste in unit TSw2.

During the reporting period, samples have been collected from core taken in drillholes USW SD-12, USW SD-9, and USW SD-7 for intact mechanical properties testing at baseline conditions. Although a lower density of samples will be tested from these holes as was tested

from the NRG holes, the experiments from these samples will help refine the mechanical properties/porosity relationships and indicate the level of north-south variability along the main drift.

The mechanical properties and supporting bulk properties from samples collected from core of USW NRG-6 were documented (Martin et al., 1994).

Activity 8.3.1.15.1.3.2 - Effects of variable environmental conditions on mechanical properties. The objective of this activity is to evaluate the effects of varying sample size, strain rate, temperature, confining pressure, lithophysal content, saturation state, and anisotropy on compressive mechanical properties. In addition, the tensile strength of unit TSw2 will be measured. Data will be used in mechanical and thermomechanical calculations of stresses and deformations induced by the presence of underground openings in unit TSw2 and overlying units and by the presence of heat-producing waste in unit TSw2.

Samples were collected from core taken from the NRG drillholes for intact mechanical properties testing. During the reporting period, Project scientists prepared and tested samples from USW NRG-6 and USW NRG-7A. The samples were characterized and prepared, and then confined compression experiments were performed. The results from 23 confined compression experiments have been reported; 11 samples were tested at 5 MPa confining pressure, and 12 at 10 MPa. In addition, average grain density was determined and reported for 46 samples. The results are being analyzed for a correlation between the mechanical properties and porosity; however, these data are not sufficient to evaluate the entire range of porosities observed in these tuffs (i.e., between about 5 and 60 percent).

Also conducted was a study of time-dependent deformation involving high-temperature experiments at creep and low strain rate conditions. During this time period, one incrementally-stepped constant stress experiment was completed when the sample failed within a few hours of the creep stress being increased from 170 to 180 MPa. The saturated sample was tested at a pore pressure of 4.5 MPa, a confining pressure of 5 MPa, and a temperature of 250°C.

Forecast: Quasi-static experiments will continue on samples from SD drillhole core and the creep experiments will continue to investigate time dependent mechanical properties. The data will be reduced, analyzed, and reported in support of the ESF design and site suitability activities.

3.11.4 Study 8.3.1.15.1.4 - Laboratory Determination of the Mechanical Properties of Fractures

The objective of this study is to provide laboratory characterization of the mechanical properties of fractures and the spatial variability thereof. The discussion applies for each new core hole and for the ESF.

The Fracture Properties Working Group, composed of several Project scientists, met nine times during the reporting period to discuss the testing activities supporting the ESF design and site suitability efforts.

Activity 8.3.1.15.1.4.1 - Mechanical properties of fractures at baseline experiment conditions. The objective of this activity is to obtain data for the mechanical properties of fractures, and the spatial variability thereof, for baseline experiment conditions. The data will be used in mechanical and thermomechanical calculations of the stresses and deformations induced by the presence of underground openings in unit TSw2 and overlying units and by the presence of heat-producing waste in unit TSw2.

During the reporting period, seven natural fractures from UE-25 NRG#4, USW NRG-6, and USW NRG-7A were characterized by gathering topographic information on each sample with a laser profilometer. Eight samples have been tested at room dry and ambient temperature conditions. The mated, rough fractures are subjected to a cycle of normal loading and then, at a constant normal stress (either 5 of 10 MPa), sheared at a constant rate. These samples have, in general, had a rounded peak shear response with a slow decrease in the shear strength to a residual, sliding value. Results from a study of mechanical properties of natural fractures at various normal stresses were documented and reported (Olsson and Brown, 1994). Samples were also collected from USW SD-9 core and are being prepared for testing.

Activity 8.3.1.15.1.4.2 - Effects of variable environmental conditions on mechanical properties of fractures. The objective of this activity is to evaluate the effects of varying normal stress, displacement rate, temperature, sample size, fracture roughness, and saturation state on the mechanical properties of artificial and natural fractures. The data will be used in mechanical and thermomechanical calculations of stresses and deformations induced by the presence of underground openings in unit TSw2 and overlying units and by the presence of heat-producing waste in unit TSw2.

Samples were collected from core taken in the SD drillholes for fracture mechanical properties testing. Some of the samples from USW SD-9 are being prepared to run a series of experiments to investigate the effects of elevated temperature on the mechanical properties and to run two creep experiments. One of the creep (or constant stress) experiments will be performed at ambient temperature and one at elevated temperature.

Work continued on developing a computer program to model the dilation, normal stiffness, and shear stiffness of single fractures in rock. An early version of the code is being used to study the changes in the aperture of a fracture under normal stress.

Forecast: Efforts will continue in the performance of baseline, elevated temperature, and creep experiments on samples from SD drillhole core. The data will be reduced, analyzed, and reported in a timely manner to support the ESF design and site suitability activities.

3.11.5 Study 8.3.1.15.1.5 - Excavation Investigations

The objective of this study is to obtain site-specific information concerning the behavior of underground excavations in the proposed repository horizon and overlying units. Most of the data will be used for testing of computer codes that will be used to predict mechanical behavior of the rock mass. In addition, some of the information will serve as direct demonstration of constructability with reasonably available technology.

Activity 8.3.1.15.1.5.1 - Access convergence experiment. The objective of this activity is to obtain measurements to (a) monitor access convergence and rock mass deformation at several discrete locations, (b) measure the radial stress distribution and in situ state of stress at these locations, and (c) routinely measure the response of the rock mass to the loads imposed by the tunnel boring machine gripper pads. This information is important to demonstrate the stability of, and state of stress around, a full-scale repository opening in rock of varying quality.

A feasibility study was started using the gripper pads of the tunnel boring machine to measure rock-mass modulus of the host rock of the ESF as it is excavated. The mechanical response of underground excavations is governed by rock-mass modulus. This parameter, therefore, is needed to evaluate whether the host rock is capable of accommodating stresses induced by repository construction, operation, and closure.

Activity 8.3.1.15.1.5.2 - Demonstration breakout room. The objective of this activity is to demonstrate constructability and stability of underground rooms with cross-sectional dimensions equivalent to those of a repository in both lithophysae-rich and lithophysae-poor material. This demonstration will include an evaluation of the deformations that occur around the openings. A secondary objective is to provide facilities for other testing (e.g., heater tests and overcoring). Demonstration of constructability and stability will contribute to empirical evaluations of nonradiological health and safety.

No progress was made during the reporting period; this was an out-year activity.

Activity 8.3.1.15.1.5.3 - Sequential drift mining. The objectives of this activity are to obtain data on the deformation response of drifts with cross-sectional dimensions equivalent to those of a repository in welded tuff, to use the data in code evaluation activities, and to demonstrate constructability and stability of repository-sized drifts in lithophysae-poor material. Data will contribute to validation of computer codes to be used to calculate mechanical responses, as well as contributing to empirical evaluations related to nonradiological health and safety.

No progress was made during the reporting period; this was an out-year activity.

Forecast: The feasibility study on using the tunnel boring machine gripper pads to measure rock-mass modulus will be completed by September 1995.

3.11.6 Study 8.3.1.15.1.6 - In Situ Thermomechanical Properties

The objective of this study is to obtain data on in situ thermal and thermomechanical properties for units TSw1 and TSw2. Properties to be obtained include heat capacity, thermal conductivity, and thermal expansion. Additional heater experiments will be conducted to characterize the waste container environment.

The experiments in this study are designed to obtain the experimental data needed to develop computational tools that can be used to predict the response of underground openings at Yucca Mountain to the elevated temperatures and stresses expected in a high-level radioactive waste repository. The addition of thermal loads makes the design of a repository unique among civil construction of underground structures. This study is designed to provide data to validate new predictive techniques, including the ability to predict preclosure stability of underground openings, and to enhance the ability to predict thermal-hydrologic flow. This study will also obtain thermal and mechanical properties at the rock-mass scale.

In December 1994, the DOE directed that a multi-participant team be assembled to review the current in situ thermal testing program and to provide DOE with a new consolidated ESF thermal test strategy that is consistent with the Program Plan. This effort is being conducted in two phases: The first phase focused on the early time period (1995 through 2001) and developed a set of information and data needs that must be met by the thermal test program to support the determination of Technical Site Suitability in 1998 and the initial license application in 2001. These needs were identified through discussions with the future users of this data in repository design, pre- and postclosure performance assessment, waste package design, and licensing. Constraints on in situ testing, and lessons learned from previous in situ thermal tests were also identified. Conceptual designs of laboratory thermal process tests and in situ thermal tests were then proposed. The results of this effort were documented in a draft report submitted to DOE on January 31, 1995 (Costin, in prep.). This report is expected to complete review and be released in early April 1995.

As a DOE report, the second phase of the thermal test definition effort, will extend the work documented in the first phase to present an integrated test strategy for the long-term thermal test effort. This includes a definition of testing required by the Program Plan to be completed by the 2008 license amendment to receive waste and on through the performance confirmation period, that may last as much as 100 yr.

The report on the second phase of the thermal test definition effort is scheduled to be submitted to DOE for review by the end of April 1995.

Activity 8.3.1.15.1.6.1 - Heater experiment in unit TSw1. The objective of this activity is to estimate the in situ thermomechanical properties of lithophysae-rich tuff (unit TSw1) and to evaluate the thermal and mechanical response of this tuff unit to elevated temperatures. The data will be used to evaluate models during this and other experiments.

No progress was made during the reporting period; this was an out-year activity.

Activity 8.3.1.15.1.6.2 - Canister-scale heater experiment. The objective of this activity is to obtain thermal and thermomechanical rock-mass measurements of the effects of thermal inputs on a representative (canister-scale) waste-emplacement borehole in lithophysae-poor tuff (unit TSw2). The data will be used to evaluate the thermal and thermomechanical models.

No progress was made during the reporting period; this was an out-year activity.

Activity 8.3.1.15.1.6.3 - Yucca Mountain heated block. The objective of this activity is to estimate in situ mechanical and thermomechanical properties of unit TSw2 and to test thermomechanical computer models. Data on the properties will be used in mechanical and thermomechanical calculations of stresses and deformations induced by the presence of underground openings in unit TSw2 and overlying units and by the presence of heat-producing waste in unit TSw2.

No progress was made during the reporting period; this was an out-year activity.

Activity 8.3.1.15.1.6.4 - Thermal stress measurements. The objective of this activity is to monitor thermally induced stress in jointed welded tuffs in an accelerated test. The data will be used to evaluate thermally induced stresses calculated with thermomechanical computer codes.

No progress was made during the reporting period; this was an out-year activity.

Activity 8.3.1.15.1.6.5 - Heated room experiment. The objectives of this activity are to evaluate the thermomechanical response of welded tuff around repository openings to expected repository conditions during both construction and operation; to develop a data base for evaluating thermal and thermomechanical design analyses and methods applicable for repository considerations; and to use actual site data in predicting drift response and support/rock interactions during construction, operation, retrievability, and postclosure.

No progress was during the reporting period; this was an out-year activity.

Forecast: The second phase of the thermal test program definition will be completed (including DOE review) by June 1995. Efforts will then focus on completing the designs of the early tests and the initial phase of detailed design for the later, more complex tests. Design of the facility at the bottom of the north ramp that is required to conduct the thermal tests will also be a priority.

The report will be expanded to consider additional data needs that must be met between 2001 and 2008, and to develop more fully the proposed in situ thermal tests by May 1995.

The study plan revision for in situ thermomechanical properties is being delayed until definition of the consolidated thermal test program is completed. The study plan will then be revised to be consistent with the consolidated thermal test program. Definition of tests and

activities within the study may change considerably based on the consolidation of thermal testing.

3.11.7 Study 8.3.1.15.1.7 - In Situ Mechanical Properties

The objective of this study is to obtain in situ measurements of the mechanical properties of the rock mass for unit TSw2.

Activity 8.3.1.15.1.7.1 - Plate loading tests. The objective of this activity is to measure the deformation modulus of the rock mass and to evaluate the zone of increased fracturing adjacent to underground openings.

No progress was made during the reporting period; this was an unfunded activity.

Activity 8.3.1.15.1.7.2 - Rock-mass strength experiment. The objective of this activity is to evaluate the mechanical behavior of the rock mass or its components by using experiments to obtain information related to the mechanical strength of single joints and to multiply jointed volumes of rock.

No progress was made during the reporting period; this was an unfunded activity.

Forecast: The draft study plan will be submitted for DOE review by August 30, 1995.

3.11.8 Study 8.3.1.15.1.8 - In Situ Design Verification

The objectives of this study are to investigate the effects of the spatial variability of the rock on drift stability, mining activities, and ground supports; to evaluate techniques for underground excavation and ground support, for selecting ground supports to be used in different rock types, and for monitoring drift stability; to quantify the emanation of radon into repository drifts and observe its dispersion with airflow; and to measure parameters needed to design repository ventilation systems.

Geotechnical design verification activities are being conducted in the North Ramp of the ESF to provide dates that can be used to confirm adequate design, construction, and long term performance from the very beginning of ESF construction. The data from these activities will also be used to support repository design and to validate the ESF design.

Activity 8.3.1.15.1.8.1 - Evaluation of mining methods. The objective of this activity is to develop recommendation for mining in the repository by monitoring and evaluating mining activities in the ESF and by conducting mining investigations.

Before the start-up of the tunnel boring machine, six stress gauges were installed in the starter tunnel, past the location of the face. These gauges were used to monitor the stress changes that occurred with the initial tunnel boring machine excavation and with the

application of the tunnel boring machine gripper pads. Data collection from this test was completed and preliminary analysis of the data began.

Rock mass quality evaluations, needed for correlations with other studies and by the ESF constructors for making ground support decisions, have been conducted, keeping pace with ESF excavation.

Activity 8.3.1.15.1.8.2 - Monitoring of ground-support systems. The objective of this activity is to develop recommendations for a ground-support methodology to be used in drifts in the repository, based on evaluations of the ground-support methodology used in the ESF and on experimentation with other ground-support configurations. Recommendations will be made for support systems to be used, as well as for methods of selection of supports that are appropriate for the ground conditions encountered.

Project scientists continued to monitor installed geotechnical instruments, and to install new geotechnical instruments, closely following the excavation of the ESF. The geotechnical instrumentation includes rock-bolt load cells, instrumented rock bolts, and strain gauges on steel sets installed as part of the ground support. Strain gauges were installed on selected steel sets before installation, and measurements made before, during, and after installation, to measure the installation loads. Readings from these instruments have identified no concerns regarding ground support.

Activity 8.3.1.15.1.8.3 - Monitoring drift stability. The objectives of this activity are to provide confidence in predictions of usability of the repository underground facilities over their 100-yr operational life, to contribute to evaluations of the effectiveness of mining methods and ground supports, to calibrate and refine criteria for determining stability of the openings, and to develop techniques for monitoring stability of the repository drifts.

Project scientists continued to monitor installed geotechnical instruments, and to install new geotechnical instruments, closely following the excavation of the ESF. The geotechnical instrumentation includes multi-point and single point extensometers and cross drift convergence pins. Readings from these instruments have identified no tunnel stability concerns.

Activity 8.3.1.15.1.8.4 - Air quality and ventilation experiment. The objectives of this activity are to measure the rate of radon emanation from the repository host rock; and to evaluate parameters and variables needed as input to or for testing of the models to be used for design of the ventilation systems in the repository underground facility.

Project scientists finalized the plans and began the procurements needed to measure of diesel exhaust in the ESF ventilation system. These plans were provided as input for the required test planning package and job package. Diesel emissions are being measured because the unburned compounds may be detrimental to both experiments to be conducted in the ESF and to waste isolation packaging.

Forecast: Efforts will continue to monitor installed geotechnical instruments, to install new geotechnical instruments, and to make rock mass quality evaluations in the ESF as it is excavated. Diesel exhaust in the ESF ventilation system will be measured and documented by August 30, 1995. Monitoring of construction blasting will be conducted as each alcove is excavated.

3.11.9 Study 8.3.1.15.2.1 - Characterization of the Site Ambient Stress Conditions

The objective of this study is to characterize the ambient (pre-repository) state of stress of the Yucca Mountain host rock and surrounding units for use as initial conditions for geomechanical models used in the design and performance assessment of the repository underground facilities.

Related International Work

See Section 3.11.11 for related work (under the heading, In Situ Stress Determination) performed under the auspices of the OCRWM international program.

Activity 8.3.1.15.2.1.1 - Anelastic strain recovery experiments in core holes. The objective of this activity is to determine the horizontal stresses at Yucca Mountain, particularly the spatial variability thereof. In situ stress data will contribute to definition of initial and boundary conditions for mechanical and thermomechanical analyses.

As a result of the study plan work scope consolidation, there will be no study plan developed for this SCP section. The work scope for Activity 8.3.1.15.2.1.1 is being deleted from the program. The proposed technique is not likely to work, would not be cost effective, and would be redundant with other planned approaches.

Activity 8.3.1.15.2.1.2 - Overcore stress experiments in the Exploratory Studies Facility. The objectives of this activity are to determine the in situ state of stress above, within, and below the repository host rock in that portion of the repository block penetrated by the ESF, and to evaluate the extent to which the ambient stress conditions are redistributed adjacent to excavations. In situ stress data will contribute to definition of initial and boundary conditions for mechanical and thermomechanical analyses.

The scope of work for this activity has been transferred to Study 8.3.1.15.1.8.

Forecast: The Site Design and Test Requirements Document will be revised to reflect these changes.

3.11.10 Study 8.3.1.15.2.2 - Characterization of the Site Ambient Thermal Conditions

The objective of this study is to evaluate available thermal data to determine the ambient (pre-repository) temperature and thermal conductivity of the Yucca Mountain host

rock and surrounding units for use as initial conditions for thermomechanical models used in the design and performance assessment of the repository underground facilities.

Activity 8.3.1.15.2.2.1 - Surface-based evaluation of ambient thermal conditions. The objective of this activity is to evaluate available thermal data to determine the ambient (pre-repository) temperature and thermal conductivity of the Yucca Mountain host rock and surrounding units for use as initial conditions for thermomechanical models used in the design and performance assessment of the repository underground facilities.

This activity was not funded in FY 1995. All work is being carried out in the closely related Activity 8.3.1.8.5.2.3 (Heat flow at Yucca Mountain and evaluation of regional ambient heat flow anomalies). Temperatures and thermal conductivities required to achieve the objectives of this activity are also needed to calculate heat flows.

Forecast: Input will be sought to the engineering plans for USW G-5 and/or USW G-6 to ensure that the hydrologic boundary between the tuffs and the Paleozoic carbonate aquifers can be characterized with sufficient resolution to identify any potential flow paths.

3.11.11 Related International Thermal and Mechanical Rock Properties Work

In Situ Stress Determination

The following is work related to Study 8.3.1.15.2.1 (Section 3.11.9) conducted cooperatively with Canada under the auspices of the OCRWM international program.

During the previous reporting period, the task team (United States and Atomic Energy of Canada Limited) gained access to an abandoned silver mine (the Amethyst mine, near Creede, Colorado), with rock characteristics resembling those at Yucca Mountain. Modified instruments were developed by Atomic Energy of Canada Limited and evaluation tests were run in the mine. Significant problems occurred with the purchased equipment and with performance in welded tuff. A German instrument did exhibit some advantages, but did not solve the problems. Further details of the investigations were provided in Austin and Thompson (1994). Petrographers conducted microscopic rock-fabric analyses to obtain detailed three-dimensional data on fracturing and mineral grains. These data are needed to evaluate observed variations in elastic rock parameters required for interpreting stress determination data. Results of the investigation will provide improved techniques and expanded knowledge for performing required in situ stress determinations in rock masses with dense fracture patterns.

During this reporting period, analysis and evaluation of stress relief data obtained at the Amethyst Mine test site during field testing activities in FY 1993-1994, proceeded. The triaxial load cell was assembled and some of the initial calibration tests performed. Petrographic analysis of granite samples from the 420 level of the Underground Research Laboratory continued. Results of the investigation will provide improved techniques and

expanded knowledge for performing required in situ stress determinations in rock masses with dense fracture patterns.

Forecast: The following actions are planned:

- Complete evaluation of stress relief data obtained at Amethyst Mine
- Complete calibration/evaluation of triaxial load cell and begin testing specimens from Underground Research Laboratory and Amethyst
- Complete petrographic analysis of Underground Research Laboratory and Amethyst and prepare report
- Perform bench scale testing evaluation of Atomic Energy of Canada Limited triaxial stress determination cell
- Complete report on technical procedures for borehole TV logging
- Complete status paper covering the work accomplished thus far under this task and defining future directions
- Consider purchasing borehole slotter equipment for bench scale testing
- Finish paper on results of fracture characterization studies at the Amethyst Mine
- Finish technical procedures for borehole TV logging using equipment developed or refined on this study.

3.12 PRECLOSURE HYDROLOGY (SCP SECTION 8.3.1.16)

3.12.1 Study 8.3.1.16.1.1 - Characterization of Flood Potential of the Yucca Mountain Site

The objective of this study is to evaluate the potential for flooding in the many small, dry, desert washes that drain Yucca Mountain. This evaluation will be used for designing the surface facilities for the proposed repository. Proper design for flood potential is necessary to ensure the safety of workers and surface facilities.

Activity 8.3.1.16.1.1.1 - Site flood and debris hazards studies. The objective of this activity is to assess the flood and debris hazards at and near the potential repository surface facilities locations to allow adequate design of facilities to prevent or reduce hazards to an acceptable level.

No progress was made during the reporting period; this was an unfunded activity.

Forecast: No activity is planned for FY 1995.

3.12.2 Study 8.3.1.16.2.1 - Location of Adequate Water Supply for Construction, Operation, Closure, and Decommissioning of a Mined Geologic Disposal System at Yucca Mountain, Nevada

The purpose of this study is to identify water supply sources for a potential repository. Four activities were identified in the SCP (1) assess the cost, feasibility, and adequacy of using Wells UE-25 J#12 and J#13 as an alternative water supply; (2) identify a primary water source; (3) identify another alternative water source (other than Wells UE-25 J#12 and J#13); and (4) identify and evaluate the potential effects of repository-related withdrawals on the ground-water flow system.

There will be no study plan developed for this SCP section. For the first activity, a DOE working paper or participant report will be developed compiling known production histories of UE-25 J#12 and J#13 from an extensive record. A second activity will identify a primary water supply for repository operations that is closer to, and topographically higher than, facilities important to safety; and a third activity will identify an alternative water source. This work concerns repository construction and is suited for a standard engineering trade study in support of a future design package for repository facilities important to safety. The fourth activity will provide for a sensitivity analysis with the flow models developed for Study 8.3.1.2.1.3 (Regional Ground Water Flow System) and Study 8.3.1.2.3.1 (Site Saturated Zone Ground Water Flow System).

No progress was made during the reporting period; this was an out-year study.

Forecast: No activity is planned for FY 1995.

3.12.3 Study 8.3.1.16.3.1 - Determination of the Preclosure Hydrologic Conditions of the Unsaturated Zone at Yucca Mountain, Nevada

The objective of this study is to compile the data collected under Geohydrology Investigation 8.3.1.2.2 (Exploratory Studies Facility Investigations) for input to Design Issue 4.4.

No progress was made during the reporting period; this was an unfunded activity.

Forecast: No activity is planned for FY 1995.

3.13 PRECLOSURE TECTONICS (SCP SECTION 8.3.1.17)

3.13.1 Study 8.3.1.17.1.1 - Potential for Ash Fall at the Site

The objective of this study is to provide required information on volcanic activity that could affect repository design performance.

Activity 8.3.1.17.1.1.1 - Survey literature regarding Quaternary silicic volcanic centers in the western Great Basin. The objective of this activity is to compile information on Quaternary silicic volcanism in the western Great Basin, the reoccurrence of which might produce an ash fall at the site.

Activity 8.3.1.17.1.1.2 - Assess potential ash-fall thickness at the site. The objective of this activity is to produce an approximate probability-vs.-thickness function for potential ash falls at the site and to estimate a particular ash-fall thickness that has less than one chance in ten of occurring in 100 yr. These hazard estimates will be considered in the design of filters in the mining and surface-facility ventilation systems.

As a result of the study plan work scope consolidation effort, there will be no study plan developed for this SCP section. All these activities rely on data from other SCP studies, or available data. The work identified in this section has been completed and was documented in Perry and Crowe (1987). Additional discussion is included in Crowe et al. (1995).

3.13.2 Study 8.3.1.17.2.1 - Faulting Potential at the Repository

The objective of this study is to provide required information on fault displacement that could affect repository design or performance.

Activity 8.3.1.17.2.1.1 - Assess the potential for surface faulting at prospective sites of surface facilities important to safety. The objective of this activity is to assess the stability of the site surface with respect to fault displacement, at locations proposed for facilities important to safety.

Activity 8.3.1.17.2.1.2 - Assess the potential for displacement on faults that intersect underground facilities. The objective of this activity is to assess the potential for displacement on faults intersecting underground facilities.

Faulting potential at the site will be assessed in a manner similar to that used to assess vibratory ground motion. This probabilistic approach will allow the significance of faults with respect to design and performance assessment to be determined. Given the similarity in these approaches, there will be no study plan developed for this SCP section. The work scope for this study is being combined with that of Study 8.3.1.17.3.6 (Probabilistic Seismic Hazard Analysis). The study plan for Study 8.3.1.17.3.6, revised during this reporting period, addresses this assessment of faulting potential at and near Yucca Mountain.

Forecast: The work scope is to be transferred to Study Plan 8.3.1.17.3.6. The Site Design and Test Requirements Document will be revised to reflect this change.

3.13.3 Study 8.3.1.17.3.1 - Relevant Earthquake Sources

The objective of this study is to identify and characterize those earthquake sources relevant to seismic hazard analysis of the site (i.e., those sources that could cause significant surface fault displacement or ground shaking at the site).

Activity 8.3.1.17.3.1.1 - Identify relevant earthquake sources. The objective of this activity is to identify earthquake sources that could generate significant surface fault displacements or severe ground motions at the site.

Project scientists continued to compile geologic, geophysical, and seismic data to support seismic source evaluation and characterization for the Probabilistic Seismic Hazard Analysis. This task is nearing completion with a study to identify relevant seismic sources in the Yucca Mountain region. Maximum fault lengths and evidence of Quaternary displacement for 88 known and suspected Quaternary faults in the area are used with empirical relationships to calculate expected maximum moment magnitudes on the faults and average peak acceleration at the Yucca Mountain site. Using the Quaternary activities and the 84th-percentile level of peak acceleration as a basis, 21 Quaternary faults are confidently identified as relevant. There are 26 additional relevant sources if faults with unknown or suspected Quaternary activity are included. All but two of these 47 relevant and potentially relevant sources are located within 60 km of Yucca Mountain. The 47 faults are the most important sources of vibratory ground motion to the potential repository. A report has been prepared for inclusion in a USGS circular and was in technical review (Pezzapane, in prep.).

Project scientists began preparing a report on seismic source evaluations by compiling the necessary data. Short summaries of the available data for some of the more important data compilations were written. Copies of published data were assembled and the data summaries have been evaluated by the seismic source characterization methodology team in a meeting held March 3, 1995, in San Francisco, California. Work continues to compile and summarize published data sets, as well as expected data from site characterization activities.

Activity 8.3.1.17.3.1.2 - Characterize relevant earthquake sources. The objective of this activity is to characterize each relevant earthquake source identified in the previous activity with a spatial description (including an expected depth or depth range), an assessment of activity, evaluations of maximum earthquake magnitude, the size and location of expected coseismic displacements (for sources in or near the controlled area), and the recurrence rate for earthquakes associated with the source. The source characterization includes an evaluation of variability in and dependency of input parameters.

Literature searches and library research were performed to compile information about historical surface-rupturing earthquakes in the Basin and Range Province and normal-faulting earthquakes in analogous regions, theoretical rupture models, and different deformational

aspects of Earth's crust; data that will be useful in the characterization of fault-displacement models and seismic sources at Yucca Mountain.

Faults in the Yucca Mountain region were examined, assessing their paleoseismic data and uncertainties. Project geologists examined the geomorphology of faulting along the southwestern Rock Valley, central Mine Mountain, and northern Cane Springs faults, and evaluated the regional tectonic implications of these structures.

Forecast: Geological, geophysical, and seismic data to support seismic-source evaluations will be compiled. A report that describes the available data to be used for seismic-source evaluations will be written.

3.13.4 Study 8.3.1.17.3.2 - Underground Nuclear Explosion Sources

The objective of this study is to characterize the potential future underground nuclear explosions at the Nevada Test Site that would result in the most severe motions at the repository site.

Activities 8.3.1.17.3.2.1 and 8.3.1.17.3.2.2. These activities rely on available data. No additional data are to be acquired.

There will be no study plan developed for this SCP section. This work is substantially complete, and the results will be reported in a participant technical report or a DOE working paper.

Forecast: No activity is planned in FY 1995.

3.13.5 Study 8.3.1.17.3.3 - Ground Motion From Regional Earthquakes and Underground Nuclear Explosions

The objective of this study is to select or develop ground-motion models that are appropriate for estimating ground motion at the site from earthquakes and underground nuclear explosions. These models will be used to determine the relevancy of seismic sources to a deterministic seismic hazard analysis, identify controlling seismic events, constrain simulated ground motions from controlling seismic events, and estimate the probabilities of exceeding given ground-motion levels at the site.

Activity 8.3.1.17.3.3.1 - Select or develop empirical models for earthquake ground motions. The objective of this activity is to select or develop empirical ground-motion models that are appropriate for estimating earthquake ground motion at the site. The models will predict ground motion as a function of earthquake magnitude and distance between the earthquake source and the site.

Project scientists have assembled seismograms from available data bases and have begun to analyze the variation of ground-motion amplitudes as a function of earthquake magnitude, source-site distance, and frequency spectra. Various regression methods and different functional forms of the attenuation equations are being applied to the ground-motion datasets and the results and uncertainties are being examined. They have chosen appropriate data processing schemes and have continued to collect earthquake-source parameters. Details of various published attenuation relations are being compared and reconciled to facilitate intercomparison of the relations.

Project scientists planned and conducted a Yucca Mountain Earthquake Scenario Workshop February 28-March 1, 1995. The workshop brought together a broad group of approximately 35 earth scientists (25 participants and 10 observers) from various government and academic institutions to discuss earthquake scenarios for Yucca Mountain and vicinity. The objectives of the workshop were to select approximately five scenario earthquakes and to specify geologic constraints and associated uncertainties for input to a set of ground-motion modeling exercises pertinent to the potential nuclear waste repository at Yucca Mountain. Observable fault characteristics such as fault length, displacement and geometry were expressed and used to constrain earthquake parameters such as magnitude, distance and focal mechanism.

Activity 8.3.1.17.3.3.2 - Select or develop empirical models for ground motion from underground nuclear explosions. The objective of this activity is to select or develop empirical ground-motion models that are appropriate for estimating ground motion at the site from underground nuclear explosions at the Nevada Test Site. The models will predict ground motion as a function of the yield and distance of the underground nuclear explosion.

During the reporting period, work commenced on two tasks: assessment of existing ground-motion models for applicability to Yucca Flat underground nuclear explosion data, and one-dimensional uphole/downhole modeling of underground nuclear explosion data. Data bases of ground motion records for both tasks were completed. The uphole/downhole modeling task was completed for vertical records and results were presented at the Fall 1994 Meeting of the American Geophysical Union (Durrani and Walck, 1994). An initial two-dimensional model to be used for purposes of subsurface motion prediction was developed using the one-dimensional models.

Forecast: Analysis of available earthquake data will continue. A report describing the ground-motion data, the analyses, and the results, including peak and frequency-dependent relationships and their uncertainties will be prepared, reviewed, and revised. Earthquake-scenario modeling results will be presented at a ground-motion modeling workshop. A report that describes the different ground-motion models will be written. In addition, the geologic constraints on the scenario earthquakes will be combined with seismological constraints and parameters to develop formal ground motion modeling exercises. Modeling work is scheduled to begin about May 1, 1995, once contracts are in place and modeling exercises are established

Appropriate ground motion models for Yucca Flat underground nuclear explosion data will be determined. The reporting for the one-dimensional uphole/downhole modeling of underground nuclear explosion data will be finalized. The results of the first two tasks and previous work will be synthesized to provide an empirical model for ground motion at Yucca Mountain from underground nuclear explosions. Data tapes containing underground nuclear explosion data will be copied and submitted to the data records management system.

3.13.6 Study 8.3.1.17.3.4 - Effects of Local Site Geology on Surface and Subsurface Motions

The objective of this study is to document systematic effects on surface and subsurface ground motions resulting from the local site geology.

Activity 8.3.1.17.3.4.1 - Determine site effects from ground-motion recordings. The objective of this activity is to determine, from ground-motion recordings, the systematic effects of local site geology on surface and subsurface motions and to identify any significant site-wide bias in ground-motion levels, as compared with average levels for the Southern Great Basin.

Activity 8.3.1.17.3.4.2 - Model site effects using the wave properties of the local geology. The objective of this activity is to develop a calibrated theoretical site-effects model for use in extrapolating the observations documented in Activity 8.3.1.17.3.4.1 to locations and depths where ground-motion predictions are needed, but where instrumental recordings are not available.

The site effects study was completed at the end of FY 1994 (Su et al., in prep). Site amplification factors were determined for 12 3-M_L=5.6 Little Skull Mountain earthquake of June 29, 1992. The 12 stations were located at a variety of sites, including hard rock, alluvial fill, ridge crest, and underground tunnel. The results of the study show that the site amplification factors are well related to the underlying geology and nearby topography at these stations.

3.13.7 Study 8.3.1.17.3.5 - Ground Motion at the Site From Controlling Seismic Events

The objective of this study is to identify the controlling seismic events and to characterize the resulting controlling ground motions. Controlling seismic events are those underground nuclear explosions or 10,000-yr cumulative-slip earthquakes that would generate the most severe ground motions at the site at frequencies of engineering significance.

Activity 8.3.1.17.3.5.1 - Identify controlling seismic events. The objective of this activity is to identify underground nuclear explosions or 10,000-yr cumulative-slip earthquakes that would produce the most severe ground motions at the site at frequencies of engineering significance. There may be more than one controlling seismic event because different events may generate the most severe ground motions in different frequency bands.

No progress was made during the reporting period; this was an out-year activity.

Activity 8.3.1.17.3.5.2 - Characterize ground motion from the controlling seismic events. The objective of this activity is to generate suites of strong-motion time histories and corresponding response spectra representative in amplitude, frequency content, and duration of site ground motions that could be generated by the controlling seismic events.

No progress was made during the reporting period; this was an out-year activity.

Forecast: Identification of controlling seismic events and development of seismic design inputs from them will take place in FY 1996 following completion of the probabilistic seismic hazard analysis (Study 8.3.1.17.3.6). The study plan for this study will be revised to address fault displacement in addition to ground motion.

3.13.8 Study 8.3.1.17.3.6 - Probabilistic Seismic Hazards Analyses

The objectives of this study are to quantify (a) the probability of experiencing ground motions of varying degrees of severity that might result from earthquakes of varying magnitudes and distances from the potential repository site, and (b) the potential for fault displacements of varying degrees of severity to disrupt the surface facilities or the underground repository. (Note: This study combines the objectives originally designated for Studies 8.3.1.17.3.6 and 8.3.1.17.2.1).

Activity 8.3.1.17.3.6.1 - Evaluate Ground Motion Probabilities. The objectives of this activity are to (a) quantify the probabilistic vibratory ground motion values appropriate for seismic design of the potential repository structures, systems, and components, and (b) provide documentation of the bases for these determinations sufficient for regulatory review and licensing.

The study plan for Probabilistic Analyses of Vibratory Ground Motion and Fault Displacement at Yucca Mountain was transmitted to DOE for technical review and was returned by DOE to USGS for comment resolution. Project staff met in Menlo Park, California, to discuss appropriate criteria for selection of expert panels and methodology teams. A preliminary list of experts in the geology and seismology of the Great Basin was drawn up and the first invitations were sent to prospective panelists. At the suggestion of the oversight committee, the size of the panel was increased from 6 to 7 members. Documentation of the selection process was done by the management team.

Project scientists assembled a first draft of the bibliography and data available for the Probabilistic Analyses of Vibratory Ground Motion and Fault Displacement at Yucca Mountain. The data management team completed writing the 3 to 5 page summaries of the data and interpretations available for each topic pertinent to seismic hazards. The summaries are intended to be a road map for the experts to help them select data sets. The overall seismic hazards bibliography was revised by including citations into separate topics.

Activity 8.3.1.17.3.6.2 - Assessment of fault displacement hazard. The objective of this activity is to assess the fault displacement hazard for repository design.

Assembly of data bases and selection of expert panels as discussed for Activity 8.3.1.17.3.6.1 above, also applies to this activity. Project scientists conceptualized and documented a methodology for assessing fault displacement that can be applied to Yucca Mountain. The first meeting of the Fault Displacement Working Group was convened to discuss different methodologies for the assessment and to identify essential data sets. A preliminary approach for fault displacement methodology was developed to create logic trees for Probabilistic Analyses of Vibratory Ground Motion and Fault Displacement at Yucca Mountain.

Forecast: The study plan will be completed and forwarded to the NRC. The first two workshops implementing the probabalistic analyses methodology will be carried out in mid April 1995. Results of these workshops will guide additional data analysis during the remainder of the fiscal year. Alternative methods of characterizing fault displacement for probabilistic analyses will be documented in a report. Future workshops will be planned.

3.13.9 Study 8.3.1.17.4.1 - Historical and Current Seismicity

The objective of this study is to compile information on reported and instrumentally recorded earthquakes that characterize the earthquake potential near Yucca Mountain. This information will be used to help identify and characterize potentially relevant earthquake sources for the deterministic hazard analysis and potentially contributing earthquake sources for the probabilistic hazard analysis; to develop regional earthquake ground-motion models; and to determine local-geologic and depth-of-burial effects on ground motion at the site.

Activity 8.3.1.17.4.1.1 - Compile historical earthquake record. The objective of this activity is to compile a record of historical seismic events in the southern Great Basin or within 100 km of Yucca Mountain that will indicate whether each cataloged seismic event is thought to be a natural earthquake, induced earthquake, underground nuclear explosion, cavity collapse, or blast. For potentially damaging earthquakes ($M \geq 5.5$) in the study region, available information will be compiled on ground-motion intensity, availability of strong-motion records, and extent and style of faulting.

During the reporting period, the catalog of historical earthquakes for the Yucca Mountain region underwent technical review and comment resolution.

The methodology for using the distribution of precariously balanced rocks as an indicator of past ground-motion levels is being documented in a report. Further constraints are being placed on the method as a result of (a) field experiments to determine the force needed to topple precariously balanced rocks, (b) laboratory experiments with models of rocks, and (c) computer modeling.

Activity 8.3.1.17.4.1.2 - Monitor current seismicity. The objective of this activity is to provide empirical information on how often earthquakes are currently occurring in the southern Great Basin; what the orientation, depth, and style of faulting are; how seismic wave amplitudes scale with magnitude and attenuate with distance in the region; and how ground motions vary with depth and with surface geology in the site area.

Seismic monitoring of the southern Great Basin continued. The CalTech-USGS Seismic Processor (CUSP) system operated satisfactorily with very little downtime, most of which was caused by the installation of an uninterruptible power supply. The computer backup system that continuously records network data was put on-line on October 27, 1994. This system replaces the outdated Develocorder system. The new backup system operated satisfactorily with the exception of the period January 1-4, 1995, when software problems resulted in the loss of about 50 percent of incoming data. A paging system was subsequently implemented to alert personnel of problems with the continuously recording backup system. An alarm system was also implemented to indicate the loss of transmission of analog and digital data from microwave telemetry sites.

Calibration of analog seismic stations continued during the reporting period. The calendar year 1994 cycle of calibrations was completed. An experiment was conducted to evaluate the calibration of CUSP waveforms. It was discovered that apparent amplitudes were too low by a factor of two. Corrections to Richter Magnitude determinations for calendar year 1994 data were being implemented.

The catalog of events and waveform data for calendar year 1994 was completed. The catalog includes 2,034 earthquakes and 249 explosions. Work was continuing on determining focal methanisms for 1994 data. Richter Magnitude determinations were compared with duration magnitudes for about 220 earthquakes. At small magnitudes, Richter Magnitude is significantly smaller than the corresponding duration magnitude. A report discussing the 1994 seismicity was being prepared.

Project seismologists deployed portable seismic instruments in Rock Valley and at locations along the Crater Flat seismic reflection line. Data were collected for most of the seismic shots associated with the seismic reflection line. Preliminary data analysis was completed. Analysis continued on the Little Skull Mountain data set. Over 500 aftershocks were analyzed to determine seismic moment and stress-drop estimates. Upgrade of the seismic network to digital recording continued. The permitting process was initiated for five additional sites bringing to sixteen the number in various stages of approval. Eight sites were selected for the installation of strong-motion instrumentation. Preparation of permit requests was initiated.

Activity 8.3.1.17.4.1.3 - Evaluate potential for induced seismicity at the site. The objective of this activity is to evaluate the potential for human activity to significantly perturb natural seismic hazard at the site by inducing seismicity at or near the site. To date, the human activities that have been identified as having a potential to induce seismicity in the site region are the impoundment of Lake Mead, the testing of nuclear devices at the Nevada Test Site, and mining of the repository itself.

Project seismologists met with tunnel engineers at Yucca Mountain and consulted with other project personnel concerning the strategy for seismic instrumentation of the ESF to monitor for excavation induced seismicity.

Forecast: Review of the catalog of historical earthquakes for the Yucca Mountain will be completed and a report issued. The report on precariously balanced rocks in the vicinity of Yucca Mountain and their implications for levels of past ground motion will be completed.

Seismic monitoring of the southern Great Basin will continue with periodic maintenance and calibration of equipment. The report on 1994 seismicity will be completed. Hardware and software upgrades will continue to integrate digital stations into the network. A technical procedure on the deployment, calibration, and operation of the portable seismic instruments will be written. Strong motion instrumentation will be installed in the vicinity of Yucca Mountain and technical procedures for its installation and operation will be prepared. Portable seismometers will be installed in the ESF to monitor for excavation-induced seismicity.

3.13.10 Study 8.3.1.17.4.2 - Location and Recency of Faulting Near the Prospective Surface Facilities

The objective of this study is to identify a site in Midway Valley sufficiently large for surface facilities in which significant Quaternary faults are absent.

Activity 8.3.1.17.4.2.1 - Identify appropriate trench locations in Midway Valley. The objective of this activity is to identify appropriate trench locations at proposed locations for repository surface facilities that are important to safety through detailed geologic mapping and remote sensing studies. The recommended locations will be used in trenching investigations in Activity 8.3.1.17.4.2.2.

This activity was completed and the trench locations are documented in the report identified in Activity 8.3.1.17.4.2.2 below.

Activity 8.3.1.17.4.2.2 - Conduct exploratory trenching in Midway Valley. The objectives of this activity are to investigate the possible occurrence of late Quaternary surface fault rupture in the vicinity of planned surface facility locations important to safety and to identify sites without evidence of significant late Quaternary faulting. This activity will provide input into the location and design of surface facilities important to safety, particularly those associated with waste handling.

No progress was made during the reporting period; report to be completed in the third quarter of FY 1995.

Forecast: This activity and the resulting report is planned to be completed in FY 1995.

3.13.11 Study 8.3.1.17.4.3 Quaternary Faulting Within 100 km of Yucca Mountain, Including the Walker Lane

The objective of this study is to identify Quaternary faults within 100 km of Yucca Mountain; and to characterize faults capable of future earthquakes with magnitude such that associated ground shaking could impact design or affect performance of the waste facility.

Activity 8.3.1.17.4.3.1 - Conduct and evaluate deep geophysical surveys in an east-west transect crossing the Furnace Creek fault zone, Yucca Mountain, and the Walker Lane. The objectives of this activity are:

- To identify and locate potential seismic source zones, including possible through-going extensions of the Walker Lane, beneath the Oligocene-Miocene cover of the Yucca Mountain area

- To determine width and subsurface geometry of such extensions and of the Furnace Creek fault zone and the relation of these features to detachment faults and to Quaternary faults

- To evaluate the postulated incipient rift zone at Crater Flat

- To characterize the crustal velocity structure and define lateral inhomogeneities in that structure in the Yucca Mountain area

- To trace the 5- and 10-s events found on Death Valley COCORP profiles through the Yucca Mountain region and, if possible, to trace reflections from the upper and lower carbonate aquifers, the Precambrian-Cambrian Pahrump Group and Noonday Dolomite, and the Proterozoic basement across the Furnace Creek fault and through the area of the projected northwest continuation in the subsurface of the Las Vegas Valley shear zone

- To identify differences in mass caused by variation in source lithology in the upper few kilometers of the crust, and correlate those sources with reflections obtained in the seismic reflection survey, or with conductivity features obtained in the magnetotelluric survey

- To identify differences in magnetic field caused by sources in the upper few kilometers of the crust and correlate those sources with reflections obtained in the seismic reflection survey, or with conductivity features obtained in the magnetotelluric survey

- To characterize conductivity structures of crust in the Yucca Mountain region, focusing in particular on the conductivity signature of the Walker Lane and Walker Belt, and if possible, trace the signature into the subsurface of conductive units such as the Eleana Formation or nonconductive units such as the lineated and

mylonitized gneisses (lower plate?) of the northern Amargosa Desert, and to correlate these features at their offsets with Quaternary faults

- To provide data for analysis to determine if buried magma bodies are present in the vicinity of Yucca Mountain.

No progress was made during the reporting period; this was an out-year activity; however, note that intermediate and deep reflection data were obtained along a 23-mi traverse across Crater Flat and Yucca Mountain in November 1994 as part of Activity 8.3.1.4.2.1.2.

Activity 8.3.1.17.4.3.2 - Evaluate Quaternary faults within 100 km of Yucca Mountain. The objectives of this activity are:

- To establish the abundance, distribution, and geographic orientation of known and suspected Quaternary faults within 100 km of the site
- To characterize Quaternary and Holocene fault and fracture pattern within 100 km of the site and, if feasible, to relate that pattern to regionally important wrench fault systems, including the Walker Lane, the Death Valley-Furnace Creek fault zone, and the Mine Mountain-Pahranagat shear zone
- To characterize Quaternary faults within 100 km of the site whose apparent length or recurrence rate indicate potential for future earthquakes of magnitude sufficient to affect design or performance of the waste facility
- To evaluate the recurrence history of that part of the Death Valley-Furnace Creek fault zone within 100 km of the site
- To identify fault scarps within 100 km of the site that may have been overlooked during conventional geologic field surveys and that may not have been apparent on conventional vertical aerial photography
- To verify the existence and age of scarps in the Nevada Test Site area that were detected by low-sun-angle photogeologic interpretation
- To determine whether the Beatty scarp originated through tectonic or fluvial processes, or both, the nature of the movement along the scarp, if tectonic, and the age of the scarp.

Regional reconnaissance studies, through evaluation of air photos and field observations, were conducted to identify Quaternary faults that may be capable of generating ground motions >0.1 g peak ground acceleration at the potential repository site. More detailed, follow-up investigations of faults in the Amargosa Desert, Belted Range, Oasis Valley, and Cawich Range areas, and along the Bare Mountain and Death Valley-Furnace Creek fault zones included field mapping, air photo interpretations, and scarp studies to determine fault lengths, slip rates, displacements per faulting event, age of faulting, and

recurrence intervals. The resulting data are being compiled on maps and in tables designed to provide the kinds of data required to characterize those faults that are potentially capable of generating peak ground acceleration >0.1 g.

A report and map, at a scale of 1:250,000, shows known or suspected Quaternary faults that are characterized for purposes of identifying sources of future seismic events (Piety, in prep.). Klinger and Piety (1994) report that studies along the Death Valley fault indicate that three and possibly four faulting events occurred during the late Quaternary, with vertical displacements of about 2.6 to 3.5 m per event; the calculated slip rate is 3 to 5 mm/yr. Along the Furnace Creek fault zone, also during the late Quaternary, three and possibly four events occurred with lateral displacements of about 2.5 to 3.5 m per event and slip rates of 5 to 12 mm/yr.

Activity 8.3.1.17.4.3.3 - Evaluate the Cedar Mountain earthquake of 1932 and its bearing on wrench tectonics of the Walker Lane within 100 km of the site. The objective of this activity is to evaluate the relevance of the 1932 Cedar Mountain earthquake to potential sources of ground shaking and rupture in that part of Walker Lane within 100 km of Yucca Mountain.

No progress was made during the reporting period; this was an out-year activity.

Activity 8.3.1.17.4.3.4 - Evaluate the Bare Mountain fault zone. The objectives of this activity are to evaluate the potential for ground shaking associated with future movement along the Bare Mountain fault zone; to estimate the age of the most recent faulting on the Bare Mountain frontal fault; to estimate the recurrence intervals of faulting; to determine the nature and age of faulting within the fault complex east of the frontal zone, and to determine the nature of tectonic control of the location and orientation of the main wash in Crater Flat; and to determine the subsurface configuration of fault zones.

Project geologists conducted analysis of previously collected data on the Bare Mountain fault. Anderson and Klinger (in prep.) concluded, based on detailed mapping, studies of fault scarps, and trench-wall mapping, that the Quaternary rate of faulting along this feature is very low, and that the age of the most recent faulting event may be no younger than late Pleistocene. The Project Principal Investigator led a field trip to Bare Mountain for members of the USGS on November 16, 1994. Included in the field trip were stops at BMT-1 and BMT-2. Discussions at the two trenches centered around evidence for or against multiple surface faulting events. The earliest estimated start date for additional trenching and soil pits at Bare Mountain is in April. The Principal Investigator attended a USGS-sponsored workshop on probabilistic seismic hazards held in Salt Lake City February 15-16, 1995, and discussed new slip-rate data for the Death Valley, Furnace Creek, and Bare Mountain faults.

Activity 8.3.1.17.4.3.5 - Evaluate structural domains and characterize the Yucca Mountain region with respect to regional patterns of faults and fractures. The objectives of this activity are to map faults and lineaments within 100 km of the site and identify those with geomorphic expression indicative of Quaternary faulting, to classify the area into

subareas (domains) containing relatively homogeneous fault and lineament, to map the areal extent of desert varnish coating, and to identify areas of suspected hydrothermal alteration.

No progress was made during the reporting period; this was an out-year activity.

Activity 8.3.1.17.4.3.6 - Analyze rotation (drag) of bedrock along or over suspected wrench faults based on rotation of paleomagnetic declinations. The objective of this activity is to determine the spatial and temporal patterns of oroflexure bending based on rotation of paleomagnetic declinations.

No progress was made during the reporting period; this was an out-year activity.

Forecast: The draft and final reports with accompanying tables and maps that will characterize the seismic characteristics of suspected Quaternary faults in the Amargosa Desert will be written and submitted. The report on Quaternary faulting within 100 km of Yucca Mountain also will be written and submitted. Trenches will be excavated and logged at Bare Mountain. Final reports on the Bare Mountain and Death Valley-Furnace Creek fault zones, characterizing the Quaternary history and seismic characteristics, will be written.

3.13.12 Study 8.3.1.17.4.4 - Quaternary Faulting Proximal to the Site Within Northeast-Trending Fault Zones

The objective of this study is to evaluate the potential for ground motion resulting from future movement of Quaternary strike-slip faults east and south of the site area.

Activity 8.3.1.17.4.4.1 - Evaluate the Rock Valley fault system. The objective of this activity is to determine the location, spatial orientation, length, width, Quaternary recurrence rate, and the location, amount, and nature of Quaternary movement of the Rock Valley fault system. Estimate the total displacement, including strike-slip and dip-slip components, of Quaternary datums.

Two 3-m (10-ft) deep trenches and six 1.5 m (5-ft) deep trenches were excavated on the south and north strands of the Rock Valley fault system in December 1994. Subsequently, trench logs were prepared on three of the trenches, and samples for radiometric dating (six for thermoluminescence and eight for uranium series) were collected. Initial findings include (a) on the south strand, the top soil unit is broken over fault traces in the youngest faulting event, which resulted in less than 10 cm of vertical displacement (horizontal displacement is also indicated, but amount could not be determined); and (b) on the north strand, perhaps three faulting events with 50 to 100 cm of apparent vertical displacements and with unknown but significant horizontal displacement took place. Probable mid-to-late Holocene sediments are not faulted at the east end of the trenched area on the north strand.

Activity 8.3.1.17.4.4.2 - Evaluate the Mine Mountain fault system. The objective of this activity is to determine the location, spatial orientation, length, width, Quaternary

recurrence rate, and the location, amount, and nature of Quaternary movement of the Mine Mountain fault system.

Project scientists conferred with colleagues on interpretive and structural problems along flank of Shoshone Mountain, and Mid Valley. No trenching is planned along the Mine Mountain fault system.

Activity 8.3.1.17.4.4.3 - Evaluate the Stagecoach Road fault zone. The Stagecoach Road fault evaluation has been transferred to Study Plan 8.3.1.17.4.6 (Quaternary Faulting in the Site Area). (See Section 3.13.14.)

Activity 8.3.1.17.4.4.4 - Evaluate the Cane Spring fault system. The object of this activity is to determine the location, spatial orientation, length, width, Quaternary recurrence rate, and the location, amount, and nature of Quaternary movement of the Cane Spring fault system.

Project geologists reviewed published data and aerial photographs. Five days were spent in the field to obtain measurements and other data on Cane Spring fault system. Field work was curtailed because of the inaccessibility of Area 27. Project geologists must be escorted by someone with proper clearance and must coordinate with such a person at a convenient time. This is important because the Cane Spring fault zone extends through Area 27.

Project geologists reviewed accessible field exposures with colleagues and discussed interpretations.

Forecast: Project geologists will draft, edit, and prepare trench logs for inclusion in data packages. They will conduct a review and analysis of structural interpretations based on trench exposures, geomorphology, and detailed mapping. A final report providing characterization of the Rock Valley fault zone as a seismic source will be prepared. A report will be prepared that provides the final characterization of the Mine Mountain fault zone as a seismic source. Field work, such as mapping and sampling, will continue on the Cane Spring fault provided that access can be gained to Area 27. Data will be compiled and analyzed for the preparation of a report on the seismic characterization of the Cane Spring fault zone.

3.13.13 Study 8.3.1.17.4.5 - Detachment Faults at or Proximal to Yucca Mountain

The objectives of this study are to supply information pertaining to distribution, displacement rate, and age of detachment faults proximal to Yucca Mountain. Key questions regarding detachment faults are whether they represent a significant earthquake source, and whether they conceal a significant earthquake source at depth. To resolve both questions, activities are focused on resolving the Quaternary behavior of postulated detachment faults.

A field review of all five activities in the detachment faulting study plan was conducted. The review team visited the Calico Hills, Red Mountain, Point of Rocks, southern

Crater Flat, northern Bare Mountain, Bullfrog Hills, Daylight Pass, Birdtrack Hills, and Yucca Mountain. Postulated detachment faults at each of these areas were examined. Simonds et al. (in prep.) summarize all available data resulting from each of the activities in this study.

Activity 8.3.1.17.4.5.1 - Evaluate the significance of the Miocene-Paleozoic contact in the Calico Hills area to detachment faulting within the site area. The objectives of this activity are to determine whether the contact of Miocene volcanic rocks on Paleozoic strata is tectonic or depositional; if tectonic, to determine Quaternary activity, if any, of the possible detachment fault; and, if Quaternary, to determine the direction and age of movement, attitude of fault plane, and nature of deformation of the Miocene (upper plate?) sequence.

Simonds (in prep.[a]) shows that although low-angle faults are present locally along the Miocene/Paleozoic contact, they represent small gravity slide blocks or slabs that formed in response to down-to-the-west offset on adjacent high-angle normal faults. Elsewhere, the Miocene/Paleozoic contact is mostly a depositional contact, and there is no evidence of detachment fault movement parallel to that surface. Peer review continued on Simonds (in prep.[b])

Activity 8.3.1.17.4.5.2 - Evaluate postulated detachment faults in the Beatty-Bare Mountain area. The objective of this activity is to determine if postulated detachment faults in the Beatty Bare Mountain have been active in the Quaternary.

Geologic mapping of key areas within the Beatty Mountain quadrangle continued. The geologic map of the Big Dune quadrangle was compiled on four 1:12,000 scale orthophoto base maps, map unit descriptions were completed, and the map was in technical review.

Activity 8.3.1.17.4.5.3 - Evaluate the potential relationship of breccia within and south of Crater Flat to detachment faulting. The objective of this activity is to determine whether breccias tectonically emplaced on low-angle surfaces beveled across the Paleozoic and younger strata are slide masses or near-surface parts of a detached upper plate; and, if either, how they relate to postulated Quaternary detachment faulting.

No progress was made during the reporting period; this was an unfunded activity.

Activity 8.3.1.17.4.5.4 - Evaluate postulated detachment faults in the Specter Range and Camp Desert Rock areas. The objective of this activity is to determine whether the basal contact of the Horse Spring Formation is depositional or tectonic; and, if tectonic, to determine whether movement was Quaternary or older, and if Quaternary, to determine the direction and amount of offset, the amount of extension, and the style of intentional deformation of the upper plate.

Field work was conducted to evaluate geologic mapping in the Point of Rocks area and a previously prepared report was revised for inclusion in the final detachment fault report.

A field review of all five activities in the detachment faulting study plan was conducted. The review team visited the Calico Hills, Red Mountain, Point of Rocks, southern

Crater Flat, northern Bare Mountain, Bullfrog Hills, Daylight Pass, Birdtrack Hills, and Yucca Mountain. Postulated detachment faults at each of these areas were examined.

Activity 8.3.1.17.4.5.5 - Evaluate the age of detachment faults using radiometric ages. The objectives of this activity are to determine if the subdetachment basement and the Bare Mountain massif cooled through the blocking temperatures of zircon and apatite during the Quaternary period; and to determine if the Northern Amargosa core complex cooled through the blocking temperatures of muscovite and biotite during the Quaternary period.

Seven preliminary ages determined by fission track methodology on metamorphic minerals from Bare Mountain and the Bullfrog Hills were completed, and the results are being analyzed.

A mineral separate of hornblende was prepared and sent to the New Mexico Bureau of Mines for analysis. Preliminary fission track age determinations were obtained and work continued to refine Ar-40/Ar-39 age determinations at the New Mexico Bureau of Mines.

Forecast: Mapping is nearly complete for most of the study areas; mapping will be completed for the Beatty Mountain quadrangle. The review draft of the manuscript on detachment faulting will receive technical review. Other reports will be prepared, presenting data and interpretations resulting from several of the activities.

3.13.14 Study 8.3.1.17.4.6 - Quaternary Faulting Within the Site Area

The objectives of this study are to identify and characterize Quaternary faults that intersect or project toward the surface facility, repository, or controlled area; and to identify and characterize Quaternary faults at the site whose length or recurrence rate suggest a potential for future earthquakes with magnitudes such that associated ground shaking could affect design or performance of the waste facility.

Activity 8.3.1.17.4.6.1 - Evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain. The objectives of this activity are to synthesize and evaluate data pertaining to location, orientation, length, width, Quaternary recurrence rate, and location, amount, and nature of Quaternary movement of faults within the site area; and to identify unrecognized faults in the site area.

The Quaternary faults being studied in detail are Crater Flat, Solitario Canyon, Windy Wash, Bow Ridge, Paintbrush Canyon, Fatigue Wash, and Stagecoach Road. Although Quaternary movement has not been demonstrated, the Ghost Dance fault is also included. Discussions concerning the investigations now being conducted are given as part of Activity 8.3.1.17.4.6.2 (see below), inasmuch as most of the current work is directed toward mapping and related studies of trenches that transect these features. Analysis and evaluation of the collected fault data are continuing, and reports are being prepared on various topics as the data become available. A field trip was conducted for personnel involved in the probabilistic

analysis of fault displacement, to evaluate preliminary results of the fault investigations (primarily from the trench studies described below).

Work continued on preparation of a digital file containing fault data for USGS Miscellaneous Investigations Map I-2520 and it was submitted for printing. On this 1:224,000-scale map, all mapped faults within a 400-sq. km area, centered approximately on Yucca Mountain, are plotted in detail, with dips of fault planes shown as well as notations describing relationships that can be observed at various points along the fault traces (including any evidence of Quaternary movement). Locations of trenches are also shown.

Activity 8.3.1.17.4.6.2 - Evaluate age and recurrence of movement on suspected and known Quaternary faults. The objectives of this activity are to determine through trenching and trench wall mapping the location, spatial orientation, length, width, Quaternary recurrence rate, interconnections at the surface, and the location, amount, and nature of Quaternary movement of the Windy Wash, Solitario Canyon, Ghost Dance, and Paintbrush Canyon faults and other suspected or possible Quaternary faults within the site area; and to determine through trenching and dating the age, amount, and nature of offset and the recurrence history of the Bow Ridge fault system and to evaluate that information in context with data contributed by other studies on the age, nature, and origin of fracture coatings and fissure fillings deposited within that zone.

Crater Flat fault

Four trenches were excavated across Crater Flat fault, but studies have not started.

Solitario Canyon fault

Logging activities began at Trench SCF-T2. Contacts and structural features were mapped, a preliminary log was compiled, and soil and lithostratigraphic units are currently being described. Additional sections of a natural exposure, labeled SCF-E1, were cleaned and flagged, exposing an additional strand of the fault. Soil profiles were completed in Trench SCF-Tf. Field reviews were conducted for all of the completed logs.

Windy Wash fault

Preliminary logs were examined and revised in the field at Trenches CF2 and CF3 on the Windy Wash fault. Selected contacts and structural features were remapped, and soil and lithostratigraphic unit descriptions were reviewed and revised. Project geologists began field revisions of preliminary trench logs, and internal technical reviews of Trenches CF2, CF2.5, and CF3 were conducted. Samples were collected for cosmogenic dating of surficial deposits exposed in Trenches CF-2 and CF-3.

Bow Ridge fault

The collection of field data from Trench 14D on the Bow Ridge fault was completed. Field reviews of the logs from both Trench 14D and 14C were also completed. The final report for the fault is being revised to incorporate results of the field reviews.

Paintbrush Canyon fault

Project geologists completed logs for walls #1, #2, and #4 at the exposures of the Paintbrush Canyon fault on Busted Butte. Descriptions of stratigraphic units and measurements of unit thicknesses and amounts of fault displacements were obtained. The top of wall #4 was reexamined and critically evaluated for faulting relations and unit boundaries, resulting in revisions of previous interpretations of stratigraphy and paleoseismicity. Exposures of the fault were prepared for the required technical field reviews.

Preliminary logs of the south wall and parts of the north wall and inner slot of Trench A1 on the northern segment of the Paintbrush Canyon fault were completed, bringing to near completion the preparation of the log for the entire trench. Samples of deposits exposed along the trench walls were collected for geochronological dating, and samples of basaltic ash were submitted for geochemical analysis and comparison with possible source tephra from the Lathrop Wells volcanic center.

Fatigue Wash fault

Samples for dating surficial deposits exposed in Trench CF-1 were collected.

Stagecoach Road fault

Stratigraphic logs of Boreholes SR-1, SR-2, and SR-3, drilled near Trench SCR-T1 on the Stagecoach Road fault were completed. Bedrock (8.5 Ma tuff) was encountered at depths of about 300 ft in the hanging wall.

Ghost Dance fault

Project geologists examined bedrock sections exposed in Trenches GDF-T1 and GDF-T3 with geologists involved in Study 8.3.1.4.2.1 (Characterization of the Vertical and Lateral Distribution of Stratigraphic Units Within the Site Area) to evaluate the structural and bedrock stratigraphic features that can be observed along the trench walls. Trench GDF-T1 was subsequently deepened, and key sections cleaned. Flagged pins in Trenches T2, T4, GDF-T1, and GDF-T3 were surveyed and coordinates established as preliminary steps in the preparation of field trench logs for each trench. Photographs were taken of the vertical walls of Trench GDF-T1 and of the vertical wall on the south side of the pad for Borehole USW UZ-7a where the Ghost Dance fault is exposed. Samples were collected for laboratory analyses from Trenches T2 and T4, and samples for U-series dating were obtained from Trench GDF-T1.

Forecast: Final reports will be written on the Crater Flat, Solitario Canyon, Windy Wash, Paintbrush Canyon, Bow Ridge, Stagecoach Road, and Ghost Dance faults, as well as on northwest-trending faults (such as the Sundance fault).

3.13.15 Study 8.3.1.17.4.7 - Subsurface Geometry and Concealed Extensions of Quaternary Faults at Yucca Mountain

The objectives of this study are to provide data on the distribution of mass, magnetic gradients, geoelectric features, and seismic velocities and reflections that will aid in evaluating the continuity of Quaternary faults where concealed by Holocene and late Pleistocene surficial deposits; to evaluate the data and its limitations; to evaluate the possibility that Quaternary faults exposed as high-angle faults at the site continue to depth as planar, high-angle faults, or alternatively, flatten at depth and merge with one or more long-angle faults; and to provide information on continuity of rock units within the repository and controlled area to assist the investigation of site geology.

There will be no study plan developed for this SCP section. There are eight activities in this SCP section. Field geophysical surveys critical to, and analysis and assessment of, the subsurface geometry and concealed extensions of Quaternary faults are to be performed under Study Plan 8.3.1.4.2.1, "Characterization of the Vertical and Lateral Distribution of Stratigraphic Units Within the Site Area." Geophysical surveys conducted for Study 8.3.1.4.2.1 will be examined as inputs for assessing concealed faults and subsurface geometries. The implications of subsurface geometry and concealed extensions of Quaternary faults will be addressed as part of the sensitivity studies associated with Study 8.3.1.17.3.6.

Forecast: Study Plan 8.3.1.4.2.1 will be revised to incorporate this scope of work. The Site Design and Test Requirements Document will be revised to reflect this change.

3.13.16 Study 8.3.1.17.4.8 - Stress Field Within and Proximal to the Site Area

The objective of this study is to provide data on ambient stress at the site and its immediate vicinity that will aid in evaluating most favored orientation and nature of future movement on faults within the site area, stability of potential pathways for radionuclide travel controlled by or related to fracture aperture, the stability of mined excavations, response of rock mass to thermal loading, and applicability of tectonic models. A secondary objective is to evaluate the potential relevance of paleostress data to prediction of future stress orientations.

As originally described in the SCP, four activities were included in Study 8.3.1.17.4.8. Because (a) the objectives and parameters assigned to two of the activities are very similar, and (b) tasks assigned to the other two activities are adequately covered by Study 8.3.1.17.4.12 (Tectonic Models and Synthesis), the scope of this study is limited to one activity as indicated below.

Activity 8.3.1.17.4.8.1 - Evaluate Present Stress Field Within and Proximal to the Site Area. The objective of this activity is to measure the vertical and lateral variation of in situ stress at and proximal to the potential repository by conducting hydraulic fracturing stress measurements and observations of stress-induced borehole breakouts in boreholes that are scheduled to be drilled adjacent to the site. The magnitudes and orientations of the horizontal and vertical in situ stresses are the principal parameters to be determined.

The study plan was prepared and reviewed by the USGS, and transmitted to DOE-YMSCO for review. The scope of the study involves in situ stress measurements in new boreholes adjacent to Yucca Mountain using the hydraulic fracturing method combined with observations of stress-induced borehole breakouts as recorded on geophysical logs.

Forecast: Work will continue on a revised study plan. Conduct of the study depends upon the drilling of proposed boreholes at localities adjacent to Yucca Mountain.

3.13.17 Study 8.3.1.17.4.9 - Tectonic Geomorphology of the Yucca Mountain Region

The objective of this study is to document Quaternary uplift and subsidence within the Yucca Mountain region and to evaluate regional variation in the nature and intensity of Quaternary faulting.

Activities 8.3.1.17.4.9.1 through 8.3.1.17.4.9.3. Activities 8.3.1.17.4.9.1 and 8.3.1.17.4.9.2 define a work scope documented in the Extreme Erosion Topical Report (DOE, 1993b), and that is still in progress through the surface mapping performed under Study 8.3.1.5.1.4. The work scope for Activity 8.3.1.17.4.9.3 is to be transferred to Study Plans 8.3.1.17.4.3 and 8.3.1.17.4.12.

There will be no study plan developed for this SCP section. The work scope already has been, or will be, transferred to, and performed under, Studies 8.3.1.5.1.4, 8.3.1.17.4.3, and 8.3.1.17.4.12.

Forecast: The study plans and Site Design and Test Requirements Document will be revised to reflect this change.

3.13.18 Study 8.3.1.17.4.10 - Geodetic Leveling

The objective of this study is to evaluate possible historical and contemporary vertical displacements across potentially significant Quaternary faults within 100 km of Yucca Mountain. A secondary objective is to characterize the historical rate of uplift and subsidence in the Yucca Mountain region and evaluate the possible existence of tectonic boundaries, coinciding perhaps with the Walker Lane or with the Furnace Creek fault zone, that may separate domains with differing rates of uplift and subsidence.

Three activities are assigned to Study 8.3.1.17.4.10: Activity 8.3.1.17.4.10.1, Relevel base-station network, Yucca Mountain and vicinity; Activity 8.3.1.17.4.10.2, Survey selected base stations, Yucca Mountain and vicinity, using global positioning satellite; and Activity 8.3.1.17.4.10.3, Analyze existing releveling data, Yucca Mountain and vicinity. Because the tasks involved in conducting these activities are closely allied, the progress and descriptions of the work being performed are combined in the following paragraphs.

To date, 90 km of leveling have been accomplished out of a total of 200 km of level-lines involved in the releveling program. In addition, quadrilaterials spanning five of the faults suspected of Quaternary movement within and near the site area are included in the periodic resurveys. Results to date indicate that no significant movements have taken place within these quadrilateral areas since measurements were begun in the early 1980s. Periodic resurveys of a trilateration network centered on Yucca Mountain, were reported in Savage et al. (1994), and also show that no significant deformation took place during the reporting period, except in the vicinity of Little Skull Mountain where measured rates of change in line lengths between stations is considered to reflect coseismic activity associated with the magnitude 5.4 earthquake that occurred there in 1992.

Twenty new global positioning system stations were identified and surveyed across Death Valley, and were tied into the Yucca Mountain global positioning system network on the east and to the Navy's Coso network on the west. This 140-km-long profile spans several major structural features including the Furnace Creek fault zone, Death Valley, Panamint Mountains, Panamint fault zone, and prominent faults near Coso Junction, California.

Forecast: The resurveying of the level-line will be continued and the data will be submitted to the Local Records Center. A progress report on the global positioning system profile from Beatty, Nevada, to Coso Junction, California will be prepared and submitted.

3.13.19 Study 8.3.1.17.4.11 - Characterization of Regional Lateral Crustal Movement

The objective of this study is to evaluate rates and orientation of historical and current crustal strain based on analysis of existing data on seismicity, historical fault, offset, and creep in the Basin Range and at Yucca Mountain.

There will be no study plan developed for this SCP section. The activity in this SCP section will receive and evaluate information from Study 8.3.1.17.4.10. No unique data are to be acquired by this study. This scope of work is to be transferred to Study 8.3.1.17.4.10.

Forecast: Study Plan 8.3.1.17.4.10 and the Site Design and Test Requirements Document will be revised to reflect this change.

3.13.20 Study 8.3.1.17.4.12 - Tectonic Models and Synthesis

The objectives of this study are to synthesize data relevant to tectonics; to develop a model or range of models that establishes the causal relation between application of tectonic forces and formation of structures observed at Yucca Mountain and vicinity, to link observed rates of formation of structures with regional rates of crustal strain; to forecast changes in tectonic setting and the manner in which changes will affect both regional crustal strain rate and tectonic stability in the Yucca Mountain region, to estimate effect of changes on rate and nature of crustal strain at Yucca Mountain and vicinity, and to estimate future rate of tectonic processes at Yucca Mountain.

Activity 8.3.1.17.4.12.1 - Evaluate tectonic processes and tectonic stability at the site. The objectives of this activity are:

- To synthesize gravity studies at Yucca Mountain and vicinity and define regional variations in mass, and attribute them, as appropriate, to variations in crustal thickness, degree of melting, shallow intrusions, distribution of specific stratigraphic units, and faults

- To synthesize magnetic studies at Yucca Mountain and vicinity and define areal variations in magnetic field and relate them, as appropriate, to distribution of specific stratigraphic units, shallow intrusions, and subsurface configuration of faults

- To evaluate regional extent of detachment faults, wrench faults, volcanic rocks belonging to the Death Valley-Pancake Range belt, regional pattern of oroclinal bending (oroflexing), regional extent of Miocene ash-flow tuffs and associated pyroclastic and epiclastic rocks, and regional extent of Paleozoic rocks known to be aquifers, aquitards, or to provide favored surfaces of detachment or thrusting

- To synthesize and evaluate information pertaining to Quaternary wrench faulting in the Walker Lane (Las Vegas to Cedar Mountain), constrain, if possible, the rate of offset and recurrence interval of potentially significant faults (including the Bare Mountain fault and faults analogous to those near Cedar Mountain), and evaluate the applicability of this information to geologic hazards at the site

- To synthesize and evaluate information pertaining to detachment faults at Yucca Mountain and vicinity and constrain the rate of displacement, subsurface configuration, and risk posed by this class of faults

- To synthesize and evaluate information pertaining to normal (and north-trending oblique and strike-slip faults) at the site and vicinity, and possibly constrain aggregate strain rate, subsurface configuration, recurrence interval, and risk posed by this class of faults

- To synthesize and evaluate information pertaining to the northeast-trending left-lateral strike-slip faults at the Nevada Test Site and vicinity, and constrain slip rate, recurrence interval, and risk posed by this class of fault.

Project geologists conducted a field review of evidence for detachment faults and strike-slip faulting relevant to tectonic models and tectonic domains that constitute the tectonic setting of Yucca Mountain. Technical data bearing on faulting in the Pahute Mesa area and volcanism in Crater Flat were reviewed.

Activity 8.3.1.17.4.12.2 - Evaluate tectonic models. The objectives of this activity are to formulate a range of tectonic models that relate the nature and estimated rates (including bounding values) of Quaternary processes (volcanism, faulting, uplift, and subsidence, lateral strain, and possibly folding) of potential significance to design and performance of the repository at Yucca Mountain; to evaluate temporal changes in tectonic activity and resulting changes in fractures and other structural features of potential hydrologic significance at and in the vicinity of Yucca Mountain (relate tectonic cycle, if it exists, to tectonic model(s)); to ensure that assumptions, inferences, and conclusions concerning tectonic processes that are important to design and performance of the repository are consistent with tectonic models applicable to the site; and to ensure that uncertainty in the data, assumptions, and inferences concerning rates and nature of those tectonic processes that are important to design or performance of the repository is adequately reflected in conclusions about those processes.

Work continued on the development of the boundary element modeling technique and code to meet QA standards. The boundary element modeling technique is a mathematical method of simulating crustal conditions for purposes of analyzing fault behavior.

Activity 8.3.1.17.4.12.3 - Evaluate tectonic disruption sequences. The objective of this activity is to evaluate disruption sequences involving faulting, folding, uplift and subsidence, and volcanism that are of potential significance to design or performance of the repository.

No progress was made during the reporting period; this was an out-year activity.

Forecast: A summary evaluation of tectonic models, boundary-element modeling results, and tectonic processes at Yucca Mountain and its geologic setting will be submitted. Models will be refined, and data will continue to be synthesized during the remainder of FY 1995, so that a revised model can be reported in FY 1996. The report "Current Evaluation of Tectonic Models for the Yucca Mountain Region" will be revised in light of new data from relevant activities and conceptual evaluations.

3.14 STUDY 8.3.1.20.1.1 - ALTERED ZONE CHARACTERIZATION

The objective of this study is to characterize the effects on the region around the potential repository that is altered by hydrothermal processes that develop in response to heating of the repository block due to radioactive decay of the emplaced nuclear waste.

Activity 8.3.1.20.1.1.1 - Field and laboratory studies of the effects of mineralogical and mechanical changes on transport processes. The impact of chemical, mineralogical and mechanical change on hydrological properties, particularly on porosity and permeability, and the kinetics of these processes, will be evaluated as a function of several environmental variables, including temperature, fluid composition, fluid flow rate, stress, and water volume to surface area ratio. Also considered in these studies will be the relationship between pore geometry and permeability as recrystallization occurs within crushed, fractured and intact materials.

Experiments were started to evaluate the effect on water composition and secondary mineral development of water-rock interaction in vitric and vitrophyric rocks that occur in the near-vicinity of the repository. The experiments will determine the rates of reactions, the controls on the solid phases that form that could influence radionuclide transport, and the effect of reactions on water chemistry. These experiments are still under way. In support of the experimental studies, efforts are under way to update available data on precipitation and dissolution kinetics, from literature sources.

Experiments are being developed to measure the impact of water-rock interaction effects (such as recrystallization, precipitation and dissolution) on porosity and permeability. These experiments support efforts to establish the capability to evaluate the impact of coupled hydrological-geochemical processes on thermal response of the repository block, and on water flux and composition entering the Engineered Barrier System/Near-Field Environment. The experimental apparatus to be used in these studies is a plug flow reactor, with flow controllers and temperature control. The system is undergoing testing. Experiments in support of these studies, which are being conducted under static fully saturated conditions at 90°, 150°, and 250°C, are continuing. These experiments focus on a range of lithologies, as a means of describing the magnitude of variation among lithologic units that may be expected for the limiting case of slow flow under saturated conditions.

Experimental measurements of precipitation rates will be conducted to evaluate the kinetics of changes in the altered zone regions where refluxing or mineral precipitation may occur. Some of these experiments will focus on the effects of solutes on precipitation rates, which is an area that has received very little attention, and yet is of major importance in establishing reaction kinetics. The experimental system to accomplish these measurements is being renovated and updated to allow appropriate measurements to be made.

Activity 8.3.1.20.1.1.2 - Evaluating existing and developing future capabilities to simulate coupled hydrothermal and reactive transport processes. The objectives of this activity are to compare codes and to evaluate their suitability for application to altered zone efforts in two steps. The first step will be to review the capabilities of the codes as they currently exist. Comparisons will be made of how the codes simulate well-documented processes. Once several codes are selected, they will be used to simulate the results of the ongoing experimental studies, and to predict the outcome of those studies. They will also be used to simulate field properties of sites selected for field study. These forecasts will be used to refine modeling strategies, as discrepancies between measurement, observation, and field data become evident.

Codes to conduct the coupled simulations, and to aid in the design of experiments evaluating coupled processes, have been obtained and installed, and test cases designed. These codes will be used to identify experimental conditions, to ensure that processes of interest will be observed and adequately monitored.

Activity 8.3.1.20.1.1.3 - Performing bounding calculations of the effect of coupled processes in the altered zone on near-field properties. The parameter values, limits and/or ranges that must be obtained to define the waste package environment are described in the SCP. To generate these values from models of specific characteristics of the near-field, initial conditions must be defined in a manner compatible with the respective near-field models. This activity will generate bounding values for those inputs.

Initial reconnaissance computations to bound the effects of coupled hydro-geochemical processes were completed and reported (Glassley, 1994). These computations demonstrate that simulating mass transport of large quantities can be accomplished. The conditions and chemical system used in the simulations were selected to determine if significant changes might occur, and whether there might be unforeseen problems in conducting the simulations. No problems were encountered, and the results demonstrated that, for the selected conditions, large masses could be redistributed around the repository.

Activity 8.3.1.20.1.1.4 - Performing bounding calculations of the effect of coupled hydrological and reactive transport processes on thermal evolution. Within the SCP, the parameter values, limits and/or ranges are described that must be obtained to satisfy the resolution strategy dealing with thermal loading decisions. To generate this information, the potential designs and operation of the repository must be used as initial conditions for simulations that determine the response, over time, of the altered zone to waste emplacement. This activity will generate bounding values for the range of scenarios considered for repository design and operation

No progress was made during the reporting period; this was an out-year activity.

Forecast: Experiments and code activities will continue. New simulations will be conducted to refine bounding conditions and expected processes.

CHAPTER 4 - REPOSITORY DESIGN

This chapter reports progress in designing the potential repository, which consists of surface facilities, underground facilities, and shafts and ramps connecting the surface and underground facilities. When the repository is prepared for permanent closure, seals will be constructed for the shafts, ramps, and exploratory boreholes. Thus, this section discusses progress in evaluating seals. The repository facilities will be designed to meet various functional and regulatory requirements, including those of the NRC.

4.1 CONFIGURATION OF UNDERGROUND FACILITIES (POSTCLOSURE) (SCP SECTION 8.3.2.2)

Development of repository layout concepts continued during the current reporting period. The modifications to the baselined ESF/Repository interface layout that were described in Progress Report #11 also continued. Revision of both the baselined ESF/Repository interface drawings and the Advanced Conceptual Design Summary Report (CRWMS M&O, 1994b) is planned for the latter part of FY 1995.

4.1.1 Design Activity 1.11.1.1 - Compile a Comprehensive List of All the Information Required From Site Characterization to Resolve This Issue

The objective of this design activity is to summarize, in one place, all the information required from site characterization for design.

Work begun last period continued. The main work has involved determining the data (information) needed from site characterization by the repository surface and subsurface design groups, and developing the format in which to transmit the data request. The following types of data needs have been identified:

- Geographic Data (topography and natural features, boundaries and cultural features, borehole location)
- Geologic Data (stratigraphy, structure, ground-water hydrology)
- Geoengineering Data (in situ rock mass conditions, rock index properties, joint parameters, rock mass quality indices, rock mechanical properties, rock thermal and thermomechanical parameters, rock dynamic properties, rock mass performance parameters, soil parameters)
- Natural Phenomena (air temperature/humidity, rainfall/snowfall, floods, wind and tornadoes, earthquakes)
- Baseline Environmental Conditions (air/noise, water quality/quantity).

Repository structures, systems, and components for which the data are needed have been identified. These structures, systems, and components are being related to the needed data by means of a matrix.

Most data needs are required only in sufficient time to support the draft Environmental Impact Statement, the Technical Site Suitability determination, and the License Application. These relatively longer-term data needs will be tabulated and formally requested in a comprehensive Repository Data Needs Document (CRWMS M&O, in prep.[d]). The Data Needs Document will identify both the intended use and the preferred source of the data (either surface-based testing or ESF construction and testing). It will also state the accuracy required from the data. SCP Table 8.3.2.2-5 will be consulted as the starting point for the evaluation of accuracy required.

Some data, however, are needed from now through the end of FY 1996 to better define the stratigraphy and to establish better stratigraphic control for repository and ESF design and current ESF construction. These near-term needs include surface mapping of the top and bottom of the TSw1 unit in Solitario Canyon and where possible, geophysical logging in some of the older boreholes in the general repository area. These near-term needs have been communicated through meetings and letters.

Forecast: The comprehensive Data Needs Document is scheduled to be completed in June 1995. The YMSCO is expected to direct that study plans be revised to include identified data needs and to eliminate unneeded data.

4.1.2 Design Activity 1.11.1.2 - Determine Adequacy of Existing Site Data

The objective of this design activity is to determine whether the available site data are sufficient for licensing. If they are not, then it must be determined whether additional data must be gathered or whether the design must be changed to accommodate the existing data. This is an ongoing determination up to License Application.

This activity is related to Design Activity 1.11.1.1. It involves evaluating the quantity and quality of currently available data, and subsequent reevaluating new or additional data as received. The proposed geophysical logging of old boreholes mentioned in Section 4.1.1 relates to this activity because it is an attempt to use boreholes previously drilled under a non-QA program to now obtain qualified site characterization data that can be used. This is a more cost effective and timely way to obtain additional data; the alternative would be to drill additional holes.

Forecast: Efforts in this activity will become an ongoing activity through most of License Application Design. The effort will end when all data necessary for License Application are available.

4.1.3 Design Activity 1.11.1.3 - Document Reference Three-Dimensional Thermal/Mechanical Stratigraphy of Yucca Mountain

The objective of this design activity is to produce topical reports that describe the three-dimensional thermal and mechanical stratigraphy of Yucca Mountain. The description will rely on information gathered from the site and will be entered into the Reference Information Base.

During this reporting period, work on a related design activity, 1.11.3.2, also resulted in progress towards the completion of this activity. An analysis was begun during the previous reporting period (CRWMS M&O, 1994c) to further define zones acceptable for waste emplacement within the limits established by the key assumptions. This analysis included the evaluation of lithostratigraphic and thermal/mechanical stratigraphic nomenclature and unit characteristics needed to identify the available, three-dimensional waste emplacement volume. A three-dimensional computer model of the Topopah Spring welded thermal/mechanical units was developed using the LYNX geology and engineering modeling system.

At the close of this reporting period, work was continuing on this task, but at that time, significant changes and unit definitions had been developed and applied to the three-dimensional computer model. Some of these significant items are discussed in more detail under the description of design activity 1.11.3.2. A report summarizing the results of the current efforts on the thermal/mechanical stratigraphy is scheduled for completion in April 1995 (CRWMS M&O, in prep.[e]).

Forecast: Work on the thermal/mechanical stratigraphy of Yucca Mountain will continue into the next reporting period and through FY 1996. The current report describing the work in FY 1995 will be issued in April 1995.

4.1.4 Design Activity 1.11.1.4 - Preparation of Reference Properties for the Reference Information Base

The objective of this design activity is to produce topical reports giving properties and describing how they were determined from field and lab measurements. These reports will be compared with the requirements of this issue to ensure that the Reference Information Base contains the required data. This work includes rock characteristics, initial conditions (in situ stress and temperature), geology (stratigraphy and structure as reported in the three-dimensional graphics model of Yucca Mountain), and design data (e.g., areal power density and borehole spacing).

The Reference Information Base is a controlled data base that summarizes data and information for use in site suitability evaluations, design and development activities, and performance assessment analyses. This data base is continually updated to reflect the progress in defining the data requirements of the primary data users, and in preparing reference properties for incorporation into the data base. This design activity is, therefore, fully implemented and controlled by procedure.

Forecast: Future progress reports will assume routine maintenance and expansion of the data base continues. Only noteworthy events, or changes to data requirements or submittals, will be reported.

4.1.5 Design Activity 1.11.2.1 - Compile Waste Package Information Needed for Repository Design

The objective of this design activity is to determine what waste package information is needed for design of the underground facility, to obtain such data, and to document it in the Repository Design Requirements Document (CRWMS M&O, 1994d).

The following data were developed, included in the Controlled Design Assumptions Document (CRWMS M&O, 1995a), and used in the repository conceptual design process. The following data were developed: waste package heat output vs. time; spent nuclear fuel thermal characteristics; waste package dimensions and weights (with and without filler material); maximum cladding temperature; and three time schedules for waste arrival, surface processing of waste packages, and underground emplacement of waste. These data will be incorporated in the Repository Design Requirements Document and the Engineered Barrier Design Requirements Document (DOE, 1994e) when they are next revised.

Forecast: Development of the above information is an ongoing effort, and the information used in repository design will be updated as changes occur. This design activity will continue to report information needs resulting from waste package and repository conceptual design processes.

4.1.6 Design Activity 1.11.3.1 - Area Needed Determination

The objective of this design activity is to determine the area required for the underground facility.

The emplacement area needed is typically expressed in one of two ways. The first is by dividing the total initial thermal output (kW) of the waste inventory by the local, or unit, thermal load (kW/acre). The second is by dividing the total waste inventory (MTU) by the local, or unit, waste loading (MTU/acre)[1]. The lower the thermal load or waste loading, the greater the area needed for emplacement. The total area needed is the emplacement area plus that for development, operations, performance confirmation, and any other needs.

[1]It should be noted that thermal output or power density in kW/acre changes with time as the waste decays, while the mass loading in MTU/acre does not. The relationship between mass loading and power density depends on the burnup and age of the spent nuclear fuel but at emplacement the conversion for the average fuel (average for boiling water reactor plus pressurized water reactor fuel) using a youngest fuel first selection criteria is about 1kW/MTU.

A design basis thermal load has not yet been selected by the Project. During the last two progress report periods, the Project assumed that the surface and subsurface configurations are to accommodate thermal loading operations for both a primary, high thermal load of 80 to 100 MTU/acre, an average local areal mass loading, and an alternative, low thermal load 25 to 35 MTU/acre (CRWMS M&O, 1995a). The repository, if limited to the primary area (CRWMS M&O, 1995a), as defined in Mansure and Ortiz (1984), cannot accommodate all of the 70,000 MTU statutory maximum at a low thermal loading. At 25 to 35 MTU/acre, only approximately 26,000 to 37,000 MTU can be disposed of within the primary area. Thermal management of waste during emplacement, as discussed later, would increase the amount that can be disposed, but still may not allow disposal of all 70,000 MTU. The current working concept for a repository layout (CRWMS M&O, 1995a) can accommodate 70,000 MTU at a thermal load of 82 MTU/acre or greater within the primary emplacement area located west (also referred to as the upper emplacement block) of the Ghost Dance fault. The combination of the primary emplacement areas east (also referred to as the lower emplacement block) and west of the Ghost Dance fault can accommodate a thermal load as low as 66 MTU/acre.

The current approach to thermal loading is to define a design thermal load that, taking into account design options and operating parameters, will accommodate the full statutory capacity of the repository. Near-term engineering activities will be focused on developing the reference design for an 80 to 100 MTU/acre areal mass loading and identifying the design features needed to maintain the alternative loading options. Flexibility related to waste package spacing and emplacement drift selection will be used to accommodate the waste for the alternative loading options.

It is widely recognized that a low thermal load limited to emplacement within the primary area would allow disposal of considerably less than the maximum 70,000 MTU allowed. This was considered unacceptable. Three approaches that could potentially address this problem include: (1) the development of a waste emplacement management strategy, (2) increase the area for emplacement by using the expansion areas, and (3) a combination of additional area and a waste emplacement management strategy.

The first strategy, waste emplacement management, is sometimes referred to as a thermal management strategy, but even though management of the thermal load is a major part of the strategy, it goes beyond strictly thermal aspects of the problem. Waste emplacement management is an attempt to reduce the effects of emplacement at a given thermal load (i.e., make the results of a given thermal load be the same as the results of an unmanaged lower thermal load). Waste emplacement management concepts include (a) varying the waste package spacing within the emplacement drifts, (b) initially placing waste packages in widely spaced drifts and later placing more in intermediate drifts, (c) repositioning the previously emplaced waste packages just before repository closure, (d) managing the waste stream to increase the waste age before emplacement, and (e) providing periodic or continuous ventilation through the emplacement drifts following emplacement. These concepts are currently the subject of thermal and ventilation studies.

The most obvious method of accomplishing the second approach, provide more area for emplacement, is to provide additional area outside of the primary area. Placement at 20 MTU/acre without any thermal management will require 3,500 acres to place all 70,000 MTU. As explained previously, the total area required would be greater. Because the primary area consists of only 1,055 acres, additional site characterization would be required. Such additional site characterization is not currently part of the Program Plan (DOE, 1994a). The cost, and any schedule impacts, have not been fully evaluated.

The third approach considers a combination of additional area and waste emplacement management. A concept that has recently been proposed to provide additional area within the primary area would be achieved by developing a multilevel repository. Three emplacement levels could be developed within the primary area west of the Ghost Dance fault, and two emplacement levels could be developed within the primary area east of the Ghost Dance fault. The emplacement levels would have a vertical separation of approximately 50 to 100 m. By placing the waste packages at 25 MTU/acre within each level, 70,000 MTU can be placed within all five levels (the additional levels would be smaller than the east and west emplacement areas in the current layout). Preliminary results indicate that the preclosure behavior of such a multilevel repository may be essentially the same as a single-level repository having a thermal load of 35 MTU/acre. The postclosure behavior would be essentially the same as a single-level repository having a thermal load of about 70 to 80 MTU/acre. More analysis is needed to determine if such a multilevel repository would have acceptable performance.

The waste emplacement management approach also points out the need to begin stating thermal loading requirements in terms of measurable performance because that is the only way the acceptance of a given thermal loading and thermal management approach can be judged.

Forecast: Waste emplacement management studies will continue with a goal of determining the maximum amount of waste that can be emplaced within the primary area for a given thermal load. A report of these studies is expected to be completed in June 1995 (CRWMS M&O, in prep.[f]). Efforts in determining areas to be characterized outside of the primary area depend somewhat on the preliminary results of the multilevel repository to be presented in that study.

4.1.7 Design Activity 1.11.3.2 - Usable Area and Flexibility Evaluation

The objective of this design activity is to analyze the three-dimensional structure and stratigraphy of Yucca Mountain to identify usable areas and ensure sufficient area is characterized to allow flexibility in design. This will be accomplished by producing graphic cross sections and maps that can be used for repository layouts to ensure they fit the geology.

Progress Report #11 stated that the Project assumed that the repository will be limited to the TSw2 geologic unit within the primary area (CRWMS M&O, 1995a). This assumption limited the scope of this design activity to investigation within the TSw2 unit and the primary

area. The assumption has since been revised to allow minor adjustments of the primary area boundary and to allow some emplacement areas in the TSw1 unit (CRWMS M&O, in prep.[f]).

An analysis was begun during the previous reporting period (CRWMS M&O, 1994e) to further define zones acceptable for waste emplacement within the limits established by the key assumption. The analysis considered geotechnical, thermal, and hydrologic characteristics of the rock and their application to repository construction. The analysis established vertical and horizontal limitations on repository development, mostly expressed in terms of standoff distances from certain features. The LYNX computer modeling software was used in the analysis to develop a three-dimensional model of the area. The model was based on interpretation of borehole geophysical logs and used the USGS LYNX Model YMP.R1.1 as a guide. Updates to this work are described below. A report summarizing the results of current efforts is scheduled for completion in April 1995 (CRWMS M&O in prep.[g]).

As originally defined by Ortiz et al. (1985), the TSw1/TSw2 contact was based on a change in lithophysal cavity content by volume from greater than approximately 10 percent in TSw1 to less than approximately 10 percent in TSw2. This contact was selected because of its thermal/mechanical significance. Some problems were encountered, however, when the USGS estimates of lithophysae, which Ortiz et al. (1985) used in their evaluation, were found to include not only the cavity, but also the vapor-phase mineral halo and alteration rind (Rautman, 1985). Several years later, at least two of the stratigraphic picks selected by Ortiz et al. (1985) were discovered to be inconsistent with the rest of the boreholes (Peck, 1991). A committee of evaluators examined core from five boreholes and concluded that the "contact of the TSw1/TSw2 units is a consistent lithologic contact" and "corresponds to the lithologic contact recognized by the USGS as the base of the upper lithophysal unit of the Topopah Spring Member." This statement redefined the TSw1 and TSw2 thermal/mechanical units, but ignored the significance of the original definition. Work on this design activity (1.11.3.2) has found that the original TSw1/TSw2 contact, as defined by Ortiz et al. can be recognized in core, and more significantly, can be recognized in borehole geophysical density logs. This has resulted in the proposal that the original definitions of the TSw1 and TSw2 thermal/mechanical units be reinstated because they have more significance in terms of the thermal and mechanical behavior of the rock, and more bearing on the siting of the emplacement horizon.

This analysis will be ongoing because its purpose is to update results as additional information becomes available from site characterization. New or revised information from all boreholes was included in the analysis performed during the current reporting period.

Results of the current efforts are being used to revise the boundaries of repository layouts previously developed. They also are the basis for the initial layouts of the multilevel repository mentioned in Section 4.1.6.

Forecast: The repository horizon definition will continue to be refined throughout FY 1995, concentrating on the vicinity of the primary area. Little or no study of potential expansion areas will be done until direction is received from the Project (CRWMS M&O,

1995a). A report describing the work to date on defining the potential repository block (CRWMS M&O, in prep.[g]) is expected to be issued in April 1995.

4.1.8 Design Activity 1.11.3.3 - Vertical and Horizontal Emplacement Orientation Decision

The objective of this design activity is to provide the performance evaluation to document the decision on emplacement orientation.

An evaluation of potential waste package emplacement modes (CRWMS M&O, in prep.[f]) was in process and is scheduled for release during the next reporting period. The emplacement mode selection will be used for the repository Advanced Conceptual Design but will require verification during subsequent License Application Design.

Forecast: The Emplacement Mode Evaluation Report will be released.

4.1.9 Design Activity 1.11.3.4 - Drainage and Moisture Control Plan

The objective of this design activity is to provide postclosure design requirements for the layout of the underground facility to limit the amount of water in contact with the container (emplaced waste package) to provide a favorable containment and isolation environment. The objective is not only to limit the amount of water in contact with the container, but also promote the migration of moisture away from the container.

Current work under this activity is closely related to activities reported in Section 4.1.16 and, to a lesser extent, to those discussed in Section 4.1.8. The current strategy is to develop a repository layout to accommodate a range of thermal loading from low to high (CRWMS M&O, in prep.[d]). Repository layouts being developed are considering combinations of waste package and emplacement drift spacing to accommodate the thermal loading strategy.

Current repository layouts provide for the entire repository emplacement level to drain to a low point (sump) at the northeast end with subsequent water removal. The emplacement drifts themselves are sloped so that no ponding will occur in them. This drainage concept applies as well to alternative layout concepts currently being studied.

As Advanced Conceptual Design proceeds, options for controlling moisture movement will be evaluated as part of the alternatives for improving repository performance.

Forecast: Work will continue in FY 1995 to further define the moisture control plan.

4.1.10 Design Activity 1.11.3.5 - Criteria for Contingency Plan

The objective of this design activity is to provide criteria for a contingency plan to deal with unexpected conditions that may be encountered during site characterization and repository construction to provide confidence that the repository, as constructed, will provide waste containment and isolation for the required repository capacity. Examples of unexpected conditions that may be encountered include small zones of perched water, localized heavy fracture zones, water recharge pathways, and localized heavily lithophysae-rich zones.

Studies to define the potential repository block, as described in Section 4.1.7, and, to a lesser extent, studies of a potential multilevel repository, as described in Section 4.1.6 support this activity. In addition, as reported in Progress Report #11, significant horizontal offsets of excavations from faults are being planned.

Forecast: Limited work on this activity will continue through FY 1995 and through License Application Design. The potential repository block definition will continually be examined as information is received from site characterization activities. In addition to the current allowances for offsets from faults, repository layout studies will make additional allowances for unexpected conditions.

4.1.11 Design Activity 1.11.4.1 - Chemical Changes Resulting From the Use of Construction Materials

The objective of this design activity is to quantify the chemical changes (e.g., change in pH) that result from the use of a given quantity of construction material (e.g., cement).

Related work is discussed under the appropriate activities of Chapter 5, Section 5.2.6.

Forecast: The related activities discussed in Chapter 5, Section 5.2.6, will provide the forecast information.

4.1.12 Design Activity 1.11.4.2 - Material Inventory Criteria

The objective of this design activity is to establish appropriate limits on the inventory of materials that will be used in construction and operation of the underground facility and write criteria for the appropriate limits on the inventory of materials that will be left in the openings after decommissioning, including backfill.

As part of performance assessment support of surface-based testing and ESF design, construction, and operation, a number of evaluations have been made to bound the potential for impacts to waste isolation capabilities of the site from both surface and subsurface materials that are expected to remain at the site postclosure. Specifically, these analyses provide input to the design process controls intended to regulate the use of materials at the site, which are implemented in the Determination of Importance Evaluations. The major

areas where quantitative bounding calculations for use of tracers, fluids, or materials were performed for specific materials are (a) muck storage, (b) discharge from the sanitary sewage leach field, (c) grouted instrumentation in boreholes, and (d) the North Ramp excavation (Design Package 2C). Because in most instances the links between geochemical perturbations and changes to the release of radionuclides are understood only qualitatively, bounding scenarios are evaluated relative to their impact to the ambient composition of the system, which for some compositional components includes the waste form itself.

The muck storage pad, located a few hundred meters southeast of the North Portal pad, was evaluated for its impact to the geochemical properties of the site. Because the excavated rock is so similar to the material at the surface, there should be little impact to local geochemistry from the natural material. Any entrained organic from accidental releases, however, could be mobilized from the muck pile into the subsurface. Therefore, the organic content of the excavated material was limited to no more than the lowest organic content of soils from the Midway Valley. In addition, if this material is to be used as backfill, more severe restrictions on organic content may be required and specific storage conditions may be needed to meet those requirements.

The sanitary sewage leach field is planned to be located about 1 km southeast of the North Portal pad. Compositional effect of the sanitary sewage leach field discharge was evaluated based on the amount organic material introduced into the "downstream" portion of the potential repository saturated-flow path below the area of the leach field. To bound the impact to waste isolation from this material, calculated areas of an organic plume were compared with a radionuclide plume from the potential repository. This calculation produced a conservative estimate that only about 12 percent of the radionuclide path would be overlapped by the affected area. Because the saturated zone is just one part of the mobile aqueous radionuclide pathway, and the indications that in this "downstream" environment organic material may enhance both fixation of dissolved metals and transport of constituents, this estimate was interpreted to indicate negligible potential for impact to waste isolation.

The potential impacts from grouted in-place borehole instrumentation were evaluated in terms of compositional perturbations from retained sulfate-bearing grout and interference with borehole sealing capabilities. These considerations led to the recommendation for estimating the amount of grout that would be left in the formation once the grouted instrumentation had been drilled out of the hole (for final sealing). In addition, no more than 50 percent of any identified sealing interval was recommended to have grout emplaced in it before the final sealing of the borehole.

For North Ramp Excavation and Construction (Design Package 2C), the potential impacts to waste isolation from retained constituents of diesel exhaust were bounded using (a) the estimated distribution of diesel usage throughout the North Ramp, (b) conservative assumptions on retention and dissolution of diesel particulate matter, NO_x gases, and SO_2 gas, and (c) a three-dimensional, advective-dispersive transport calculation. These three constituents were evaluated relative to their potential to perturb the concentrations of dissolved organic carbon, NO_3^-, and SO_4^{2-} in the aqueous phase at the closest potential waste package. On the basis of the evaluation, limiting emission rates for the diesel exhaust

constituents were provided to the design group, and tests were planned to measure actual retention of these constituents in the tunnel. A similar calculation provided limits for these constituents from *all* retained substances in the North Ramp.

The dry chemical used in the planned fire protection system was specifically evaluated. The extinguishing material, which consists primarily of monoammonium phosphate ($NH_4H_2PO_4$) and ammonium sulfate ($(NH_4)_2SO_4$), was evaluated for potential impacts to waste isolation resulting from perturbations to the nitrate (NO_3^-), sulfate (SO_4^{2-}), and phosphate (PO_4^{3-}) content of the ground water. The amount of potentially retained fire suppression material was based on a design fire that required the discharge of 200 lb (90.72 kg) of the compound over 40 ft (12.2 m) of the tunnel, together with the removal of 95 percent of the material via vacuuming and removing equipment with material adhering to it. The peak compositional perturbations at the closest potential waste package (37-m offset) were calculated using a three-dimensional advective dispersive transport equation. These values indicate that for the bounding scenario that changes to sulfate and nitrate can be expected to represent negligible impact for waste isolation. The perturbation to phosphate in the system was viewed as negligible because the spent fuel itself contains about 0.01 percent phosphorus, which vastly exceeds the amount potentially added from the fire system.

A procedure was prepared that requires reporting the use and removal of planned and actual tracers, fluids, and materials at the Yucca Mountain site by all affected YMP organizations and individuals. Data on planned use and removal are input to Determination of Importance Evaluations that evaluate potential impacts of use and removal of tracers, fluids, and materials on Q-List items, site characterization testing, and waste isolation. The Determination of Importance Evaluations may restrict use and removal of tracers, fluids, and materials (e.g., on underground water and organics use). Data on actual use and removal, including accidental spills/releases and associated cleanup, are provided to the tracers, fluids, and materials data base, a component of the YMP technical data base.

Forecast: The effects of materials on waste isolation and establishing controls will continue to be evaluated throughout FY 1995.

4.1.13 Design Activity 1.11.4.3 - Water Management Criteria

The objective of this design activity is to establish appropriate limits on the amount of water that will be used for underground facility construction and operation, indicating amounts and locations for individual operations, and to convey those limits to Issue 4.4.

Several analyses bounding the potential impacts of water use during construction and operation of the ESF have been developed and implemented in the repository surface and subsurface design packages. The primary analyses were developed for the underground discharge of dust control water during construction of the North Ramp and the discharge of septic tank effluent from the operation of the sanitary sewer.

The potential impact of water discharged in the North Ramp on repository performance was evaluated in terms of effects on aqueous radionuclide transport through the backfill portion of the Engineered Barrier System and unsaturated zone. The greatest sensitivity was related to the near-field aqueous radionuclide transport through the backfill portion of the Engineered Barrier System. Potential impacts were bounded using total system performance assessment calculations of expected variations in the integrated radionuclide releases from the Engineered Barrier System compared with the variations in near-field transport that could occur due to increased water saturation.

Septic tank discharge in the sanitary sewage leach field was analyzed to identify a suitable location for the effluent discharge such that the infiltrating water and contaminants could not encroach the conceptual repository or other potentially usable areas for waste emplacement. In addition, the analysis considered potential impacts to the saturated zone, particularly with respect to the migration of contaminants into areas below potential waste emplacement locations. The analysis established the nearest location to the North Portal such that the leach field discharge is not expected to affect existing conditions near potential waste emplacement locations or impact performance as a result of changes along aqueous radionuclide pathways.

Forecast: Water use during the construction and operation of the ESF will continue to be evaluated. The surface water use analysis will be updated to improve its consistency with field observations and measurements. The underground water use evaluation will be reviewed in light of any improved analyses for water movement, waste package corrosion, radionuclide release, and radionuclide transport in the geosphere.

4.1.14 Design Activity 1.11.5.1 - Excavation Methods Criteria

The objective of this design activity is to identify any constraints to be placed on excavation because of postclosure performance considerations. The concern is to limit excavation induced changes to rock mass permeability.

The status of this work is essentially described in Progress Report #11. The only change was a minor change in one of the assumptions regarding the excavation method. The previous assumption was that all repository drift excavation would be performed by mechanical methods. That assumption has been changed to allow drill-and-blast excavation where mechanical excavation is not feasible (CRWMS M&O, 1995a). Progress Report #10 stated that blasting constraints would be developed only if further Advanced Conceptual Design studies indicated significant excavation by blasting will be required for repository development. Significant excavation by blasting is not expected to be required for repository development. Therefore, special blasting constraints need not be developed, and standard controlled blasting specifications are sufficient.

Forecast: Tracking of progress in equipment development by the Colorado School of Mines, as discussed in Progress Report #11, will continue throughout FY 1995.

4.1.15 Design Activity 1.11.5.2 - Long-Term Subsidence Control Strategy

The objective of this design activity is to evaluate the potential for postclosure surface subsidence and also the impact of ground movement in the vicinity of the excavations on waste containment and isolation.

No progress was made during the reporting period; this was an unfunded activity.

Forecast: Subsidence mechanisms and roof stability will be studied as part of thermomechanical and ground control studies to be performed during FY 1995. Reports on each are planned to be issued during the next reporting period (CRWMS, M&O, in prep.[h] and in prep.[i]).

4.1.16 Design Activity 1.11.6.1 - Thermal Loading for Underground Facility

The objective of this design activity is to establish the allowable thermal loading as a function of waste age and burnup. Determination will start with far-field calculations and consider near-field effects to ensure practical waste distribution exists that meet near-field constraints.

A proposal for a Program Thermal Strategy was developed that provided the steps needed to obtain sufficient information to make a thermal loading recommendation. On the basis of available information and analyses, the thermal effects in the mountain have been determined to be complex and will require in situ thermal testing to resolve a number of the issues. Thus, the proposed strategy recommends maintaining flexibility and provides a phased approach to obtaining the necessary information.

The proposed thermal loading strategy provides the basis for moving forward in light of the uncertainties about thermal effects on engineered and natural barrier performance. The goal of the strategy is to focus design activities on reference design thermal load of 80 to 100 MTU per acre as a working hypothesis. This loading allows emplacement of up to the statutory maximum of 70,000 MTU in less than the primary repository area of approximately 1,200 acres.

Risks associated with this strategy will be mitigated by maintaining design flexibility to accommodate higher and lower areal mass loadings and by pursuing a robust performance confirmation program. A lower loading would be appropriate if testing and modeling show that the negative aspects of heat dominate the performance of the natural system. A higher loading would be appropriate if testing and modeling show that the reference thermal load is not a high enough loading to produce a prolonged dry environment for the Engineered Barrier System, and that preclosure can continue to be met at a higher thermal loading. The highest areal mass loading to be considered for emplacement will be specified in the license application, as the Maximum Design Thermal Loading. The license application will focus on a single reference design thermal load with alternative thermal load options in case that loading does not perform as required by the regulations.

Using this strategy, the evaluation of Technical Site Suitability in 1998 will rely on evaluations of preclosure and postclosure performance of the repository system for the reference thermal load and the alternative areal mass loadings that are being carried as options. Similarly, the 2001 license application will present the design and performance assessment predictions for a repository system that will safely operate at the reference thermal load, as well as for the alternative loadings. For the license update to receive and emplace waste in 2008, DOE will present test data that demonstrate adequate understanding of thermal effects to justify initial waste emplacement and will further refine the long-term performance confirmation program. Results of this testing program, together with experience gained during operation of the repository, will provide the basis for the license amendment for repository closure and decommissioning.

Forecast: The thermal strategy will continue to be refined as it is implemented in the engineering, site, and regulatory areas. The goal is to remain flexible and modify the approach as test results are obtained, and refine supporting analyses.

4.1.17 Design Activity 1.11.6.2 - Borehole Spacing Strategy

The objective of this design activity as originally planned was to develop a strategy for the spacing of waste packages within the repository, which included spacing of the emplacement boreholes and of the drifts containing the emplacement boreholes. As stated in Progress Report #11, however, the Project has changed from emplacement of waste packages in boreholes to in-drift emplacement of waste packages. Thus, the objective now is to develop a strategy for the spacing of waste packages that includes spacing of the emplacement drifts and waste packages within the drifts.

This activity is closely related to Section 4.1.16 (Design Activity 1.11.6.1). The emphasis in Section 4.1.16, however, is on developing an overall repository thermal load and related goals and constraints, while the emphasis here is in developing the details to achieve the selected thermal load and meeting the established thermal goals and constraints. This activity is also related to the waste emplacement management concepts discussed in Sections 4.1.6 and 4.1.8.

As explained in Progress Report #11, emplacement drift spacing and waste package spacing are interdependent. For a given thermal loading, waste package and emplacement drift spacing are inversely related. A small waste package spacing and a large emplacement drift spacing can produce the same overall thermal loading as a large waste package spacing and small emplacement drift spacing. The temperatures on the surface of the waste package and in the rock mass, however, will not be the same for each.

A high thermal load requires both the drift spacing and waste package spacing to be small, thus allowing little ability to vary spacing. Thus, the relationship and consideration mentioned above are less important. The ability to vary spacings increases as thermal loading decreases, and much ability to vary exists at low thermal loads. Current studies are on layouts that meet the range of thermal loads currently identified as preferred and options.

Current studies are considering two basic strategies to maintain flexibility with regard to thermal loading. One concept places closely spaced waste packages in widely spaced (90 m) drifts; the second concept places more widely spaced waste packages in more closely spaced (45 m) drifts (CRWMS M&O, in prep.[f]). The first concept is being called "localized disturbance." Because of the close waste package spacing, above-boiling conditions and dryout zones would be created immediately surrounding the drift. The drifts would be far enough apart that the boiling fronts of adjacent drifts would not coalesce, thus allowing mobilized water to move downward in the sub-boiling region between the drifts. The second concept is being called "minimal disturbance" and represents an attempt to distribute the heat as evenly as possible to create the least disturbance to the host rock. The decision as to which concept is considered more desirable has not been made. Thermal modeling of these concepts has begun.

Both concepts are superimposed on a pattern of parallel drifts spaced 22.5 m on center. In the first concept, waste packages are placed in every fourth drift, and in the second concept, they are placed in every other drift. This allows flexibility to emplace at higher thermal loads if desired.

Forecast: Modeling of thermal load emplacement concepts will continue through FY 1995. A report on waste emplacement management is expected to be issued in June 1995 (CRWMS M&O, in prep.[f]).

4.1.18 Design Activity 1.11.6.3 - Sensitivity Studies

The objective of this design activity is to determine predicted repository thermal and thermomechanical response to variations in model input data. This information will be used to evaluate adequacy of data gathered and to determine that goals have been met with proper confidence.

These studies continued during the reporting period. The systems study being conducted to evaluate the thermal loading that should be selected for the underground facility has progressed. A summary of the recent efforts follows:

Systems studies were done with the main objective of providing input to the design of the testing program. A limited sensitivity analysis on selected parameters important to waste isolation and thermal loading was done to establish the influence of heat on performance. As a part of this ongoing sensitivity analysis, the effect of the multi-purpose canister on the system will be examined. This effort will provide recommendations that can be translated into requirements for testing and/or analysis to ensure that the program has a robust characterization program.

Various uncertainties were identified as important to understand and resolve so that performance could be better established, to support the thermal loading decision. On the basis of the analyses completed, it is clear that critical factors contributing to the hydrologic uncertainties need to be better understood. They include bulk permeability, fracture densities,

and percolation flux. More effort needs to be done to obtain verification of hydrothermal models and ultimately validate these models with some underground data. The waste package corrosion performance and impact of fuel variability must be understood. Reducing uncertainty associated with thermal goals and establishing how important a particular goal is will be needed. Some uncertainties in cost related to site characterization, construction, and operation concepts must be resolved. Finally, the site characterization program must address the extent of usable repository area. The useable area will dictate the capacity of the repository once the appropriate thermal load is determined (see Section 4.1.6).

Thermal management, which can include aging of the waste, ventilating the emplacement drifts, and selecting specific waste packages based on heat output, has been found to provide a certain amount of flexibility toward tailoring the thermal effects in the mountain, particularly for the preclosure period. To further evaluate some of these thermal management options, an effort to couple a ventilation code with a thermohydrologic code was initiated under the Thermal Loading System Study. The VTOUGH code is being coupled with a ventilation code. The resultant coupled code should be able to estimate the amount of sensible heat and moisture that can be removed from the mountain during the preclosure period. Initial runs have been started and the results should be forthcoming in the near future.

Forecast: The FY 1995 Thermal Loading System Study will concentrate on identifying site related parameters that impact performance assessments and will recommend testing that can be used to help focus the testing program.

4.1.19 Design Activity 1.11.6.4 - Strategy for Containment Enhancement

The objective of this design activity is to document how design of the underground facility has taken into account containment, especially keeping the containers dry for 300 yr. The SCP suggested that temperatures around the edges of the underground facility will not be as high as in the middle. Therefore, decreasing the waste package spacing around the edges of the underground facility to increase the temperatures there should be considered.

Thermal studies performed to date show this "edge effect" is a long-term phenomena, taking 300 yr or so to develop. The edge effect is a significant consideration at a high thermal load. Its relevance at lower thermal load depends on whether the localized disturbance or minimal disturbance concept described in Section 4.1.17 (Design Activity 1.11.6.2) is selected. The effect does not apply to the minimal disturbance concept but may apply to the localized disturbance concept. For any thermal load, reducing the waste package spacing around the repository edges may cause higher short-term local temperatures. This result has not been fully demonstrated in studies to date, and its significance has not been evaluated. The edge effect is being considered as part of current waste emplacement management studies. Other aspects of these studies are mentioned in Sections 4.1.6 and 4.1.17.

The waste package containment lifetime also depends on waste package design and materials selection. Significant increases in containment lifetime are expected from past

changes in the design. The SCP described thin-walled containers of austenitic stainless steel, whereas current plans are to use a multibarrier container with both corrosion-resistant and corrosion-allowance barriers and a much greater total thickness. The selection of materials to provide long containment is discussed in Section 5.1.4 under Activity 1.10.2.4.1.

Forecast: The edge effect will continue to be considered as part of waste emplacement management studies, and will be discussed in a report to be issued during FY 1995. (CRWMS M&O, in prep.[f]).

4.1.20 Design Activity 1.11.6.5 - Reference Calculations

The objective of this design activity is to provide a set of calculations, documenting predictions of postclosure thermal and thermomechanical response of the host rock, which may be used to address performance assessment issues. Thermal and thermomechanical response analyses performed to satisfy this design activity can be divided into near-field and far-field analyses; the near-field analyses can be further divided into container scale analyses and drift scale analyses.

Container scale deals with rock behavior in the immediate vicinity of the waste package and its effect on the waste package. This portion of the analysis was originally intended to focus on the stability of the boreholes in which the waste packages were to be placed. With a change to in-drift emplacement by the Project, as explained in Progress Report #11, however, borehole stability is no longer a concern, and the canister scale analysis will now focus on effects of backfill on waste packages.

With the change to in-drift waste package emplacement, drift scale analyses, to the extent that backfill is considered, overlap some with the container scale analyses. This analysis deals with postclosure behavior of the rock in the immediate vicinity of the emplacement drift and the potential for that rock to move or collapse and develop new paths for radionuclides to reach the accessible environment.

No studies specifically addressing the near-field aspects of this activity were funded during the period. The only work related was a slight change in the Project assumption regarding backfill. It is still assumed that backfill will not be used in emplacement drifts, but the emplacement design now must not preclude the option to backfill (CRWMS M&O, 1995a).

Waste package thermal analyses include calculations of repository and emplacement drift temperatures. This work is reported in Section 5.1.3 under Activity 1.10.2.3.1.

Far-field analyses deal with the far-field performance of the repository. This mostly involves thermal response of the rock mass and the effect of temperature on rock joints. Studies regarding temperature distribution in the rock as caused by various repository thermal loads are relevant to this activity. Scoping studies for the Total System Performance Assessment are also relevant.

Forecast: Near-field thermal and thermomechanical studies of drift temperature and stability will be conducted during FY 1995, and reports will be issued (CRWMS M&O, in prep.[h],[i],[j]).

4.1.21 Design Activity 1.11.7.1 - Reference Postclosure Repository Design

The objective of this design activity is to establish what information will constitute the reference postclosure design for use in performance assessment and document this information in the Advanced Conceptual Design and License Application Design reports.

Advanced Conceptual Design for the repository continued with the "focused" Advanced Conceptual Design approach being fully implemented. In addition, two documents regarding the reference Postclosure Repository Design were published. The first document (CRWMS M&O, 1995a) contains a compilation of assumptions related to requirements, technical data, and design concepts which were necessary to facilitate the design process. The document also contains a list of repository/waste package functions and a first draft of a repository operations concept. The second document (CRWMS M&O, 1994f) contains a summary of the waste package and repository design concepts as they currently exist. The waste package design is nearing the end of Advanced Conceptual Design and the repository is in the very early stages of Advanced Conceptual Design. As the designs progress they will be documented in the Interim Advanced Conceptual Design Summary Report followed by the Final Advanced Conceptual Design Summary Report.

Forecast: The design effort will continue on the basis of horizontal in-drift emplacement of large waste packages.

4.1.22 Design Activity 1.11.7.2 - Documentation of Compliance

The objective of this design activity is to document that the issue has been resolved by determining if the postclosure design complies with the design goals of this issue and to document this compliance in the Advanced Conceptual Design and License Application Design reports. This activity draws from the results of many other activities.

Advanced Conceptual Design of the repository continued following the focused approach described in Progress Report #11. The Controlled Design Assumptions Document (CRWMS M&O, 1995a) was updated. The update consisted of consolidating and revising previous assumptions, creating new assumptions, revising and expanding the list of repository/waste package functions, and expanding the repository concept of operations.

Regulatory requirements for the waste package include containment during handling and emplacement, substantially complete containment after emplacement but during the containment period, and control of criticality. Progress has continued in these areas. Descriptions of the work are given in Sections 5.1.3 and 5.1.4.

As the designs progress, they will be documented in the interim and final Advanced Conceptual Design summary reports.

Forecast: The design effort will continue through FY 1995. Writing the summary reports is an out-year activity.

4.2 REPOSITORY DESIGN CRITERIA FOR RADIOLOGICAL SAFETY (SCP 8.3.2.3)

4.2.1 Design Activity 2.7.1.1 - Design Evaluation for Compliance with Radiological Safety Design Criteria and Performance Goals

The objective of this design activity is to evaluate the repository design against the radiological safety design criteria and performance goals at each phase of the design and provide feedback to the designers on needed corrections or modifications.

Among the specific objectives for this issue are performance goals for limiting the concentration of naturally occurring radon, for shielding properties of the host rock, and for limiting releases of radioactive materials based on eventual exposure of the workers and public.

Evaluating the repository design against radiological safety and performance goals was not funded during the period, but radiological design criteria are being considered during design. Design concepts to achieve worker radiological safety underground include (a) separating the emplacement and development areas, including their respective ventilation systems; (b) transporting the waste package inside of a cask shielded to stand-alongside radiation levels; (c) moving the waste packages into the emplacement drifts using remote control methods; (d) placing shielding doors over the entrances to emplacement drifts; and (e) excluding personnel from emplacement drifts containing waste packages. Some of these have been mentioned in other sections of this report.

Forecast: The following will be initiated during the next reporting period: identification and evaluation of radiological conditions, identification of radiological hazards for subsurface activities, outline of special radiological equipment design needs, description of special structural requirements for shielding, and evaluation of radiological impacts of off-normal situations.

4.3 NONRADIOLOGICAL HEALTH AND SAFETY (SCP SECTION 8.3.2.4)

4.3.1 Design Activity 8.3.2.4.1.1 - Design Activity to Verify Access and Drift Usability

The methods used to develop the conceptual design of the repository were based on preliminary data. The ESF offers an opportunity to verify these design activities and to substantiate or provide the basis for adjustment of the design techniques used. The extent of

the ESF is sufficient to ensure that the demonstrated design techniques, the data obtained, and the test results will generally be applicable throughout the subsurface facilities with only minor modifications.

A second set of analyses of the 2C section of the North Ramp was completed and transmitted to YMSCO. The analyses examined the impacts of in situ, thermal, and seismic loading on the stability of the North Ramp. In addition, large-scale body effects were identified that may have performance assessment implications. Specifically, large zones of tension and compression were predicted that may impact hydrologic flow paths. These results are currently being evaluated.

Forecast: A strategy and planning document for development of the scientific basis for design is planned to be developed. The document will outline a basis strategy, identify specific activities that contribute to development of the scientific basis for design, and show how these activities should be phased with the repository design activities needed to support a recommendation for Technical Site Suitability and for License Application.

Several design assumptions identified in the Controlled Design Assumptions Document will be substantiated through the consolidation of existing data and through making data readily accessible to Project participants. Specific areas that will be substantiated include those of rock mass thermal expansion coefficient, rock mass quality indices, and rock mass deformation moduli. Activities will focus on the substantiation needs concerning mechanical data in the technical data section of the Controlled Design Assumptions Document.

4.3.2 Design Activity 8.3.2.4.1.2 - Design Activity to Verify Air Quality and Ventilation

Studies are required to assess the impact of site characteristics on the ventilation requirements necessary to provide a safe working environment. Site characteristics will determine dust quantities produced during construction, in situ gas types and quantities, and the wall roughness required for the ventilation flow calculations.

During construction of the ESF, the influence of the construction method on dust generation and dust control methods can be evaluated. Similarly, the value of drift roughness used for the determination of delivery of sufficient air to the working areas of the repository, can be verified based on the construction method, the rock quality, and the support system used in the ESF construction.

No progress was made during the reporting period; this was an out-year activity.

Forecast: No activity is planned for FY 1995.

4.4 PRECLOSURE DESIGN AND TECHNICAL FEASIBILITY (SCP SECTION 8.3.2.5)

4.4.1 Design Activity 4.4.3.1 - Operations Plan to Accompany the Advanced Conceptual Design

The objective of this design activity is to produce an operations plan to accompany the Advanced Conceptual Design.

A draft Concept of Operations for the Mined Geologic Disposal System is in the revised Controlled Design Assumptions Document (CRWMS M&O, 1995a), but it will be made a stand-alone document. The Concept of Operations covers the period beginning with receipt of waste at the Mined Geologic Disposal System through establishment of postclosure institutional barriers. It describes, at a level of detail appropriate to Advanced Conceptual Design, all Mined Geologic Disposal System operations in the following major categories: surface operations, subsurface operations, system performance evaluation, Mined Geologic Disposal System support operations, and permanent closure. Some of the operational concepts are listed in the Controlled Design Assumptions Document as assumptions to be substantiated.

Forecast: The Concept of Operations will be updated as the Advanced Conceptual Design is further developed during FY 1995.

4.4.2 Design Activity 4.4.3.2 - Operations Plan to Accompany the License Application Design

The objective of this design activity is to produce an operations plan to accompany the License Application Design.

No progress was made during the reporting period; this was an out-year activity.

Forecast: No activity is planned for FY 1995.

4.4.3 Design Activity 4.4.4.1 - Repository Design Requirements for License Application Design

The objective of this design activity is to develop the design requirements for the repository for use in the License Application Design.

No progress was made during the reporting period; this was an out-year activity.

Forecast: No activity is planned for FY 1995.

4.5 SEAL CHARACTERISTICS (SCP SECTION 8.3.3.2)

4.5.1 Study 1.12.2.1 - Seal Material Properties Development

The Yucca Mountain sealing program concentrates on cementitious and earthen materials emplaced in shafts, ramps, boreholes, and underground openings for the proposed repository. The strategy for sealing the proposed repository is to place seals in the shafts, ramps, and boreholes so that they do not act as potential pathways for flow and to provide seals in selected underground openings to control water flow within the repository. Current efforts are focused on in situ and laboratory testing of cementitious seal components planned for used in sealing exploratory boreholes at Yucca Mountain. Potential sealing locations include nonwelded Topopah Spring Tuff and the Calico Hills nonwelded tuff.

The issue of primary importance for borehole sealing is seal material performance, both short term and long term. Seal performance is related to the emplacement technique(s), as well as the durability (mechanical, geochemical) of the emplaced seals. Laboratory testing is under way to evaluate cementitious seal performance under a range of environmental conditions. The cementitious seal materials include Portland-based cements identified in Licastro et al., (1990), which are expected to be geochemically stable in the host rocks at Yucca Mountain. Plans are being developed for a series of shallow in situ experiments near Yucca Mountain to evaluate the strategy for sealing exploratory boreholes at Yucca Mountain (Fernandez et al., 1994).

Activities 1.12.2.1.1 and 1.12.2.1.2. Preliminary laboratory experiments are under way to evaluate the performance of Portland and gypsum-based cementitious sealing materials. Rheologic properties of the viscous grouts and mechanical and fluid flow properties of the hardened grouts are being evaluated. In addition, prototypical lab tests in small-scale seals emplaced in 6-in- (15-cm) diameter cores of Topopah Spring Tuff with a central co-axial hole (for seal emplacement) are under way. These tests will provide critical information for in situ test design, as well as guide future laboratory efforts.

Forecast: Laboratory tests in candidate cementitious sealing materials will continue throughout FY 1995. Testing will focus on the mechanical and fluid flow performance of Portland-based and gypsum-based cements emplaced in small-diameter co-axial holes in 6-in- (15-cm) diameter cores of TSw2. These tests will include push-out tests of hardened cements to evaluate interface shear strength between seal and rock as well as gas and water permeability tests on intact and sheared seal plugs. Durability testing of hardened seal plugs is also planned; however, the actual tests (which may include heat and wetting and drying) will probably begin in FY 1996.

4.5.2 Design Activity 1.12.2.2 - A Degradation Model for Cementitious Materials Emplaced in a Tuffaceous Environment

No progress was made during the reporting period; this was an out-year activity.

Forecast: No activity is planned for FY 1995.

4.5.3 Study 1.12.2.3 - In Situ Testing of Seal Components

Study Plan 8.3.3.2.2.1, "In Situ Testing of Seal Components" provides the control for this work. Pretest planning and preparation are under way so that preliminary estimates of in situ seals performance can be made. These tests will represent the first evaluation of the strategy for sealing exploratory boreholes at Yucca Mountain. A potential surface test site is being identified. Two types of tuff are currently being investigated: the densely welded Topopah Spring welded tuff (TSw2) and the nonwelded Paintbrush unit (PTn). A tentative site near Fran Ridge has been identified for the TSw2 tests. Site selection activities for the nonwelded Paintbrush unit are ongoing. These shallow-surface-based tests can be used to evaluate initial seal performance using typical emplacement techniques, as well as provide a test-bed to begin evaluating of the durability of the seals. Seals are planned to be routinely tested to evaluate potential deterioration of seal performance through time. Because the emplaced seals will be shallow [< 20 ft (6 m)], they can be overcored at time intervals for laboratory tests to evaluate geochemistry changes of the seal materials.

Forecast: Pretest planning and preparation for in situ borehole sealing tests will be completed in FY 1995. This includes completing of site selection activities for the nonwelded Paintbrush unit tests. All necessary documentation, including criteria letters and job packages, will be completed.

4.5.4 Design Activity 1.12.4.1 - Development of the Advanced Conceptual Design for Sealing

Design Subactivity 1.12.4.1.1 - Define subsystem design requirements. The objective of this design subactivity is to develop design requirements that will assist the designer in the development of sealing components.

Work is under way to support the Advanced Conceptual Design for sealing. This input is primarily aimed at evaluating the design assumptions and repository design concepts in light of the sealing requirements and concepts outlined in the SCP and by Fernandez et al. (1987). Designs for sealing will be finalized after in situ testing has been completed.

Design Subactivity 1.12.4.1.2 - Perform trade-off studies to support advanced conceptual design development. The objective of this design subactivity is to provide technical justification for the selection of specific design options.

No progress was made during the reporting period; this was an unfunded activity.

Design Subactivity 1.12.4.1.3 - Develop advanced conceptual design for seals. The objective of this design subactivity is to provide design details during Advanced Conceptual

Design that can be used to develop the License Application Design and to support the performance assessment activities.

No progress was made during the reporting period; this was an unfunded activity.

Forecast: The evaluation of design assumptions relative to sealing will be completed.

4.5.5 Design Activity 1.12.4.2 - Development of the License Application Design for Sealing

Design Subactivity 1.12.4.2.1 - Define subsystem design requirements The objective of this design subactivity is to refine design requirements that will assist in the development of sealing components for the License Application Design.

No progress was made during the reporting period; this was an out-year activity.

Design Subactivity 1.12.4.2.2 - Perform trade-off studies to support license application design development The objective of this design subactivity is to provide technical justification for the selection of the final seal designs.

No progress was made during the reporting period; this was an out-year activity.

Design Subactivity 1.12.4.2.3 - Develop license application design for seals The objective of this design subactivity is to provide the License Application Design for seals.

No progress was made during the reporting period; this is an out-year activity.

Forecast: No activity is planned for FY 1995

CHAPTER 5 - WASTE PACKAGE

The waste package consists of the waste form (spent nuclear fuel or high-level waste glass), possibly a multi-purpose canister, and a disposal container. The waste package program includes the development of waste package design bases, design analysis, materials testing and modeling, development of a reference design, waste form testing and modeling, and characterization of the waste package emplacement environment. Progress in the waste package program is described in this section.

5.1 WASTE PACKAGE DESIGN (SCP SECTION 8.3.4.2)

5.1.1 Design Activity 1.10.2.1 - Concept Development

Significant progress was made in integrating the design efforts for the multi-purpose canister and its disposal container. Five design analyses have been prepared or are being prepared that consider the requirements that the Mined Geologic Disposal System places on the multi-purpose canister to ensure that it will be compatible with disposal. The analyses were prepared in accordance with applicable Quality Administrative Procedures. The subjects of the analyses are weight, dimensional envelope, and configuration (CRWMS M&O, 1995), dryness of the multi-purpose canister cavity and composition of fill gas (CRWMS M&O, 1995), access for addition of filler materials (CRWMS M&O, in prep.), criticality control (CRWMS M&O, in prep.), and materials (CRWMS M&O, in prep.). Several of these analyses are discussed in more detail in the following sections. The process of comment resolution on these analyses has significantly clarified the interface between multi-purpose canister design and disposal container design.

A major upcoming deliverable is the Waste Package Conceptual Design Report (CRWMS M&O, in prep.). This report will summarize progress in waste package development for all Advanced Conceptual Design, and its publication will mark the end of that design phase. Because of its broad scope, the report is already being prepared and drafts of several sections have been written.

Activity 1.10.2.1.1 - Advanced Conceptual Design concepts. The three previously reported concepts for multibarrier disposal containers are still in use. But because both low and high thermal loads are now being considered, effort has been made to consider a disposal container that is suitable for a low thermal load. A low thermal load is expected to impose greater requirements for corrosion resistance on the disposal container because the environment is expected to be humid, whereas for a high thermal load a dry environment is expected based on currently unverified modeling predictions. One approach to providing additional corrosion resistance is to add a third metallic barrier, but it is not clear whether three barriers are necessary or sufficient.

Activity 1.10.2.1.2 - Design basis fuel. The design basis fuel analyses reported in the previous two progress reports (DOE, 1994c; DOE, 1995m) have been modified and extended with the following features:

- Thermal statistics (percentiles) are taken with respect to heat per assembly, rather than heat per MTU
- Design basis fuel is now extended to boiling water reactor fuel. (Such fuel was omitted previously because it is generally less stressing than pressurized water reactor fuel and because a parameterization for criticality of boiling water reactor fuel is not available yet)
- A 10 yr age is used throughout, for consistency.

Percentiles are computed with respect to performance parameters based on the scenario of receiving the oldest fuel first. Details of the calculations will be given in a design analysis (CRWMS M&O, in prep.).

Recommended pressurized water reactor design basis fuel. A heat output of 800 watts per assembly was chosen for the thermal/shielding design basis. This is more stressing than that specified for the multi-purpose canister because a larger coverage was desired. This heat output can be produced by a range of values of age, burnup, and initial enrichment. For a given heat, the older fuel will have higher burnup, and will decay more slowly (giving a higher integrated heat over the repository life); therefore, the more conservative design basis would have the older fuel at the higher burnup. Most of the hot fuel, however, will be close to 10 yr in age, and so the older fuel is not very representative. Therefore, an age of 10 yr was used. The burnup giving 800 watts per assembly at this age is expected to be somewhat less than 50 GWd/MTU so an initial enrichment of 4.2 percent was chosen. This is slightly less than the average initial enrichment in the characteristics data base for 50 GWd/MTU. For an age of 10 yr and an initial enrichment of 4.2 percent, the characteristics data base indicates that 48.086 GWd/MTU burnup will give 800 watts per assembly.

For the criticality design basis, the fuel characteristics are an age of 10 yr, a burnup of 20 GWd/MTU, and an initial enrichment of 3 percent. This design point was selected from the range of values giving the target $k_\infty = 1.13$, where k_∞ is the neutron multiplication factor for an infinite system. The burnup was chosen so that the enrichment which gives $k_\infty = 1.13$ falls in middle of the range of actual enrichment values for fuel having that burnup (20 GWd/MTU).

These design basis recommendations are summarized in the following table.

Table 5-1.
Recommended Pressurized Water Reactor Design Basis Fuel,
for 93 percent Combined Coverage

Parameter	Thermal/shielding	Criticality
Burnup	48.086 GWd/MTU	20.000 GWd/MTU
Initial enrichment	4.2%	3%
Age	10 yr	10 yr
Oldest-Fuel First Coverage (93.1%)[a]	94.3%	97.6%

a. These figures refer to the parameters heat per assembly, and k_∞ ; they *do not* refer to burnup and initial enrichment.

Recommended boiling water reactor design basis fuel. The thermal requirement for boiling water reactor fuel is much less stressing than that for pressurized water reactor fuel. Computations indicate that the boiling water reactor fuel that would be thermally equivalent to the pressurized water reactor design basis fuel as follows:

1. The total heat for a waste package with 21 pressurized water reactor assemblies at 850 watts each is 17.85 kW; to get the same amount of heat from a package with 40 boiling water reactor assemblies would require over 400 watts per assembly, which is greater than any of the boiling water reactor fuel in the oldest-fuel-first scenario.

2. The largest boiling water reactor burnup in the characteristics data base is 49 GWd/MTU; that burnup, however, gives only 388 watts per assembly at 10 yr after discharge; 49 GWd/MTU is used for the thermal design basis, simply because it is the largest burnup in the data base for boiling water reactor fuel, even though it does not give as high a heat per package as the pressurized water reactor thermal design basis fuel. The boiling water reactor fuel simply cannot be as stressing as the pressurized water reactor thermal design basis fuel.

Although the criticality control requirement for boiling water reactor fuel is generally expected to be less stressing than that for pressurized water reactor fuel, a design basis fuel must nevertheless be chosen so that waste package designs can be evaluated. The approach used for pressurized water reactor fuel cannot be used because a parameterization for the reactivity of boiling water reactor fuel is not available yet. Until such a formula is developed, the boiling water reactor criticality design basis fuel will be as close to the corresponding pressurized water reactor fuel as is appropriate. If the age and initial enrichment are taken to be the same as those for the pressurized water reactor design basis fuel (10 yr and 3 percent), the smallest burnup that can be found in the characteristics data base is 21 GWd/MTU, and so

that figure will be used. The fraction of boiling water reactor fuel covered by these parameters can be estimated as follows.

For a criticality design point specified by age, burnup, and initial enrichment, all the fuel having higher enrichment and lower burnup will have a higher k_∞, and higher effective neutron multiplication factor k_{eff}. But higher values of k_{eff} can occur either at higher enrichments and higher burnups or at lower enrichments and lower burnups. To estimate the actual fraction of boiling water reactor fuel not covered, an analogy with pressurized water reactor fuel is used.

For pressurized water reactor fuel with 20 GWd/MTU and 3 percent initial enrichment, 2.4 percent of the fuel will have a higher k_∞. From tabulated statistics in the referenced analysis, 1.26 percent of pressurized water reactor fuel is found to have a higher enrichment and lower burnup. Thus, the ratio of the amount of fuel having a higher k_∞ to the amount having a higher enrichment and lower burnup is 1.9. The design analysis also shows that 2.23 percent of boiling water reactor fuel will have higher enrichment and lower burnup than the design basis fuel (21 GWd/MTU and 3 percent initial enrichment). By using the ratio above, it is estimated that 2.23 percent × 1.9 = 4.2 percent of the fuel that will have higher k_∞ than that for the design basis fuel, so this design basis fuel will be more stressing, with respect to criticality, than 95.8 percent of the fuel. Since the thermal/ shielding design basis covers 100 percent of the boiling water reactor fuel, the combined coverage is the same as the criticality coverage. These parameters are summarized in the following table.

Table 5-2.
Recommended Boiling Water Reactor Design Basis Fuel
(approximately 96 percent combined coverage)

Parameter	Thermal/shielding	Criticality
Burnup	49 GWd/MTU	21 GWd/MTU
Initial enrichment	3.74%	3.0%
Age	10 yr	10 yr
Oldest-Fuel First Coverage (95.8%)	100%	95.8%

Forecast: The design analyses on multi-purpose canister requirements currently being prepared will be completed. Waste package Advanced Conceptual Design will be completed, and the Waste Package Conceptual Design Report issued.

5.1.2 Design Activity 1.10.2.2 - Design Tools

The design and analysis programs for which verification and validation were reported previously are still in use. Work has begun on verification and validation of SCALE (Standardized Computer Analyses for Licensing Evaluation), a comprehensive set of programs for shielding, criticality, burnup, and related analyses.

Forecast: The verification and validation of SCALE will be completed during the next reporting period.

5.1.3 Design Activity 1.10.2.3 - Design Evaluations

Activity 1.10.2.3.1 - Thermal. The focus of the thermal design efforts has been on four main areas: (1) evaluation of the repository and emplacement drift thermal behavior and its effect on waste packages, (2) evaluation of waste package thermal conditions with regard to meeting the required licensing requirements, (3) benchmarking spent nuclear fuel effective conductivity models against experimental data to ensure that the peak cladding temperatures are predicted accurately, and (4) generating evaluations and sections of the Waste Package Conceptual Design Report (CRWMS M&O, in prep.[o]). The Program Plan (DOE, 1994a) affects this work heavily with regard to generating different repository thermal load requirements and waste package spacing/loading requirements, and determining whether the waste package designs will meet the licensing requirements. A change in the Program Plan concerning the spent nuclear fuel receipt requirements, repository thermal loading, or acceptance of a specific transportation package can result in new thermal evaluations to ensure that all Mined Geologic Disposal System and licensing requirements will be met for the new plan.

The thermal evaluation can be divided into three parts: (1) an analysis of the repository and emplacement drift temperatures, (2) an analysis of the internal waste package temperatures, and (3) an analysis of peak cladding temperatures. Each analysis provides information to the next analysis. Three sets of finite element models were generated to represent the repository, the waste package, and a spent nuclear fuel assembly.

A set of three-dimensional finite element models of the repository was constructed to determine near-field thermal behavior for a high and three low thermal loading scenarios. The high thermal loading scenario assumed a repository loading of 20.5 kg U/m^2 (83 MTU/acre). The three low thermal loading scenarios maintained a 6.18 kg U/m^2 (25 MTU/acre) loading but investigated the effects of various waste package spacings and drift spacings. At a high thermal loading, waste package surfaces were maintained above the boiling point for more than 1,000 yr. At low thermal loadings, near-field temperatures were significantly different between large and small waste package spacings at the same areal mass loading. Larger waste package spacings result in a larger heat sink area and lower near-field temperatures. Because of the importance of the first few years to the fuel cladding temperature, a minimum waste package spacing for a given waste package capacity and thermal output could be derived that is otherwise independent of thermal loading.

Specific finite element models were constructed for multi-purpose canisters with capacities of 12 and 21 pressurized water reactor assemblies and 24 and 40 boiling water reactor assemblies. Each of the models is based on the Multi-Purpose Canister Conceptual Design Report (CRWMS M&O, 1994). Individual vendor designs will be evaluated in the future to ensure that the Mined Geologic Disposal System licensing requirements are met. Each of these models was evaluated for each of the four repository thermal loading scenarios. Three pressurized water reactor and one boiling water reactor design basis fuel types were examined for each scenario. Results for waste package performance and peak cladding temperatures indicate that the multi-purpose canister conceptual designs are compatible with the Mined Geologic Disposal System thermal requirements. Peak cladding temperatures were evaluated with both the effective thermal conductivity model and the Wooton-Epstein correlation.

A key thermal goal for waste package design is the 350°C cladding temperature limit. Peak cladding temperatures in the waste package can be determined by assuming an effective conductivity in the waste package model, applying the Wooton-Epstein correlation, or using a finite element model that represents a spent nuclear fuel assembly in the waste package. A finite element model of an assembly was constructed to (a) benchmark the model against dry storage cask experiments that provide experimental data for cask container, basket, and spent fuel cladding temperatures and (b) develop a better smeared/homogeneous effective conductivity. The benchmark calculations indicate that using the Wooton-Epstein correlation is conservative. The improved thermal conductivity model based upon the experimental data provides a sound basis for a conservative best estimate of peak cladding temperatures.

Over-prediction of spent nuclear fuel cladding temperatures caused by excessive conservatism can constrain waste package design and limit capacity. While the results of the experimental data benchmarks for effective conductivity model are preliminary, the test cases indicate that the effective thermal conductivity model for spent nuclear fuel is more accurate than other approaches. Further, the calculated effective thermal conductivities were primarily a function of temperature. Dependable smeared properties for spent nuclear fuel could be used in the waste package thermal model to predict cladding temperatures and simplify waste package thermal analyses so that only two models are needed.

Activity 1.10.2.3.2 - Structural. Structural analyses include preliminary analyses of the effects of a rock drop onto a drift-emplaced waste package and drops of waste packages onto unyielding surfaces. The results of these analyses will be reported in the Waste Package Conceptual Design Report (CRWMS M&O, in prep.[o]).

Rock Drop Analyses

A three-dimensional finite-element model of a multibarrier waste package for uncanistered fuel was developed to explore the resistance of such a waste package to rock falls. The particular waste package modeled had an interlocking basket and a capacity of 12 pressurized water reactor assemblies. The model includes the outer barrier, inner barrier, and the basket assembly. The orientation of the waste package for the drop was with the

basket members at 45 degrees to vertical. This orientation gave the highest stresses in the barriers during the rock drop.

In the analysis, it was conservatively assumed that all the kinetic energy of the falling rock is imparted to the waste package as mechanical energy. Thus, no energy is absorbed by shattering of the rock, and the deflection of the rock is negligible compared with the deflection of the waste package. Another important assumption is the modeling of the impacting rock as a sphere. This geometry was selected because the impact of a sphere will result in a broad distribution of stress onto the waste package, whereas with a sharp wedge geometry, the pointed region of the rock would deform because of the high stress concentration at the impact point.

The elastic-plastic response of the waste package was determined for three drop heights corresponding to the starter tunnel, ESF tunnel, and emplacement drift tunnel sizes. The highest of these drops is that for the starter tunnel, 8.4 m. Preliminary results indicate that this waste package can withstand the impact of a 19,100 kg rock falling from this height without the breaching of any barriers.

Correlations were developed to determine the responses of multi-purpose canisters with disposal containers to rock falls, and the results will be reported in the Waste Package Conceptual Design Report. The distance of the rock fall depends on waste package size because the drop height is calculated as the difference between the height of the tunnel and the height of the top of the waste package when stored on its side. Using the correlations to the preliminary analysis, it has been determined that for drops in the starter tunnel, the minimum rock masses that could fail the waste packages could withstand are as follows:

Waste Package Capacity	Minimum Rock Mass
21 pressurized water reactor assemblies	≈ 31,600 kg
40 boiling water reactor assemblies	≈ 33,100 kg
24 boiling water reactor assemblies	≈ 25,200 kg
12 pressurized water reactor assemblies	≈ 24,800 kg

Waste Package Drop Analyses

One of the accident conditions that the waste package must be able to withstand is a drop of the waste package itself. The most damaging drop scenario is a corner drop, which is composed of two separate drop events: initial impact and slap down. For waste package impact angles near vertical, the initial impact dominates and the waste package response resembles the end drop condition. For impact angles near horizontal, the slap down phase dominates, and the assembly response resembles the side drop condition.

Two waste package models have been created to analyze the waste package drop accidents. The waste packages modeled are (a) a multi-purpose canister with 21 pressurized

water reactor assemblies in a disposal container and (b) a multi-purpose canister with 24 boiling water reactor assemblies in a disposal container. In the corner drops analyzed, the center of mass of the waste package was directly above the point of impact. In each instance, this resembles the end drop condition and results in the largest deformation pattern on the barrier. Thus, the effect of second impact on the opposite side of the waste package will not be as severe as that of the first. The slap down case was analyzed separately.

A one-half symmetry three-dimensional finite-element model was developed for each waste package. The analysis includes the basket assembly, fuel assembly weight, multi-purpose canister shell, and disposal container. Elastic and plastic properties of each material are considered as inputs to the finite-element analysis. Taking advantage of the symmetry reduces the model size, allowing more detail in the half that is modeled. Some minor simplifications, however, such as closing the gap between the disposal container and multi-purpose canister shell to provide element connectivity and applying the fuel load by increasing the basket density, were still required to control run times and output file size.

The skirt on the outer barrier works as an impact limiter during the 2-m corner drop. Sharp curvature bending of the impacted corner is the reason for very high stresses, which may result in ductile rupture. Failure is expected in this part of the disposal container. Preliminary analysis indicates that the maximum principal stress in the skirt is greater than the ultimate tensile stress of the outer barrier material; so it can be concluded that there is a localized material breach around the region of impact in the skirt. The analysis concludes that a 2-m drop will cause ductile rupture of the skirt, but neither breaching of the outer barrier nor yielding of the basket will occur for either type of waste package.

For impact angles near horizontal, the slap down phase dominates and the response resembles that for a side drop. The hypothetical slap down accident analyzed here is that of a waste package striking a flat, essentially unyielding horizontal surface in a position for maximum expected damage. The waste package models described above were used again in this analysis. The geometry was the same, but the starting orientation was changed. In each model, the waste package is initially in contact with the unyielding surface and is constrained at the point of contact, allowing rotation only. The angle of the waste package with respect to vertical was chosen so the waste package will overturn.

The results indicate that the maximum compressive stress is located near the end of the waste package away from the initial contact point. The maximum tensile stress is near the maximum compressive stress, but away from the line of impact. The maximum tensile stress is less than the ultimate tensile stress of the outer barrier material, so it can be concluded that slap down will not result in a breach of the outer barrier. Analysis of the basket loads is in progress for the waste package with 21 pressurized water reactor assemblies, as is analysis of both shell and basket for the waste package with 24 boiling water reactor assemblies.

The other types of multi-purpose canister in their respective disposal containers were not modeled because their behavior would be nearly identical. The only difference in waste packages of the same weight classification, 125 ton or 75 ton, is the mass of the multi-purpose canister. The differences in mass are small, and, according to conservation of energy

calculations for impact, the impact forces will vary less than 1 percent between the two, 125-ton waste packages and less than 1.5 percent between the two, 75-ton waste packages.

Activity 1.10.2.3.3 - Criticality. The neutronics activities performed during this reporting period have included work in the following areas: supporting the burnup credit effort, writing the disposal criticality analysis reports, supporting evaluations of the multi-purpose canister, writing the multi-purpose canister section of the Waste Package Conceptual Design Report, preparing for the start of License Application Design, developing a fault tree and probabilistic risk analysis for a criticality event, and other supporting efforts concerning neutronics issues for disposal. The work performed in each of these areas is discussed below in more detail.

Supporting the efforts to obtain burnup credit has remained a major activity in this reporting period. Mined Geologic Disposal System Development has supported Waste Acceptance Storage and Transportation in preparing the Burnup Credit Topical Report. Mined Geologic Disposal System Development provided the information needs on isotopic data for disposal burnup credit, for incorporation into the overall test plan being managed by Waste Acceptance Storage and Transportation. Many of the isotopes that are important for burnup credit during storage and transportation are also important for disposal. Some major tasks were started to refine the methodology for disposal criticality control using burnup credit.

Preparation of the disposal criticality analysis reports--started during the reporting period--is a large effort that will take several years. The Disposal Criticality Analysis Topical Report will present the methodology for performing disposal criticality analysis (including the use of burnup credit) for any fissile waste form, waste package design, and proposed repository. The report is to be released late in FY 1999 and will contain a great deal of supporting data. The Disposal Criticality Analysis Technical Report will contain the same methodology as the topical report, but will not contain the supporting data, and will be released late in FY 1996. The technical document preparation plan for the topical report was prepared.

A white paper was written comparing the use of neutron absorbers in panels and rods for criticality control in the multi-purpose canister. A design analysis was created that gives the Mined Geologic Disposal System "specific long-term criticality control requirement," to support the updating of the multi-purpose canister subsystem design procurement specification. The Mined Geologic Disposal System and Waste Acceptance Storage and Transportation worked together on integrating the multi-purpose canister and disposal container design plans. Mined Geologic Disposal System Development has been creating various contingency plans and options in case vendor-supplied multi-purpose canisters are later found unacceptable for disposal.

The neutronics subsection of the multi-purpose canister section of the Waste Package Conceptual Design Report was written. This section contains the previously reported results for the multi-purpose canister conceptual design, as well as additional analyses for the multi-purpose canister conceptual designs. The results reported include the standard criticality and

radiation shielding performance of the four standard multi-purpose canister conceptual designs (125 ton and 75 ton sizes, configured for pressurized water reactor and boiling water reactor fuel) plus special evaluations of the effectiveness of filler material in multi-purpose canisters, the effectiveness of disposable control rods in multi-purpose canisters, and the effects of replacing the aluminum-boron alloy criticality control materials with zirconium alloys containing hafnium.

In anticipation of finishing the Waste Package Conceptual Design Report, and concluding the waste package Advanced Conceptual Design activities, preparations have been under way to start the initial License Application Design activities. The initial activities consisted of preparing qualified design analyses for candidate material properties, formally qualifying additional computer codes, establishing what exact fuel assembly types to expect from the reactor sites that are unable to use multi-purpose canisters, and supplying input into the Mined Geologic Disposal System licensing strategy document.

Fault tree analysis focused on the three basic initiating events capable of introducing water into the local drift environment in a manner that could create the conditions necessary for a waste package criticality, and on the principal immediate consequences of these initiating events. The initiating events are (a) the possible concentration of the episodic infiltration flux by a fracture directly over a waste package (hereinafter referred to as the "concentration" scenario), (b) concentration as in the first scenario but with a greatly enhanced flow rate, and (c) the possible flooding of a drift caused by an external event that produces a significant rise in the water table (for which the principal mechanisms are changing of the climate to wetter conditions or a severe tectonic event) or by high infiltration combined with poor drift drainage. The main immediate consequences are (a) breaching of the waste package by corrosion, and (b) subsequent dissolution of the basket and/or leaching of the neutron absorber from the basket.

These events and consequences can be interpreted as failure modes and organized as in Table 5-3. These events and consequences can also be interpreted as interrelated events. Complete results of the analysis will be given in a design analysis.

Other neutronics efforts include reviewing and commenting on various documents that address disposal neutronics issues and performing conceptual evaluations of disposal of various additional waste forms.

Activity 1.10.2.3.4 - Cost Estimation. A report on waste package cost estimates was issued (CRWMS M&O, 1995). The cost update information presented is the result of the initial Title I effort to reevaluate waste package costs associated with particular fabrication scenarios (step-by-step fabrication simulation). This is an ongoing activity; the cost estimates will be subject to continuing refinements.

Table 5-3. Summary of Failure Modes and Effects Leading to Criticality (Page 1 of 2)

Component	Function	Failure Modes	Mechanisms	Effects	Comments
Emplacement drift: immediate rock environment	Provide an environment that ensures long waste package life by limiting contact with water and other hazards	Permits water contact at a moderate flow rate	Hydraulically conductive ceiling fracture concentrates infiltrating water onto waste package	Eventual corrosion of barriers, and possible filling of waste package, and leaching of neutron absorber.	Requires infiltration of surface water to initiate sequence. Requires proper corrosion hole configuration to fill waste package.
		Permits water contact at a high flow rate	Flow concentrated and increased by moderate climate change	Same as above	Same as above, but much less likely.
		Permits flooding	Flooding from cataclysmic climate or tectonic change	Eventual corrosion, filling and leaching of absorber	Impossible for at least 20,000 years
		Fails to prevent mechanical damage to waste package	Rock fall or faulting incident on waste package.	Possible breach of waste package barriers depending on amount of applied stress and degree of barrier degradation. Immediate filling if flooded conditions occur.	Sequence not included in current fault tree.

Table 5-3. Summary of Failure Modes and Effects Leading to Criticality (Page 2 of 2)

Component	Function	Failure Modes	Mechanisms	Effects	Comments
Waste package barriers	Isolate spent nuclear fuel from environment and prevent intrusion of water to interior.	Waste package barriers breached, allowing moderator entry and neutron absorber removal.	Corrosion of barriers by intruding water.	Waste package eventually breached. Immediate filling under flooded conditions. Specific corrosion hole configuration required for filling by overhead dripping.	Rate of corrosion varies according to drift conditions. Rates of sufficient magnitude to cause breach in the time frame of this analysis are conditional on water intrusion.
			Pre-existing through-wall defect in both barriers	Waste package barriers breached. Immediate filling if flooded conditions occur.	Sequence not included in current fault tree.
Waste package basket	Maintain spent nuclear fuel in a subcritical condition	Insufficient neutron absorber available to maintain subcriticality under moderated conditions	Sufficient neutron absorber leached from basket material by intruding water	Waste package criticality if fuel assemblies maintain appropriate geometry and basket filled with water.	Leaching is conditional on waste package breach and intrusion of water.
			Basket material doped with insufficient absorber during fabrication	Waste package criticality if fuel assemblies maintain appropriate geometry and basket filled with water.	Sequence not included in current fault tree.

Forecast: The thermal analyses reported above will be described in a draft section of the Waste Package Conceptual Design Report in April 1995. The remainder of FY 1995 will be spent performing a detailed thermal analysis of the defense high-level waste container and the uncanistered spent fuel waste package, writing and issuing the Waste Package Conceptual Design Report, and performing Title I waste package design.

The slap down analyses of multi-purpose canisters in disposal containers will be completed. Analyses for rock drops and waste package drop accidents will be described for the Waste Package Conceptual Design Report. The sections include those for the multi-purpose canister disposal containers, for the defense high-level waste containers, and the uncanistered fuel waste packages.

5.1.4 Design Activity 1.10.2.4 - Material Selection Design Support

A three-volume report was issued (Van Konynenburg et al., in prep.), which serves several purposes. The first volume introduces the engineered materials effort for the YMP. It defines terms and outlines the history of selection and characterization of these materials, and lists current candidate materials. The second volume tabulates design data for engineered materials, and the third volume is devoted to corrosion data, radiation effects on corrosion, and corrosion modeling. The second and third volumes are intended to be evolving documents, to which new data will be added as they become available from additional studies. Initially, volume three provides information currently available for environments most similar to those expected in the potential repository.

Activity 1.10.2.4.1 - Materials selection process. A paper was issued on testing strategy for substantially complete containment (CRWMS M&O, 1994). The paper described future testing efforts on container materials in support of substantially complete containment. Testing of both inner and outer container materials was considered for both high and low thermal loads. For a high thermal load, the corrosion-allowance outer container will be initially subjected to hot and dry air, and then to cooler and somewhat moister air. For these conditions, data on air/stream oxidation, as well as aqueous corrosion resistance, will be needed. For a low thermal load, these barriers will be subjected to cooler and moist air for most of the containment and post-containment periods. For these conditions, data will be needed for air/stream oxidation, as well as aqueous corrosion resistance, with strong consideration for the effect of microbiologically influenced corrosion.

Corrosion data are needed for corrosion-allowance materials as a function of temperature and humidity. In an aqueous environment, these materials may be susceptible to general corrosion, galvanic corrosion, and microbiologically influenced corrosion. While localized attack such as pitting and crevice corrosion may also occur in this class of material, its susceptibility may be significantly less than that of corrosion-resistant materials.

Although the ground water in the vicinity of the proposed repository is known to be benign with a near-neutral to slightly alkaline pH, the corrosion-allowance materials will be tested in the following four environments:

- Simulated ground water (similar to J-13 water)
- Concentrated ground water (20 to 100 times ionic concentration of UE-25 J#13)
- Acidified concentrated ground water (pH ≈ 2)
- Alkalized concentrated ground water (pH ≈ 12).

The concentrated ground water was considered to simulate a dry-out condition followed by resaturation with concentration of ionic salts. The acidified concentrated ground water would represent an extreme case of microbiologically influenced corrosion. As for the alkalized concentrated ground water, the acidified concentrated ground water would simulate reactions between man-made materials, such as concretes or grouts, and the aqueous environment. A long-term (up to five years) test plan will be pursued, which will include a wrought carbon steel (ASTM A 516), a cast carbon steel (ASTM A 27), and an alloy steel (2-1/4Cr - 1Mo). Tests will be conducted at temperatures below boiling, preferably at 60° and 90°C in water, in the vapor phase above the water, and in some instances at the water line.

For corrosion-resistant materials, general corrosion, localized corrosion, galvanic corrosion, microbiologically induced corrosion, resistance to stress corrosion cracking, and hydrogen embrittlement will be evaluated. Susceptibilities to general corrosion, pitting/ crevice corrosion, galvanic corrosion, and microbiologically induced corrosion will be evaluated by using coupons. Fracture mechanics-based notched compact tension specimens will be used to understand the initiation and propagation of stress corrosion cracks in simulated ground water and concentrated ground water, mentioned earlier. Crack growth rate tests currently incorporate Types 304L and 316L stainless steel, Alloy 825, Alloys C-4 and C-22, and Ti Grade 12. In addition to these materials, moderately corrosion-resistant alloys such as Alloy 400 and CDA 715 will be tested. Furthermore, Ti Grade 16 will be included in this testing program. The generated data will be used in developing predictive models. The following test matrix is recommended.

Degradation Mode	Corrosion-Allowance Materials	Moderately Corrosion-Resistant Materials	Highly Corrosion-Resistant Materials
Oxidation	+	o	•
Aqueous Corrosion	+	o	o
Galvanic Corrosion	+	+	+
Pitting Corrosion	o	+	+
Crevice Corrosion	o	+	+
Stress Corrosion	o	o	+
MIC	+	+	+

Key to symbols:
+ : Major effort in testing and modeling
o : May be tested
• : Need not be tested

Activity 1.10.2.4.2 - Container shell. Progress in selection of container shell materials is described under Activity 1.10.2.4.1.

Activity 1.10.2.4.3 - Shield plug. A shield plug is not included in the design of the disposal container. Accordingly, no effort has been made in selecting shield plug materials.

Activity 1.10.2.4.4 - Spent nuclear fuel basket (structural). Selection of basket structural materials for the multi-purpose canister is discussed in a design analysis (CRWMS M&O, in prep.[n]). Materials similar to those recommended for the multi-purpose canister are being considered for disposal containers for spent fuel.

Activity 1.10.2.4.5 - Spent nuclear fuel basket (criticality). Selection of basket structural materials for the multi-purpose canister is discussed in a design analysis (CRWMS M&O, in prep.[n]). Austenitic stainless steel with boron is still the material of choice for disposal containers for spent fuel. Should this prove to have insufficient durability for long-term criticality control, more costly and corrosion-resistant materials (such as zirconium-hafnium alloys) will be considered. Such materials might be more effective in disposable control rods than in a basket.

Activity 1.10.2.4.6 - Filler material. Iron shot remains the first choice for filler material. Current efforts are described in Section 5.5.5.

Activity 1.10.2.4.7 - Fill gas. The fill gas requirements for the multi-purpose canister were analyzed to determine whether the fill gas might cause unacceptable degradation of the performance of the Mined Geologic Disposal System. The Multi-Purpose Canister Subsystem Design Procurement Specification provides requirements for vacuum drying of the multi-purpose canister and subsequent filling. Different readers have proposed various interpretations for the specification. A design analysis (a) analyzed the wording of the specification to determine limits on the quantity of water and the composition of the gases that will be present, and (b) determined limits on amount of degradation that could result from the available gases (CRWMS M&O, 1995). The analysis considered nominal loading conditions only, not accidents.

Close examination of the specification showed that liquid water would not be present. The amount residual of water is small enough that it would not significantly damage the multi-purpose canister or the spent nuclear fuel that it contains. Effects of potentially reactive gases in the multi-purpose canister were also analyzed. The gases included hydrogen, oxygen, and nitrogen, which could be present from residual gases left after vacuum drying, and impurities in the fill gas. The damage that could be caused by these gases is negligible. It was concluded that the specification places sufficiently stringent conditions on the dryness requirements for the multi-purpose canister cavity environment after loading and closure operations at the purchaser site. No reason was found to impose additional restrictions on water or gases.

Forecast: Work on materials selection will continue. The design analysis on materials requirements for key components of the multi-purpose canister will be approved and issued.

5.1.5 Design Activity 1.10.2.5 - Performance Evaluations

This design activity includes work on materials performance. Activities addressed are container oxidation and corrosion, degradation by mechanical stress, and thermal degradation of fuel cladding.

Activity 1.10.2.5.1 - Container oxidation and corrosion. Corrosion calculations were previously reported for degradation of a carbon steel barrier in humid air. For these calculations, the time-temperature-humidity results were taken from Buscheck's mountain-scale thermohydrologic model of a repository (Buscheck et al., 1994). The conditions for the repository horizon as functions of position and time were used as input to an equation (McCoy, 1994) for corrosion rate as a function of temperature, relative humidity, and thickness of corrosion product layer.

A shortcoming of the corrosion calculation is that the temperatures and relative humidities are inaccurate. In the thermohydrologic model, the waste packages are smeared into a disk heat source. Since the heat input is spread over the repository horizon, the predicted temperatures are lower and the humidities are higher than what will be seen at the surface of a waste package. The corrosion calculations were extended in three ways during the current reporting period. Each of the extensions represents an attempt to better estimate the temperature and humidity at the waste package surface.

The first extension of the calculations improved the temperatures and humidities by using results from a drift-scale thermohydrologic model. The drift-scale model differed from the mountain-scale model in that the waste packages were represented by infinite cylindrical heat sources in open drifts. Periodic boundary conditions are imposed, with the effect of simulating an infinite array of drifts. Because it more accurately reflects the local heating of the waste packages, the drift-scale model predicts rapid dry-out at the waste package surface. In contrast, the mountain-scale model predicts that dry-out takes tens of years at high thermal loads and never occurs at low thermal loads. These differences in conditions are reflected in the results of the corrosion calculations. In the original calculations, corrosion was rapid at short times. With results from the drift-scale model, corrosion is suppressed for hundreds to thousands of years.

The second extension used results from the mountain-scale thermohydrologic model, as in the original calculation, but the temperature and humidity for the repository horizon were corrected to account for the local heating by the waste packages. The temperature correction was calculated from a heat transfer correlation that was derived from calculations by Bahney (McCoy, 1995) for a waste package in an empty drift. The relative humidity at the surface of the waste package was calculated assuming that the absolute humidity at the surface of the waste package and at the repository horizon are identical. Because the vapor pressure of water increases with increasing temperature, the relative humidity at the surface of the waste package was reduced.

The results of this calculation agreed with those from the first extension in that corrosion is suppressed for hundreds to thousands of years. They also provide information on

how corrosion rate varies from the center to the edge of the repository. For a low thermal load, a moderate corrosion rate is seen for all packages, regardless of position. At short times, local heating keeps the waste packages dry and suppresses corrosion. At longer times, humidity and corrosion rate rise for all packages. The results for a high thermal load are strikingly different. For most of the packages, corrosion performance is excellent because repository-scale drying keeps humidity and corrosion rate low for a long time. At the extreme edge of the repository, substantially larger corrosion rates are seen because humid conditions return earlier. Both high and low thermal loads, however, provide acceptable performance.

The third extension was like the second, but the heat output of the waste packages was varied in three ways: (1) by multiplying the standard heat output by a constant (as a simulation of different burnups), (2) by changing the age of the fuel at emplacement, and (3) by using heat outputs for high-level waste glass rather than for spent nuclear fuel. The purpose of this extension was to determine the effects of having different waste packages with different heat outputs. The approach is most applicable if waste packages are commingled at a fine scale.

Multiplying the standard heat output for spent nuclear fuel by 0.5 or 1.5 resulted in modest changes (typically about a factor of two) in corrosion depths. These changes reflect the differing amounts of local heating and drying. Varying the age of the emplaced fuel from 10 to 50 yr resulted in negligible changes in corrosion depths. At short times, the heat output is large enough that corrosion is suppressed for either age. At long times, the heat output changes so slowly that young and old fuel are barely different in heat output. For high-level waste glass, heat output drops drastically between 100 and 1,000 yr. After the first few hundred years, the corrosion penetration curves closely resemble those for the original calculations without local heating.

Activity 1.10.2.5.2 - Waste package degradation by mechanical stress. Activities on stress analysis are described under Activity 1.10.2.3.2 (Section 5.1.3).

Activity 1.10.2.5.3 - Thermal degradation of fuel cladding. Fuel cladding is potentially significant as a barrier that will help to provide compliance with the requirements for controlled release of radionuclides. Even perforated cladding will provide significant confinement because the perforations are typically quite small. In contrast, grossly failed cladding would allow relatively easy release of radionuclides from the fuel. Under certain conditions, oxidation of the fuel cladding and pellets could cause such gross failure. A study was recently performed to evaluate the significance of oxidation for degradation of spent nuclear fuel (McCoy, 1995).

Intact fuel rods can perforate by creep rupture if they are stored at a high temperature, but it is generally agreed that a creep rupture failure will produce only a small perforation. Once the cladding is perforated, the gas pressure equalizes between the inside and outside of the cladding, and creep degradation ceases. If the rod is stored in an inert atmosphere, as in an intact disposal container, no additional degradation occurs. If the atmosphere is oxidizing, however, two types of oxidation become possible. The simpler is oxidation of the cladding,

which could gradually thin the cladding until it is gone. The second type is oxidation of the fuel pellets. Einziger (1994) distinguishes two steps in this process, and his description focuses on the cladding: First, the spent nuclear fuel oxidizes locally in the vicinity of the perforation. This eventually leads to a volume increase of the fuel and to formation of a macroscopic split in the cladding. Second, after the split forms, continued oxidation of the fuel pellets near the ends of the split causes the cladding to gradually "unzip," that is, split axially. These two steps are called "split initiation" and "split propagation" here. The first of Einziger's steps lasts until U_3O_8 begins to form; the second corresponds to oxidation of the remainder of the fuel to U_3O_8.

Einziger has presented rate equations for cladding oxidation, split initiation, and split propagation. These equations were combined with information on fuel rod geometry to determine characteristic times for the various degradation processes for a typical pressurized water reactor fuel assembly.

Fuel temperatures will depend on the mass loading and the choice of backfills. For waste packages emplaced without backfill, temperatures for fuel in multi-purpose canisters were taken directly from calculations by Bahney (1994). The calculations are conservative because Bahney's results are for the hottest fuel. Bahney did not analyze waste packages emplaced with backfill. Fuel temperatures were estimated, however, for steady-state, conductive heat transfer through the backfill.

For mass loadings being considered by the Project and emplacement without backfill, fuel temperatures will be low enough that oxidation of the cladding will cause negligible damage even if the disposal container provides no protection. For emplacement with immediate placement of backfill, destruction of the cladding by oxidation is possible only if the disposal containers fail very early. Such degradation can be controlled by delaying emplacement of backfill.

For perforated fuel rods, temperatures are sufficiently high at short times that some protection by the disposal container is necessary. For a low mass loading (5.93 kg U/m^2) and no backfill, the fuel must be protected from oxidation for about 35 yr to prevent the cladding from splitting at some later time; for a high mass loading (20.5 kg U/m^2), the fuel must be protected from oxidation for about 130 yr. These times are extended to 150 yr and 510 yr, respectively, if a crushed tuff backfill is used.

Because the requirements for protection by the disposal containers are small, intact fuel rods are expected to remain intact unless perforation occurs by some other mechanism, such as creep rupture. Fuel rods with perforations are not expected to split unless the disposal container fails very early.

Cladding oxidation and splitting of the cladding as a result of fuel pellet oxidation are significant only at high temperatures. But when the fuel rods are hot enough for significant degradation to occur, the surface of the disposal container will be above the boiling point. As a result, failure of the disposal container by corrosion is unlikely during this period.

Forecast: Additional information will be sought on the dependence of corrosion rate on relative humidity, and calculations of the effects of other humidity dependencies will be performed.

5.2 POSTEMPLACEMENT NEAR-FIELD ENVIRONMENT (SCP SECTION 8.3.4.2)

5.2.1 Design Activity 1.10.1.1 - Consideration of 10 CFR 60.135(a) Factors

Analysis of Thermal Loading Design Options: Localized Disturbance to Extended Disturbance

A significant portion of the modeling efforts in both the near-field hydrology task and the thermal loading systems study has been devoted to addressing a wide range of thermal loading design options. Modeling efforts are directed at developing a complementary suite of in situ heater tests that (a) adequately resolve the major hypotheses for thermal-hydrological flow, (b) determine the extent to which coupled thermal-hydrological-geomechanical-geochemical phenomena may affect the outcome of those hypotheses, and (c) support the thermal design of the repository system in a timely manner.

The proposed thermal loading strategy provides the basis for moving forward in light of the uncertainties about thermal effects on engineered and natural barrier performance. The goal of the strategy is to focus design activities on an areal mass loading of 80-100 metric tons uranium per acre as a working hypothesis. This loading allows emplacement of up to the statutory maximum of 70,000 metric tons of uranium in less than the primary repository area of approximately 1,200 acres.

Risks associated with this strategy will be mitigated by maintaining design flexibility to accommodate higher and lower areal mass loadings and by pursuing a robust performance confirmation program. A lower loading would be appropriate if testing and modeling show that the negative aspects of heat dominate the performance of the natural system. A higher loading would be appropriate if testing and modeling show that the working hypothesis is not a high enough loading to produce a prolonged dry environment for the Engineered Barrier System, and that preclosure requirements can continue to be met at a higher thermal loading.

Very distinct advantages with a phased repository loading approach that initially uses widely spaced drifts emplaced with closely spaced waste packages were identified. Initially, waste packages would be emplaced at a low repository-wide areal mass loading, by skipping every other drift (or perhaps by emplacing every third or fourth drift). Drifts that are not initially emplaced would be used for monitoring the performance around the emplaced drifts. If every other drift is initially emplaced and emplacement occurred over a 24-yr period, there could be up to 12 yr of monitoring before the decision whether to use the remaining drifts had to be made (or the decision made to emplace waste packages in the expansion areas). The initial lower areal mass loading phase of the phased repository loading approach could be called the localized disturbance concept, while the higher areal mass loading phase could be called the extended disturbance concept. It is reasonable to assume that the decision to increase the repository-wide areal mass loading from a localized disturbance to an extended

disturbance concept would not occur unless the extended disturbance concept could be shown to be associated with extended-dry repository conditions.

A significant issue for the thermal loading systems study is the compatibility of large multi-purpose canisters containing either 12 or 21 pressurized water reactor fuel assemblies per waste package, with various thermal criteria being considered for a low areal mass loading repository. These criteria include the following:

1. Peak waste package temperature
2. Peak drift-wall temperature
3. Duration of the boiling period on the waste package
4. Duration of the boiling period on the drift wall
5. Maximum spatial extent of the boiling point isotherm
6. Temperature histories in various hydrostratigraphic units such as the basal vitrophyre (TSw3).

Criteria 1 and 3 are related to thermal goals associated with waste package performance. Criteria 2 and 4 are related to thermal goals associated with the near field and Engineered Barrier System). Criterion 2 is also related to thermal goals associated with mechanical stability of the emplacement drifts. Criteria 4 through 6 are related to the extent to which the thermal effects may influence the ambient hydrological system, with criterion 4 having a near-field focus, criterion 5 having both a near-field and far-field focus, and criterion 6 primarily having a far-field focus.

The Effect of Repository Thermal Design on Water Contact Modes

A major concern for waste package performance is how water contacts a waste package, thereby affecting its integrity and (if containment is breached) affecting radionuclide dissolution and transport to the water table. The degradational mechanisms of greatest concern for waste package integrity, such as stress corrosion cracking, pitting corrosion, or microbial attack, require the presence of liquid water. The rates for many of these mechanisms are increased under warm, humid conditions.

The two primary modes of water contact on the waste package are (1) advective aqueous-phase flow and (2) condensation of water vapor on the waste package surface. The critical factors for the second mode are the relative humidity *RH* and temperature at the waste package surface. Regardless of whether mobile liquid water is present, ambient relative humidity at the repository horizon is humid (approximately 98 to 99 percent). If the ambient relative humidity could be sufficiently reduced, waste package corrosion rates would be minimal (Stahl et al., 1994). Moreover, even for breached waste packages, waste-form dissolution is minimal if no mobile liquid water is present.

There are two ways to reduce relative humidity at the waste package surface: (1) drive a large fraction of the initial pore water from the vicinity of the waste packages and (2) maintain a steep enough temperature gradient away from the waste package.

The primary means of reducing the pore water are repository-heat-generated drying and ventilation. To reduce relative humidity to 70 percent, the liquid saturation S_l (the fraction of the pore space filled with liquid water) must be reduced to less than 20 percent. An areal mass loading that does not drive repository temperatures well above the boiling point will only slightly reduce average relative humidity conditions.

Even if repository heat does not substantially reduce average relative humidity conditions in the repository, it is still possible to substantially reduce relative humidity at the waste package surface itself for a considerable period of time. The relative humidity at the waste package surface can be quite low even if ambient (humid) relative humidity conditions prevail in the host rock immediately adjacent to the emplacement drift. A large difference in relative humidity between the emplacement drift wall and the waste package can arise as a result of the temperature difference between these locations. This local reduction of relative humidity within the emplacement drift is called the "local-ΔRH effect." Various concepts for the Engineered Barrier System need to consider the impact of an engineered temperature drop from the waste package to the drift wall on reducing relative humidity on the waste package surface.

During the initial heating stage of the repository, the waste packages act as point-heat sources. If spaced close enough, these point-heat sources coalesce into a line-heat source. Heat flow away from the line-heat source will be radial until interference with heat flow from the neighboring drifts nulls out the lateral component of heat flow, resulting in heat flow that is primarily vertical (upwards and downwards). If the line-heat loads are spaced far enough apart, there will always be a lateral component to the heat flow away from the drifts. This persistent lateral component of heat flow facilitates a larger temperature drop between the waste package and drift wall than would occur for more closely spaced line-heat loads. Consequently, closely spaced waste packages in widely spaced drifts allow for a more persistent temperature drop between the waste package and the drift wall than does the approach of using closely spaced drifts, and thereby facilitate a more substantial reduction in relative humidity on the waste package that persists after the host rock has rewetted back to ambient (humid) relative humidity conditions.

Major Categories of the Localized Disturbance Concept

As mentioned earlier, there are several thermal criteria to be considered with regard to the localized disturbance concept. In general, there are varying degrees of localization of the thermal effects on the ambient hydrological system; but several major categories of the localized disturbance concept can be classified, including the following:

1. Sub-boiling waste package, sub-boiling host rock

2. Above-boiling waste package, sub-boiling host rock

3. Above-boiling waste package, above-boiling host rock during the preclosure period

4. Above-boiling waste package, above-boiling host rock within localized (cylindrical) boiling zones

5. Above-boiling waste package, above-boiling host rock, and boiling zones that eventually coalesce; with emplacement drifts far enough apart to promote preferential shedding for some period of time in the pillars and a significant local-ΔRH effect.

The first localized disturbance category would preclude boiling effects within the Engineered Barrier System as well as within the near-field host rock; but it may be incompatible with backfill or large multi-purpose canisters. The second localized disturbance category attempts to minimize heat-mobilized water in the near-field host rock since that water may be brought into the emplacement drifts. The third localized disturbance category does not eliminate the possibility of heat-mobilized water entering the emplacement drifts, but limits its occurrence to the preclosure period during which time the effectiveness of measures to mitigate the boiling effects (such as ventilation and drip shields) could be monitored.

The fourth localized disturbance category does not eliminate the possible occurrence of heat-mobilized water; but because the boiling zones do not coalesce, the possibility of ponding significant quantities of either condensate or naturally infiltrating water above the repository is reduced. The effectiveness of shedding these sources of water around the emplacement drifts (and through the repository horizon) can be monitored for 100 yr. Moreover, the spatial scale over which the observations are made during the monitoring period is comparable to the spatial scale over which maximum boiling effects will occur. Consequently, the fourth localized disturbance category avoids the "scaleup" problem between the scale of observations and the scale over which (boiling-driven) thermohydrological behavior must be sufficiently understood.

Because the boiling zones eventually coalesce, the fifth category listed above is not a true localized disturbance category, but rather a hybrid of the localized disturbance and extended disturbance concepts. Category 5 may pond more water than category 4. With wide drift spacing, however, the period of boiling coalescence may be relatively short; moreover, there is still a substantial component of lateral heat flow that tends to drive vapor flow radially away from the emplacement drifts and that continues to yield a significant local-ΔRH effect in the drifts themselves. In addition to the local-ΔRH effect, this category may also be shown to benefit from an overall reduction in relative humidity in the repository (including much of the pillar areas) for an extended period of time. Areas in the repository where average relative humidity conditions are not substantially drier than ambient will still benefit from the local-ΔRH effect.

Forecast: On the basis of an extensive suite of calculations, the transitions between these five major categories of the localized disturbance concept will be mapped as a function of areal mass loading, lineal mass loading, drift spacing, spent nuclear fuel age, and ventilation.

5.2.2 Study 1.10.4.1 - Characterize Chemical and Mineralogical Changes in the Postemplacement Environment

The objective of this study is to establish, to the degree required in Performance Issues 1.4 and 1.5 (SCP Sections 8.3.5.9 and 8.3.5.10), the information necessary to characterize the chemical and mineralogical properties and processes of the waste package environment for expected and certain unexpected conditions. To accomplish this objective, the study will determine the effects of chemical reactions on the rock-water system of the repository horizon over a range of temperatures and chemical conditions that bound the postclosure waste package environment.

Activity 1.10.4.1.1 - Rock-water interactions at elevated temperatures. This activity is being deleted by a change to the Site Design and Test Requirements Document. Its objectives have been moved to new Activities 1.10.4.1.8, 1.10.4.1.9, and 1.10.4.1.11.

Activity 1.10.4.1.2 - Effect of grout, concrete, and other repository materials on water composition. This activity is now reported under Activity 1.10.4.5.1, as a result of changes to the Site Characterization Program Baseline, Revision 8.

Activity 1.10.4.1.3 - Composition of vadose water from the waste package environment. This activity is being deleted by a change to the Site Design and Test Requirements Document. Its objectives will be met by Study 8.3.1.2.2.7.

Activity 1.10.4.1.4 - Dissolution of phases in the waste package environment. This activity is being deleted by a change to the Site Design and Test Requirements Document. Its objectives have been moved to new Activity 1.10.4.1.10.

Activity 1.10.4.1.5 - Effects of radiation on water chemistry. This activity is being deleted by a change to the Site Design and Test Requirements Document. Its objectives have been moved to new Activities 1.10.4.1.12 and 1.10.4.5.7.

Activity 1.10.4.1.6 - Effects of container and borehole liner corrosion products on water chemistry. This activity is reported under Activity 1.10.4.5.2, as a result of changes to the Site Characterization Program Baseline, Revision 8.

Activity 1.10.4.1.7 - Numerical analysis and modeling of rock-water interaction. This activity was divided between geochemistry and man-made material activities in Site Characterization Program Baseline, Revision 8. This activity is being deleted by a change to the Site Design and Test Requirements Document. Its geochemistry objectives have been moved to new Activities 1.10.4.1.13, 1.10.4.1.14, and 1.10.4.1.15.

Activity 1.10.4.1.8 - Hydrothermal testing of vitric and tuffaceous rocks under saturated conditions. The objective of this activity is to conduct a series of long-term saturated tests to determine the solid phase reaction products and chemical characteristics of the water that develop during interaction of rocks within the vicinity of the potential repository horizon, with reference ground water and other waters at elevated temperatures.

No progress was made during the reporting period; this is an out-year activity.

Activity 1.10.4.1.9 - Hydrothermal testing of vitric and tuffaceous rocks under unsaturated conditions. The objective of this activity is to conduct a series of long-term tests similar to those of Activity 1.10.4.1.8, except that water activity will be controlled to ensure that the activity is always less than 1.0. These tests will evaluate how pore water chemistry and secondary mineralogy may evolve under conditions where water activity is less than 1.0. Reaction rates and mechanisms may also be substantially changed under these conditions. Furthermore, changes in degree of hydration may occur for hydrous phases, with a corresponding change in mineral volume. This work is designed to complement other work addressing mineral stability and geochemical evolution of the site (Studies 8.3.1.3.3.2 and 8.3.1.3.3.3). This work will examine mineral stability issues for temperature conditions, fluid conditions, and mineral assemblages not considered by the work performed under those study plans.

Studies of the effect of changes in relative humidity on rocks that occur within the vicinity of the repository horizon were started. These studies will evaluate the rates of reaction, the extent and mechanism of reaction, and the impact on water chemistry. Results to date demonstrate that dramatic alteration of the material occurred within four months of the start of the experiments. Alteration was evident at relative humidities as low as 70 percent, consistent with literature reports in which the rate of glass alteration decreases significantly at relative humidities of less than 70 percent. These experiments are continuing.

Activity 1.10.4.1.10 - Mineral dissolution and precipitation. The objective of this activity is to obtain knowledge of the dissolution kinetics of the phases present in the host rock of the near-field environment, and the precipitation kinetics of product mineral phases. This information is required to interpret observed changes in fluid composition and associated development of product mineral phases in hydrothermal rock-water interaction studies.

No progress was made during the reporting period; this is an out-year activity.

Activity 1.10.4.1.11 - Ion exchange and sorption. The objective of this activity is to obtain knowledge of the effect that ion exchange and sorption may have on the composition of mineral phases and the composition of coexisting water. This information is required to interpret observed changes in fluid composition and associated development of product mineral phases in hydrothermal rock-water interaction studies.

No progress was made during the reporting period; this is an out-year activity.

Activity 1.10.4.1.12 - Rock-water interaction and water chemistry changes in the presence of a radiation field. The objective of this activity is to obtain knowledge of the interaction of ionizing gamma radiation with the air-steam atmosphere and pore water in the near-field environment, with the concomitant spectrum of possible effects on the rock, pore water, and emplaced materials.

No progress was made during the reporting period; this is an out-year activity.

Activity 1.10.4.1.13 - Simulation of rock-water interaction. The objective of this activity is to conduct simulations of the rock-water interaction experiments described in Activities 1.10.4.1.8 and 1.10.4.1.9, using as appropriate, models and data generated from Activities 1.10.4.1.10, 1.10.4.1.11, and 1.10.4.1.12. The activity will also conduct simulations of natural systems in which processes of interest occur. The activity evaluates computer codes and data bases, but does not actually develop codes or data bases. The results of this activity will allow simulations of repository conditions thousands of years into the future.

No progress was made during the reporting period; this is an out-year activity.

Activity 1.10.4.1.14 - Validation of EQ3/6 reaction path modeling codes. The objective of this activity is to validate the EQ3/6 code package to be used in Activity 1.10.4.1.13. This activity will use laboratory hydrothermal experiments not used in previous modeling efforts, analogous natural systems, field-based studies, and ESF studies to validate the calculational approach.

This activity includes work on the New Zealand process analog site that is being used to:

- Develop conceptual and analytical models of dissolution and precipitation kinetics relevant for Yucca Mountain conditions by resolving conflicts that exist between laboratory-based and field-based measurements of dissolution rates
- Test relevant thermodynamic data and modeling techniques by simulating rock-water interaction in hydrothermal systems relevant to Yucca Mountain
- Develop techniques and strategies for using natural systems to accomplish necessary code and model testing
- Define the envelope of uncertainty that bounds simulations and projections of geochemical processes.

Work on the New Zealand site was temporarily stalled because of changes in DOE procurement policies during the contract renewal process. The contract has been completed, and work will continue as planned, but with a five month delay. This subcontract will allow work to be continued in:

- Evaluating fluid mixing and mineral-fluid equilibria at elevated temperatures in silicic volcanic rocks to test the EQ3/6 code and its thermodynamic data base GEMBOCHS
- Measuring and evaluating rates of solid dissolution/corrosion in thermal features
- Determining rates and controls of silica precipitation from heated fluids, and measuring of the naturally occurring actinide-series isotopes in geothermal rocks and

fluids as a function of temperature, lithology, water chemistry and colloid content to evaluate the transport of radionuclides in repository-type environments

To evaluate historical discrepancies between laboratory- and field-based measurements of precipitation, a field-based study was started that examines the mechanisms and controls on silica precipitation in concrete-lined drain fields.

Activity 1.10.4.1.15 - Rock-water interaction simulation of scenarios for license application. The objective of this activity is to use the EQ3/6 code to simulate rock-water interactions for short- and long-term periods, for specific scenarios required for license application. The results will establish the geochemical and mineralogical characteristics of the waste package environment for expected and certain unexpected conditions. The characteristics will include the expected changes in primary and secondary mineralogy that would occur as a result of interaction of the vadose water with the waste package environment thermal and radiation fields, and with the host rock. The compositional evolution of the vadose water will also be established for the range of temperatures and radiation doses expected in the waste package environment.

No progress was made during the reporting period; this was an out-year activity.

Activity 1.10.4.1.16 - Experiments and simulations to determine the effect of geochemical processes on hydrological processes. The objective of this activity is to determine, through experiments, simulations, and study of natural systems, how geochemical processes couple with hydrological processes. The geochemical processes include dissolution and precipitation of minerals. The hydrological properties of fracture apertures, pore sizes, pore and fracture connectivity, and imbibition properties of the rock will in turn modify the flow pathways and flow rates of water and vapor as heating and cooling of the repository occur. This activity will evaluate the extent to which chemical changes will modify the hydrological properties. It will also determine under what conditions these changes are of greatest significance for geochemistry.

No progress was made during the reporting period; this is an out-year activity.

Forecast: The activities outlined above will continue throughout FY 1995.

5.2.3 Study 1.10.4.2 - Hydrologic Properties of Waste Package Environment

The objectives of this study are to conduct experimental and modeling studies relevant to the range of potential thermal loads to (a) identify hydrological and transport processes at Yucca Mountain that significantly affect waste package performance, radionuclide release and transport; (b) develop a detailed conceptual and quantitative understanding of repository-heat-driven flow processes that govern the waste package environment, including temperature, relative humidity, and flow conditions throughout the repository and Engineered Barrier System; (c) conduct experiments and develop related models to assess the impact of repository-altered matrix and fracture properties on nonequilibrium fracture flow; and

(d) develop and conduct laboratory and in situ tests for model validation and hypothesis testing that provide the basis for confidence building and substantiation of compliance with the substantially complete containment and controlled Engineered Barrier System release requirements.

Related International Work. See Section 5.2.7 for related work (under the heading Design and Analysis of Disturbed Zone Experiments) performed under the auspices of the OCRWM international program.

Activity 1.10.4.2.1 - Single-phase fluid system properties. This activity is being deleted by a change to the Site Design and Test Requirements Document. Its objectives have been moved to new Activities 1.10.4.2.4. and 1.10.4.2.5.

Activity 1.10.4.2.2 - Two-phase fluid system properties. This activity is being deleted by a change to the Site Design and Test Requirements Document. Its objectives have been moved to new Activities 1.10.4.2.4 and 1.10.4.2.5.

Activity 1.10.4.2.3 - Numerical analysis of flow and transport in laboratory systems. This activity is being deleted by a change to the Site Design and Test Requirements document. Its objectives have been moved to new Activities 1.10.4.2.5 and 1.10.4.2.6.

Activity 1.10.4.2.4 - Laboratory hydrological property measurements. The objectives of this activity are to determine the hydrological properties of repository horizon Topopah Spring Tuff samples and other rock units that may fall within the altered zone. The properties include effective porosity, saturated liquid- and gas-phase permeability, matric suction potential vs. liquid saturation, effective coefficient for the binary diffusion of air and water vapor, and Klinkenberg coefficient. The properties will be measured under ambient conditions and thermally altered conditions that are relevant to the heating and cooling cycle for a range of potential thermal loads.

The experiment to determine the effect of confining pressure on fracture healing, as observed previously by project geophysicists, has been completed. A fractured Topopah Spring Tuff sample from the USW G-4 hole was used. Saturated water permeability in the sample was measured as a function of temperature at a confining pressure of 1 MPa and a pore pressure of 0.5 MPa. The confining pressure was further increased to 2, 3 and 5 MPa, while the pore pressure was kept at 0.5 MPa, and the measurements were repeated at each pressure. The overall permeability decrease during this 6,100-hour experiment was from about $18 \times 10^{-15} m^2$ to about $2 \times 10^{-15} m^2$. About 69 percent of this permeability decrease occurred during the first temperature cycle at 1 MPa confining pressure. The chemical analyses and scanning electron microscopy examinations indicate that deposition of silicate minerals may have occurred during the first heating of the sample; dissolution and deposition may have occurred in the subsequent heating and cooling cycles. Freshness of the fracture surfaces may have stronger effect on the rock-water interaction than confining pressure. A paper describing this work has been prepared (Lin et al., 1995, in prep.).

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Measurement of electrical resistivity as a function of water saturation and temperature continued. The measurements at 95°C are almost complete. Most of the samples broke during the experiment. Preparations of more samples from the USW G-4 hole and the Large Block Test cores to complete the measurements at 95°C were completed. Gold electrodes have been deposited on these samples, and the samples are being dried so that the weights of the gold electrodes can be determined. The electrical impedance data collected so far have been modeled using a complex nonlinear least square routine to fit the frequency dependent response. Preliminary results show distinct impedance responses depending on saturation level. Cation exchange capacity can be estimated by using a form of the Waxman-Smits equation and obtaining fits to the resistivity vs. saturation data. A paper to be submitted to a peer reviewed journal is being prepared.

For the experiment of determining the moisture retention curve and one-dimensional imbibition, the moisture retention experiments using USW G-4 cores at high temperatures continued. Measurements at 95°C were completed. The samples are in the cooling phase. The temperature was lowered to 80°C, and the relative humidity was started at 20 percent. Fresh samples were added so that the effect of test history (i.e., cycling to high temperatures) on the measurement can be assessed. Additional samples from the Large Block Test core have also been prepared.

Some feasibility tests were conducted to evaluate the possibility of using a resonant cavity to measure relative humidity in rock samples in the laboratory. These tests were to determine the effect of rock proximity on the calibration of a resonant cavity and to solve the droplet formation problem. These tests indicated that it is feasible to use the resonant cavity to measure relative humidity in laboratory rock samples. Means of more accurately controlling the relative humidity at elevated temperatures for the calibration of the resonant cavity are being investigated. One of the methods is to use appropriate salt solutions in an autoclave type container in an oven that can control temperature accurately.

X-ray imaging to determine water saturation continued. A small block of 2.5 x 10 x 10 cm of Topopah Spring Tuff from Fran Ridge, with a tensile fracture in the middle, was used to test the x-ray scanning capability. Water doped with potassium iodine was added to the top of the sample, and radiographs are being taken as a function of time to try to determine the distribution of water content. Two tests have been conducted on this sample. First, the two halves of the block were put together well matched. Water was observed entering the fracture and the matrix very slowly. A v-shaped imbibition front with its tip on the fracture was observed. More than one month after this experiment started, however, the tip of the imbibition front only moved through about half of the block. The block was re-packed with 25-micron shims on the fracture surfaces, and the experiment was repeated. Water flowed along the fracture within a couple of hours. The water then imbibed into the matrix almost uniformly from the fracture. The images are being processed to determine saturation as a function of time, and the wetting front location as a function of time. A video of the images of the second experiment is being produced to show the fracture flow vs. imbibition process.

A progress report (Roberts and Lin, 1994) summarizing the hydrological properties of Topopah Spring Tuff, measured in the laboratory, was published.

Activity 1.10.4.2.5 - Model validation experiments. The objectives of this activity are to develop and conduct laboratory tests for model validation and hypothesis testing that provide the basis for confidence building and substantiation of compliance with the substantially complete containment and controlled Engineered Barrier System release requirements. The experiments will test the adequacy of the models to represent hydrological and transport processes at Yucca Mountain that significantly affect waste package performance radionuclide release and transport.

No progress was made during the reporting period; this is an out-year activity.

Activity 1.10.4.2.6 - Model development and analysis of thermal hydrological flow and transport. The objectives of this activity are to conduct modeling studies for the range of potential repository thermal loading options and for the thermal loading cycle to:

1. Identify coupled thermal-hydrological-geochemical-geomechanical processes, transport processes, and ambient site conditions (e.g., bulk permeability distribution) that significantly affect the waste package and Engineered Barrier System environment (i.e., affect waste package performance and radionuclide dissolution, release and transport), with emphasis on their effect on temperature, relative humidity, and flow conditions throughout the repository and Engineered Barrier System.

2. Determine the parameter sensitivity of the thermohydrological behavior in the near-field and Engineered Barrier System to a range of expected site conditions, waste package designs, repository configurations, waste package loading scenarios and repository operational options (e.g., ventilation and backfill). Of particular importance is dryout and rewetting behavior.

3. Develop mathematical and numerical models of repository-heat-driven flow and radionuclide transport, emphasizing the waste package and Engineered Barrier System environment. These models should be capable of treating the importance of coupled thermohydrological-geochemical-geomechanical and transport processes in the thermally altered zone, including (a) nonequilibrium fracture-matrix interaction, (b) coupled reactive transport, (c) the effects of coupled fracture-aperture deformation, and (d) the effects of heat-altered thermal and hydrological flow and transport properties.

4. Establish hypotheses critical to the prediction of thermohydrological behavior and EBS performance. Design laboratory- and field-scale experiments that critically test these hypotheses.

5. Develop validated subsystem models of the waste package and Engineered Barrier System environment. The experiments of Activity 1.10.4.2.5 will be used, in part, to validate the models.

Code Development, Qualification, and Maintenance

Version 7.7 of the V-TOUGH code was certified for use in quality-affecting work. Substantial improvements to the NUFT code have been implemented during this period. Several new direct matrix solution methods have been implemented as well as several new preconditioning options into the conjugate gradient method solver. These new solvers are robust enough to efficiently solve problems with highly nonlinear characteristic curves and widely varying grid element sizes. With the use of the new solvers, NUFT is capable of solving typical two-dimensional and three-dimensional thermohydrological problems four to six times faster than the V-TOUGH code. A nested mesh option has also been implemented in the NUFT code. A driver program that integrates the NUFT code with University of Nevada-Reno's CLIMATE code (Danko and Mousset-Jones, 1993) has also been developed.

Integration of Modeling with Laboratory and Field Experiments

The goals of laboratory and field experiments are to (a) measure fundamental material properties for input into the codes, (b) determine consistency of conceptual models with processes observed in experiments, (c) partially validate mathematical models by calibration, and (d) perform hypothesis tests. Conversely, the model will be used to design experiments and interpret collected data. An extensive suite of scoping calculations has been conducted for both the Large Block Test and in situ heater tests that will be conducted in the ESF. This progress report describes the major issues that need to be considered in designing these tests. Subsequent progress reports will describe the scoping calculations for heater test design and the conclusions from those calculations.

A key issue that will require integration of modeling studies with laboratory and field experiments is the evaluation of the effects of thermal loading on the capability of the Mined Geological Disposal System to contain and isolate radionuclides.

The proposed thermal loading strategy provides the basis for moving forward in light of the uncertainties about thermal effects on engineered and natural barrier performance. The goal of the strategy is to focus design activities on an areal mass loading of 80-100 metric tons uranium per acre as a working hypothesis. Design flexibility will be maintained to accommodate higher and lower areal mass loadings and by pursuing a robust performance confirmation program.

Hypothesis testing can help determine the impacts of areal mass loading on heat-mobilized fluid flow in the unsaturated zone. The primary hypotheses concern the following:

- Whether buoyant, gas-phase convection significantly affects unsaturated zone moisture movement

- Whether binary gas-phase diffusion significantly affects unsaturated zone moisture movement

- Whether heterogeneity in the heat load distribution and/or gas- and liquid-phase pathways focuses enough condensate drainage to cause this heat-mobilized water to contact waste packages and drive radionuclide transport.

For repository systems with thermal loads that significantly mobilize fluid flow, as with a high areal mass loadings repository, these hypotheses address how that mobilization occurs. Field tests, including the Large Block Test, to be performed at Fran Ridge (Lin et al., 1994), and in situ heater tests to be conducted in the ESF (e.g., the Engineered Barrier System Field Test) will help evaluate issues associated with thermal loading, including resolution of the major hypotheses. These tests are described in Study Plan 8.3.4.2.4.4. Portions of these heater tests should be conducted under sub-boiling conditions to address the post-boiling period of a high areal mass loading repository system. Portions of the heater tests will be conducted under above boiling conditions to address the effect of boiling for either a low or high areal mass loading repository system, and to establish the technical justification for an increase in the repository areal mass loading.

Hypothesis testing can help determine the extent to which a well-planned thermal management scheme can generate conditions in the repository that promote waste package integrity and reduce the potential for radionuclide dissolution and transport. The primary hypotheses concern the following unknowns:

- Whether heat conduction dominates heat flow

- Whether above-boiling temperatures (or the temperature drop between the drift wall and the waste package) correspond to a sufficient reduction in relative humidity and the absence of mobile liquid water near waste packages

- How long rewetting the waste package environment to humid conditions lags behind the end of the boiling period (or how long the temperature drop between the drift wall and waste package results in a sufficient reduction in relative humidity on the waste package)

- Whether enough condensate buildup occurs to significantly affect drying and rewetting.

The above-boiling portions of the heater tests are needed to support the resolution of this second set of major hypotheses and to further support the resolution of the first set of hypotheses. The significance of buoyant, gas-phase convection is easier to evaluate when thermal testing is conducted under above-boiling conditions (Buscheck et al., 1993b).

Thermohydrological scoping calculations are being conducted to design Large Block Test and ESF heater tests that provide useful and timely information for resolving the major hypotheses and to observe potentially critical coupling between thermohydrological processes

and geomechanical and geochemical processes. How the heat load is applied to the rock during the heater tests must be relevant to repository conditions, and the experimental design must allow the resolution of hypothesis tests. A primary concern is that the heated area of rock must be large enough to accomplish the following:

- Incorporate a network of fractures that is sufficiently connected to examine important heat-driven processes such as buoyant gas-phase convection
- Allow the development of condensate perching above the boiling zone
- Examine whether heterogeneities in the gas- and liquid-phase pathways focus enough condensate drainage to cause water to drip into drifts and possibly onto waste packages
- Prevent edge-cooling effects from dominating thermohydrological flow processes
- Determine the significance of buoyant gas-phase convection on moisture movement and heat flow.

Model calculations are being carried out (Buscheck et al., 1993a; Buscheck et al., 1993b) to address the question of in situ heater test size. To meet the above criteria, a minimum heated area of 500 m^2 is required (i.e., a disk with a radius of 12.5 m).

The other potentially important mechanism for heat-driven fluid flow mobilization during sub-boiling conditions is binary gas-phase diffusion. Analysis of potential heater tests clearly shows that under above-boiling conditions, the effects of binary gas-phase diffusion (even if substantially enhanced) tend to be swamped by boiling effects. Thus, a sub-boiling heater test will be required to diagnose the potential importance of binary gas-phase diffusion.

Forecast: Laboratory testing of core and small block samples will continue. Analysis of consolidated thermal test geometries and of localized-disturbance repository geometries will continue.

5.2.4 Study 1.10.4.3 - Characterization of the Geomechanical Attributes of the Waste Package Environment

The objective of this study is to characterize the geomechanical response of the rock in the near field to the changing conditions expected to occur over the lifetime of the repository. This includes providing data from laboratory, field and modeling investigations that can be used to support technical site suitability and a high-level finding for rock properties. Particular emphasis is on coupled processes and behavior at elevated temperatures and at long times.

Activity 1.10.4.3.1 - Block stability analysis. This analysis will provide information on the potential for impact and static loads on the waste package caused by rock blocks moving along pre-existing fractures.

The purpose of the modeling task is to evaluate several different constitutive thermal-mechanical models for applicability in simulation of geomechanical behavior in the near-field, and to develop coupled models for rock behavior at elevated temperature. Current efforts are oriented toward the Large Block Test and a time-dependent finite difference method is being used. The code being used, FLAC, is capable of treating both mechanical and thermally induced stresses and deformations. It is a two-dimensional code in which materials are represented by arbitrarily shaped quadrilateral zones. The code is based on a Lagrangian scheme and is capable of using several built-in material models, including the ubiquitous joint model that has previously been used to simulate thermomechanical behavior in tuff.

During the reporting period, the input modules for thermomechanical simulations were revised to accommodate the revised Large Block Test conditions, and to be compatible with the simulations being conducted for hydrological analysis of the Large Block Test. The input model was formulated assuming elastic behavior for the rock mass and using values of bulk density determined from laboratory measurements of cores, and bulk and shear moduli determined from laboratory velocity measurements discussed above. This is a two-dimensional model and assumes plane strain, equivalent to assuming a large thickness in the third dimension. The model assumes dry conditions and is being used to find the displacements and stresses resulting from the heating under these conditions.

The thermal boundary conditions are adiabatic at the sides of the block, isothermal at 60°C on the top of the block and 20°C at the ground surface around the block, together with fixed isothermal boundaries at the far edges of the model 34 m from the block and at a depth of about 25 m below the block. The loading is gravitational loading plus atmospheric pressure at the surface, and achieves stress equilibrium before heating. The heating program in the model uses the same parameters as the hydrologic model (i.e., heating using 1500 W for about 75 days followed by a period of reducing the heating at a rate of 16.7 W/day for 18 days, then a slower reduction of heating at a rate of about 1.7 W/day for 87 days, and a final step reduction to zero power).

Thermomechanical calculations are currently under way using an elastic constitutive model to verify the model behavior. After these preliminary calculations are completed, the ubiquitous joint and Mohr-Coulomb constitutive models will be used in the future to represent the rock mass.

Activity 1.10.4.3.2 - Borehole damage analysis. The objective of this activity is to provide information on the potential for static loads on the waste package and for radionuclide releases caused by spalling or borehole breakup.

No progress was made during the reporting period; this is an unfunded activity.

Activity 1.10.4.3.3 - Geomechanical properties analysis. This analysis will provide information on the nature of changes in the geomechanical properties of the rock in the near-field environment and how these changes will affect the performance of the waste package and Engineered Barrier System over the lifetime of the repository. Two types of laboratory tests are being conducted under this task; tests on small blocks to determine rock mass properties at the 0.5 m scale, and tests on cores to determine the effect of radiation on mechanical properties.

The purpose of the small block tests is to investigate the coupled thermomechanical, thermohydrological, and thermochemical response of the rock to conditions similar to the near-field environment of the potential nuclear waste repository. A small block of Topopah Spring Tuff, obtained from the Fran Ridge site was prepared for testing. This block is approximately 64 x 32 x 25 cm, and it exhibits the typical Topopah Spring Tuff fabric of subhorizontal vugs in pink and gray densely welded tuff. The block was instrumented with displacement transducers configured to measure displacement over several different length scales, and across fractures as well as regions of matrix material

Two sets of compression tests have been conducted. Each set consisted of a series of five tests. In the first test of a series, the axial stress was raised to 1 MPa and then reduced to ambient. In the remaining tests, the axial stress was raised to 2, 3, 4, and 5 MPa respectively, followed by lowering the axial stress to ambient. The purpose of this design was to test the apparatus measurement devices and to gather information on hysteresis in the stress strain behavior at low stress levels. Preliminary analysis of the stress-strain behavior for the first set of tests indicates that for axial stress in the range 0 to 5 MPa, the Young's modulus for this sample is approximately 3 GPa and that, as expected, most of the deformation occurs across fractures. This value for Young's modulus is considerably lower than the value of approximately 40 GPa determined for core samples.

A second suite of uniaxial compression tests was conducted on the block approximately four weeks after the first set. Analysis of the stress-strain behavior indicates a similar modulus to that reported for the first set and that, as expected, most of the deformation occurs across fractures. In addition, noticeable spalling occurred at several locations on the block. This was not observed during the first cycle of testing and indicates that subcritical crack growth occurs even at very low stresses in this rock when it is subject to cyclic loading. This may be relevant for evaluating the effect of seismic shaking of the potential repository over long times and at elevated temperature and humidity.

A block of about 30 x 30 x 70 cm is being tested under a uniaxial load of about 5 MPa at room temperature to measure its bulk deformation, deformation of fractures, and deformation in the matrix. Boundary heaters will be installed on the block to conduct tests at elevated temperatures planned for later this fiscal year.

Compressional wave velocity was also measured in a few blocks of Topopah Spring Tuff from the Fran Ridge site at ambient temperature and pressure conditions. Preliminary results show the P-wave velocities are in the range 3.8 to 4.7 km/s, which agrees with results from the G-Tunnel tests. In addition, elastic waves traveling through unfractured tuff were

about 10 percent faster than waves that had significant parts of the travel path passing through fractured rock.

Testing to determine the effect of radiation consists of a series of laboratory compression tests on irradiated and non-irradiated core samples to determine if radiation affects mechanical properties. To ensure that appropriate quality controls are used in collection of the data, a Technical Implementation Procedure was prepared, and the first draft is currently being reviewed. Thirty core samples of Topopah Spring Tuff from the Fran Ridge site have been prepared and are currently being irradiated using a Cobalt-60 radiation source. A hydraulic press suitable for the compression testing has been set up. Several load cells and displacement transducers appropriate for the tests have been located and are being calibrated. Testing is planned to start in early May.

Forecast: Laboratory tests and Large Block Test simulations will continue, as noted above.

5.2.5 Study 1.10.4.4 - Engineered Barrier System Field Tests

The laboratory tests described in Studies 8.3.4.2.4.1 through 8.3.4.2.4.3 require validation by in situ field tests in the repository horizon to establish the applicability of the laboratory studies to the repository block. The objective of this study is to investigate the geomechanical and geochemical behavior and movement of water in the rock mass under the influence of the thermal loading of the waste package. The study will investigate heat-flow mechanisms, fracture aperture change, geochemical reactions, the relationship between boiling and dryout, and the rewetting of the dryout region when the repository is cooled down. Coupling between heat, hydrology, geomechanics, and geochemistry, will be included in the study.

Activity 1.10.4.4.1 - In situ testing. The objectives of this activity are to develop detailed planning documents for the Engineered Barrier System field test, to checkout and debug techniques and hardware, to perform comparative evaluations of candidate test component methods, to procure equipment, to purchase or manufacture test components, to calibrate and install test components, and to conduct in situ testing.

Large-Block Test

The Large Block Test has recently been replanned to eliminate loading with a stress similar to the in situ horizontal overburden stress at the potential repository horizon. The purpose is to improve the understanding of some of the thermal-hydrological processes and to obtain data and properly plan tests that will support license application. The Large Block Test is designed to be consistent with the Program Plan. This test focuses on processes that are associated with the emplacing of waste in accordance with the current strategy (i.e., emplacement to achieve minimum thermal disturbance at the early stage of a repository, then increase the thermal loading later) but the understanding of processes can be applied to other emplacement scenarios.

The Large Block Test will meet three objectives:

1. It will develop and evaluate techniques and instrumentation for monitoring changes in thermal and hydrological, and to a limited extent, mechanical properties in a heated unsaturated zone rock mass. These techniques will be used in the Engineered Barrier System field tests.

2. It will improve understanding of the coupled thermohydrological processes required to develop models that can be used to predict the hydrologic responses of the near-field environment. The analyses of the near-field environment will be part of the evaluation of isolation capabilities required for any license application.

3. It will provide preliminary data both for the development of models as mentioned above, and for performing the scoping calculations that will be the basis of the test design of the Engineered Barrier System field test. The later Engineered Barrier System field test will provide site related data and process evaluation that will serve as the basis for license application. The Large Block Test is prototyping and scoping in nature, but the Quality Assurance Requirements and Description will apply. The appropriate level of controls will be specified in grading reports. The testing phase will be conducted as a quality-affecting activity.

The following critical thermohydrological issues are to be addressed in the Large Block Test:

- Whether heat conduction dominates heat transfer in fractured welded tuff.

- Whether heating (even low thermal load) promotes relative humidity reductions (drier) in this fractured rock mass where fracture density and connectivity are somewhat representative of that expected for Yucca Mountain, and where saturation and matrix properties are also representative.

- Whether heating can generate significant condensate buildup above the heaters, and whether condensate shedding affects the moisture movement.

- The extent to which heterogeneity in the gas- and liquid-phase pathways can focus condensate drainage. If this were to occur in the repository, it could cause heat-driven moisture to contact waste packages and drive radionuclide transport.

- How long rewetting to humid conditions lags behind the end of the heating period.

- The significance of buoyant, gas-phase convection in affecting moisture movement.

- The significance of binary gas-phase diffusion in moisture movement.

Each of these issues will be posed as a hypothesis to be tested; these hypotheses and the associated pre-test calculations will be documented before test start-up.

Thermal and moisture barriers and guard heaters will be installed around the outside of the block so that the movement of moisture in the block is as close to one-dimensional as possible. The deformation of the fractures during the test will not be constrained. The effect is probably not significant for those portions of the thermohydrological processes that are largely dominated by the matrix. Those processes that depend on fracture aperture or asperity contact/stress will very likely be affected by the differences between in situ tests and the Large Block Test. In the Large Block Test, the fracture system may open up because of applied thermal loading. To minimize the potential for block instabilities or disintegration, a restraint system will be designed that consists of vertical tie downs and horizontal banding or straps, similar to that on the block now. These independent systems are designed to prevent toppling, block mobilization, and fracturing, but they cannot prevent twisting or similar deformations that could result in shearing along fractures. The rock may fracture between the heater holes, but these fractures will not invalidate the test as long as the block remains stable.

The test will be conducted in stages, starting with sub-boiling heating, that can be reached quickly. Then the block will be heated to a maximum temperature of about 140°C at the heater plane followed by a cool-down phase that will be conducted so that the hypotheses that have been identified can be evaluated, and test methodology/instrumentation can be tested to temperatures that would be appropriate for the Engineered Barrier System field tests.

An engineering plan was developed for the Large Block Test. Included in the plan are detailed construction operation procedures. The draft plan was revised after the test was rescoped to eliminate the load retaining frame and is currently in review.

The large block was protected with insulation material so that the influence of weather on the block was minimized. The high wall to the west of the large block was determined to be safe. The excavation to prepare the ground for the concrete pad around the large block was completed. The drilling of the horizontal instrument holes was started in mid March.

Fracture mapping of the five exposed surfaces of the large block was completed. Modeling of the fracture data using Earth Vision was used to project the fracture distribution within the block. The model was used to specify the location of the horizontal instrument boreholes and the surface instruments. The fracture locations will be verified during the drilling of these holes.

A progress report was prepared (Lin et al., 1995).

Small Block Tests in the Laboratory

The initial moisture content of some small samples obtained adjacent to the large block during the excavation was determined using the drying/saturation technique. All samples showed a level of saturation above 95 percent, which is greater than the 60 to 80 percent determined previously in some of the vertical boreholes by using neutron logging. The discrepancy is probably caused by the water used in drilling the pre-split holes before the excavation.

A few dozen small blocks were shipped to the laboratory for testing. Laboratory activities are summarized in Sections 5.2.3 and 5.2.4.

Exploratory Studies Facility Tests

A Project-wide effort was initiated to consolidate thermal test planning in support of ESF tests in this study and studies in SCP Section 8.3.1.15.

Activity 1.10.4.4.2 - Sampling and Sample Analyses. The objective of this activity is to collect and analyze material samples (rock, gas, and water) before, during, and after heating of the rock. The laboratory analyses of the samples will determine hydrologic and geochemical properties of the rock and chemistry of the gas and water.

No progress was made during the reporting period; this was an out-year activity.

Activity 1.10.4.4.3 - Pre- and post-test calculations. The objective of this activity is to perform scoping calculations in support of test design, planning document development, and reducing and analyzing test data. This activity includes the verification and validation process necessary to qualify the numerical methods to be used if such verification and validation has not been accomplished by another activity.

Three pre-test model calculations have been conducted. These models are homogeneous permeability, horizontal heterogeneous permeability, and vertical heterogeneous permeability. The temperature distribution in the block is not sensitive to the heterogeneity; however, the moisture distribution in the block strongly depends on the heterogeneity distribution. A progress report on the pre-test scoping calculations was written (Lee, 1995).

Forecast: The Large Block Test instrument holes will be drilled and the core analysis will be used to refine the Earth Vision fracture model. Gas permeability measurements will be used to analyze the fracture network. Instrument procurement will continue.

5.2.6 Study 1.10.4.5 - Characterize the Effects of Introduced Materials on Water Chemistry in the Postemplacement Environment

The objective of this study is to identify significant chemical modifications of the near-field environment from what would be expected under natural conditions. The modifications are caused by the construction and operation of the repository. The natural conditions are defined by Study 1.10.4.1 (Section 5.2.5). A complete picture of the modified chemical system thus includes, in addition to construction materials, introduced air and water, the reintroduction of crushed tuff or muck and the introduction of accompanying microbial populations.

Activity 1.10.4.5.1 - Effect of grout, concrete, and other repository materials on water composition. This activity is being deleted by a change to the Site Design and Test

Requirements Document. Its objectives have been moved to new Activities 1.10.4.5.5, 1.10.4.5.6, 1.10.4.5.7, 1.10.4.5.8, and 1.10.4.5.10.

Activity 1.10.4.5.2 - Effects of container and borehole liner corrosion products on water chemistry. This activity is being deleted by a change to the Site Design and Test Requirements Document. Its objectives have been moved to new Activities 1.10.4.5.6, 1.10.4.5.7, and 1.10.4.5.10.

Activity 1.10.4.5.3 - Effects of introduced materials in presence of radiation field. This activity is being deleted by a change to the Site Design and Test Requirements Document. Its objectives have been moved to new Activity 1.10.4.5.7.

Activity 1.10.4.5.4 - Numerical analysis and modeling of introduced materials/water interaction. This activity is being deleted by a change to the Site Design and Test Requirements Document. Its objectives have been moved to new Activity 1.10.4.5.11.

Activity 1.10.4.5.5 - Integration: Program Planning; identification, characterization and screening of materials; and bibliographic maintenance and literature review. The objectives of this activity are to prepare planning documents, to develop a list of materials that might be used in the repository (including locations, quantities, and concentrations), to develop a chemical data base regarding the materials, to rank the materials on the basis of aggressiveness under expected and certain unexpected repository conditions, to identify materials for which information is inadequate, and to gather, synthesize, and evaluate data from the literature. These objectives are not necessarily sequential, and some products will be updated throughout the study.

Organizational work has begun on developing activity plans. Authors were selected to write plans for the ESF swipe tests (part of SCP Activity 1.10.4.5.7), microbial effects testing (part of SCP Activity 1.10.4.5.9), and computer module development (1.10.4.5.11).

An activity intended to support the identification of significant construction materials is being developed. Ultimately this activity will provide a decision-making matrix of materials, chemical consequences and alternative materials. An annotated bibliographic reference data base is being developed to support the materials activities. Background materials concerning microbially induced corrosion and the proposed Yucca Mountain repository are being assembled and examined in support of the bibliographic data base. Work has also begun to assemble literature for the selection of appropriate historical analogs for study. The literature will augment the bibliographic data base. A literature review of microbially mediated chemistry is also being developed.

Activity 1.10.4.5.6 - Solubility and stability experimental studies at ambient and elevated temperatures. The objective of this activity is to conduct dissolution and precipitation kinetics experiments to determine the sensitivity of the kinetics to temperature and fluid composition. Stoichiometric and nonstoichiometric dissolution, and saturated and unsaturated environments will be addressed. The experiments are intended to identify dissolution and precipitation mechanisms, the effects of solid solution on rates of dissolution and precipitation,

the solid reaction products, and the resulting water chemistry. Solid, liquid, and gas phase stability will be addressed.

No progress was made during the reporting period; this was an out-year activity.

Activity 1.10.4.5.7 - Chemical reactivity stability experimental studies at ambient and elevated temperatures. The objective of this activity is to conduct chemical reactivity experiments on soluble products of introduced solid phases, on introduced organic and inorganic fluids, on introduced material interactions with water and vapor in the presence of a radiation field, on the potential effects of introduced materials on predicted natural chemical reactions, and on the significance of natural mineral moderation (e.g., zeolites and buffering effects) on the aggressiveness of introduced materials.

Scoping experiments in the diesel fuel hydrous pyrolysis area have been completed. The final report is presently in technical review, and is expected to be published by November 1995.

The present focus of the Project in the area of introduced materials is the use of diesel fuel in the ESF. The isotopic composition of the stable isotopes (C, N, and O) in diesel exhaust and its associated particulate materials has the potential for altering the isotopic composition of materials in or around the ESF, particularly water. Stable isotopic signatures are routinely used in hydrologic studies. These emissions could potentially alter the isotopic composition in natural systems and therefore warrant careful characterization.

The isotopic composition of water and other aspects of the natural environment may be significantly altered by the construction of the ESF. This construction can be viewed as the imposition of a larger and more complex chemical system of interdependent effects. Diesel fuel/exhaust is only one part of the potential chemical modification alteration of the natural environment. For example, the exposure of the local rock to air by excavation may have a major impact on stable isotopic signature. The isotopes of other important elements such as chlorine may be affected by introduced materials. In addition to the disturbance of isotopic systems, an environment having altered CO_2 concentrations could possibly have other effects. For example, increased carbonation of concrete has been observed in the biosphere, where there are elevated CO_2 levels (Severinghaus, 1994).

Activity 1.10.4.5.8 - Colloid stability experimental studies at ambient and elevated temperatures. The objective of this activity is to identify introduced materials that can produce colloids, their nature, and their stability. This activity is intended to complement other work being conducted in Study 8.3.1.3.5.2.

No progress was made during the reporting period; this was an out-year activity.

Activity 1.10.4.5.9 - Biodegradation stability experimental studies at ambient and elevated temperatures. The objective of this activity is to identify and characterize microbes that might be introduced into the repository, and microbes (both native and introduced) that derive nourishment from introduced materials that could be brought into the repository. The

activity will identify introduced materials that will encourage microbe growth, identify chemical products of microbial degradation, and identify and evaluate the potential for introduction and growth of microbes from external sources. This activity is intended to complement other work being conducted in Study 8.3.1.3.4.2.

The ESF swipe test isotopic study described in Activity 1.10.4.5.7 can be used to define important aspects of microbial ecology (e.g., CO_2 metabolism) in the ESF, which will be of significance to understanding test interference and can be used as an analog to a repository environment.

A Technical Workshop on Microbial activity at Yucca Mountain was scheduled for the second week of April 1995. The Project enlisted the expertise of the microbial biology scientific community at large as well as key technical representatives within the Project, to help develop the subactivity plan for work in microbial degradation. The immediate aim is to define the relevance of microbiologically influenced corrosion-related processes on the design of a radioactive waste repository under conditions similar to those at Yucca Mountain, to determine key parameters that must be considered in evaluating microbiologically influenced corrosion in a disturbed subterranean environment, and to direct the most effective means of investigating the identified factors.

Activity - 1.10.4.5.10 - Historical analogs. The objective of this activity is to identify sites of interest (determined from the materials list developed in Activity 1.10.4.5.5) to collect samples from these sites, to analyze the samples for the information identified in Activity 1.10.4.5.5 to provide constraints for the experiments in Activities 1.10.4.5.7, 1.10.4.5.8, and 1.10.4.5.9 and to provide long-term data not obtainable from experiments for the development of the introduced material-rock-water interaction simulation activity (1.10.4.5.11).

No progress was made during the reporting period; this was an out-year activity.

Activity 1.10.4.5.11 - Computer modeling and code development. The objective of this activity is to develop the necessary codes (if not otherwise available) and to conduct predictions and simulations of experiments, natural analogs, and repository performance with respect to introduced materials effects on the near-field environment. Validation of developed models is included in this activity. This activity is complementary with Study 8.3.4.2.4.1.

The present approach to this activity is that the most efficient and cost-effective direction in chemical modeling is to produce material-class-specific chemical modeling modules. Each module will highlight the significant chemical concerns of a chemical class of materials. Each module will incorporate the appropriate, EQ3/6-based, abiotic and microbial sub-modules. Many of the microbial aspects of the sub-modules will be addressed in the biochemical workshop that is described in Activity 1.10.4.5.9. The material-class-specific chemical modules will create a tractable modeling effort, because the modules can be process and location specific. The modular approach also appears to be the most efficient manner to develop and maintain flexibility in predictive capabilities, and to address inevitable modifications in repository construction and design features.

Related International Work. Please see Section 5.2.7 for related work (under the heading Fundamental Materials Investigations) performed under the auspices of the OCRWM international program.

Forecast:. Study plan comments will be resolved and three activity plans will be completed. Development of computer modules will continue. A preliminary report on historical analogs will be completed.

5.2.7 Related International Postemplacement Near-Field Environment Work

Design and Analysis of Disturbed Zone Experiments

The following is work related to Study 1.10.4.2 (Section 5.2.3), conducted cooperatively with Sweden under the auspices of the OCRWM international program.

During the previous reporting period, laboratory experiments in transparent fracture replicas demonstrated that (a) the magnitude of liquid flow reduction caused by gas phase formation following pressure reduction is controlled by fracture geometry, and to a lesser degree by the partial pressure of the dissolved gas, and (b) the gas phase accumulates in the larger apertures and does not go back into solution as predicted by theoretical models that assume chemical equilibrium between the gas and liquid phases. An understanding of this phenomenon is necessary to apply the results of hydrologic characterization conducted in the near-drift region to the undisturbed formation. In all cases modeled using TOUGH2, flow reductions due to degassing were comparable to analytical solutions developed in FY 1993, but significantly smaller than observed in the laboratory experiments. The study included finite and infinite systems and examined transient and steady state behavior. Preliminary modeling of degassing using actual aperture distribution of fracture replicas used in the laboratory experiments suggested that nonequilibrium effects will have to be added to TOUGH2 to represent degassing effects in the laboratory properly. Degassing refers to the formation of two-phase flow conditions when the reduction in ground-water pressure causes dissolved gases to come out of solution. Laboratory degassing experiments with radial flow geometry (converging flow) indicated the same order of flow reduction compared with the linear flow tests. Simulations with TOUGH2 are utilizing data from the field and laboratory experiments to test the prevailing conceptual model of two-phase flow for degassing conditions. Corresponding work is not planned for investigations at Yucca Mountain. Nevertheless, the insights to be obtained will advance the fundamental understanding of two-phase flow in fractured rock, relevant to issues of fast-path flow at Yucca Mountain, as well as, the understanding of likely changes in the unsaturated zone that will be caused by heating, degassing, and vaporization induced by the emplacement of waste. A test plan for degassing and two-phase flow experiments at the Hard Rock Laboratory (Äspö, Sweden) was developed by the project participants. Core samples of fractures in the region of the test site were shipped to participants.

During this reporting period, a pilot degassing test at the Hard Rock Laboratory in Äspö, Sweden, was conducted. The purpose of the pilot test was to study the effect of

degassing on borehole inflow rates, as a function of borehole pressure. Tests during December 1994, showed no evidence of degassing; however, tests conducted during January and February 1995 indicated a reduction in transmissivity that could have been caused by degassing. The difference in test results is attributed to an increase in gas contents measured between December and January. The low gas contents measured in December suggest that the borehole pressures below the partial pressure of the dissolved gases in the ground-water were not obtainable with the existing equipment configuration.

Forecast: A second series of degassing tests has been proposed, to be conducted in another borehole at the Hard Rock Laboratory where the ground-water dissolved gas contents are higher. The proposed test series includes gas injection tests to measure two-phase flow parameters. The TOUGH2 numerical model will be tested with laboratory data from additional fracture replicas and flow geometries to assess how to improve the model representation of experimental results. The focus will be on improved representation of fracture aperture distribution and the incorporation of nonequilibrium degassing and dissolution processes. Laboratory degassing experiments will be conducted on replicas from the Hard Rock Laboratory and Yucca Mountain fractures to test the current hypotheses of the importance of fracture geometry on the extent of flow reduction due to degassing for a wider range of fracture geometries.

Effects of Grouting Around an Excavation

The following is work, related to Activity 1.5.5.2 (Section 5.6.12), and Activity 1.6.2.1 (Section 6.5.1), conducted cooperatively with Sweden under the auspices of the OCRWM international program.

The original intent of this task was to use data on grouting to determine the value of a homogeneity parameter (σ), which has been found to be a useful quantitative measure of the field-scale heterogeneity of permeable media, in an analytic model (the log-normal transport model) for transport through fractured permeable media. The basic analytical development of the log-normal transport model has been completed, and some applications have been developed for bounding radionuclide release at Yucca Mountain. Chesnut (1994a) describes the model in Section 6.5 of this report. Applications to the ground-water travel time issue and forecasts of radioactivity release to the accessible environment are discussed in Sections 6.5 and 5.6.12 of this report and have also been published (Chesnut, 1994b).

Currently, investigators are using all available data, including probe hole inflow measurements and tracer tests to determine the heterogeneity parameter (σ). A draft report on analyses of these data will be completed shortly. In addition, work is under way to extend the theoretical development to nonisothermal systems for application to the near field environment at Yucca Mountain. This involves a combination of analytical development and numerical modeling, and a progress report is almost complete.

All of this work has direct application to Yucca Mountain. Subject to continuing comparisons of the log-normal transport model with field observations and numerical models, it appears to offer a realistic bound to field-scale transport processes that replaces the classical

dispersion approach. A particularly useful result is that the parameter is much less sensitive to the spatial and temporal scale of the transport process than is the apparent dispersivity, making it possible to scale up from short-term tests over limited distances.

Forecast: The basic analytical development of the log-normal transport model has been completed, and some applications have been developed for bounding radionuclide release at Yucca Mountain. Parameters for Yucca Mountain will be determined by analysis of cosmogenic and bomb-pulse isotope data. Work on data from Sweden will include application to new tracer experiments as data become available, and comparison with more detailed modeling efforts to determine if they can be adequately represented by this simplified approach. The method will be modified to accommodate uncertainty in the parameters.

Fundamental Materials Investigations

The following is work related to Study 1.10.4.5 (Section 5.2.6), conducted cooperatively with Canada under the auspices of the OCRWM international program.

During the previous reporting period, experimental work began to obtain thermodynamic data for crystalline phases present in cementitious materials that may be emplaced in a repository at Yucca Mountain. Experiments have been initiated to determine the phases that may occur at elevated temperatures, with emphasis on calcium silicate hydrates in cement-based grouts and concretes. The behavior of these materials during the lifetime of the repository may affect the chemistry of associated fluid phases with which they are in contact, analogously to the response of the host rocks. Heating of these materials has the potential to release large quantities of water from the hydrated phases.

During this reporting period, the following progress was made: (a) Ca-Si-H_2O phases (pure phases of 1.1 nm tobermorite, xonotlite, and hillebrandite) have been synthesized and are ready for distribution to the sites selected for thermodynamic measurement; (b) thermodynamic measurement of Ca-Si-H_2O phases began (sample encapsulation began for samples to be measured by drop calorimetry, and development of sample encapsulation methodology for samples to be measured by differential scanning calorimetry and by heat pulse calorimetry began); (c) relative humidity studies continued (experimental work continued on the stability of calcium silicate phases as a function of relative humidity); (d) chemical modeling work began (work began to develop the abiotic chemical module for cementitious materials, which will have EQ3/6 as its base, but will be far more flexible for the application to Portland cement-based materials and will allow quick assessment of new and expanded data base sets that have been developed as a result of present and previous work in this program).

Forecast: Syntheses of 1.4 nm tobermorite, afwillite, gyrolite, and okenite are planned. In addition to the phases noted above, these minerals are required to model the chemical degradation of cementitious materials that would be emplaced in a repository. These phases will be characterized by nuclear magnetic resonance and x-ray diffraction. In addition, their hydration and dehydration behaviors will be investigated and investigations conducted to provide information on water availability as a function of temperature and repository life and to determine their thermodynamic properties in a more definitive manner than presently exists.

The equipment required to pursue these experiments, at elevated temperature, is expected to arrive. Much of the planned work is described by Meike et al. (1994).

5.3 CHARACTERISTICS AND BEHAVIOR OF THE WASTE FORM (SCP SECTION 8.3.5.10)

5.3.1 Activity 1.5.1.1 - Integrate Waste Form Data and Waste Package Design Data

Subactivity 1.5.1.1.1 - Integrate spent fuel information. The Preliminary Waste Form Characteristics Report was published and distributed. An assessment of the spent fuel testing data and model needs is being written in support of the Controlled Design Assumptions Document (CRWMS M&O, 1995a).

Subactivity 1.5.1.1.2 - Integrate glass waste form information. As part of the glass model development effort, work is continuing on collecting and evaluating borosilicate glass dissolution data that are obtained outside of the Project. These data will be evaluated for inclusion in the next version of the Waste Form Characteristics Report.

Subactivity 1.5.1.1.3 - Integrate waste package and repository design information. The waste form characterization staff collaborated with the design staff to ensure that the characterization envelope is consistent with the design features being considered.

Forecast: Data obtained will be incorporated into a draft revision to the Waste Form Characteristics Report. This report is expected to be revised by section, rather than as a whole.

5.3.2 Activity 1.5.2.1 - Characterization of the Spent Fuel Waste Form

Subactivity 1.5.2.1.1 - Dissolution and leaching of spent fuel. The purpose of spent fuel waste form testing is to develop the predictive models and the technical bases for determining the rate of release of radionuclides from failed disposal containers under conditions appropriate to the potential repository. A systematic effort has been ongoing for several years to determine the effect of temperature and water chemistry on the dissolution response of the spent fuel inventory from unirradiated UO_2 to high burnup spent fuel. The current dissolution/release testing techniques in progress are flow-through tests and unsaturated tests. The flow-through tests have large ratios of water volume to surface area, and test solution concentrations remain below the solubility limits for the actinides. The unsaturated tests have low ratios of water volume to surface area, resulting in a drip/film flow mode of dissolution/release testing. The test solutions have colloidal formations. This effort also includes dissolution testing of the higher oxidation states of uranium because of the potential degradation of spent fuel by oxidation in a repository, before water contact.

Flow-Through Dissolution Testing of Oxidized Fresh Fuel

A flow-through test plan for UO_{2+x} experiments delineated a minimum of 16 experiments to determine the effects of temperature and water chemistry on the dissolution of the higher uranium oxides. By the end of December, all original 16 experiments were completed. Also, 8 additional experiments, consisting of the remaining temperature pairs of the original 16, were finished. The spent fuel flow-through plans have test matrices that will determine the dissolution rate response for the different spent fuel types (pressurized water reactor/boiling water reactor) over the range of burnup and fission gas release plus some aggressive water chemistries and temperatures of potential environments in a repository.

On the basis of the above dissolution testing, a series of EQ3/6 computer calculations were completed to better understand the observed dissolution response of $UO_3 \cdot H_2O$ in equilibrium with high carbonate solutions and the consequent lowering of the solution pH. Various uranyl carbonate complexes form when carbonate solutions contact uranium oxides. The formation of these complexes releases hydrogen ions into solution from the bicarbonate anion, thus lowering the pH of the solution.

Flow-through Dissolution Testing of Spent Fuel

Gray and Wilson (in prep.) documents progress and results for continuing studies of the dissolution behavior of spent fuel.

Unsaturated Dissolution Testing of Spent Fuel

The unsaturated dissolution tests are in progress to evaluate long-term dissolution/release performance of spent fuel. The current test matrix has two approved testing materials [approved testing material-103 (30 MWd/kgU pressurized water reactor fuel) and approved testing material-106 (43 MWd/kgU pressurized water reactor fuel)]. These tests examine the dissolution behavior of pressurized water reactor fuels in a saturated water vapor atmosphere and in dripping water at two drip rates. Initial results from the two low-drip-rate tests indicate spent fuel alteration has occurred and suggests a possible oxidation mode of the fuel in the repository that occurs by contact between the fuel and liquid. These tests have also shown that waste form colloids are a significant means of release for transuranics for low water volume modes of wetting. This colloidal mode of radionuclide transport needs to be addressed in the waste package/Engineered Barrier System release models. The observations made in both of these test activities have ramifications for the performance of waste in the Engineered Barrier System, the design of the Engineered Barrier System, and the performance of the repository.

Subactivity 1.5.2.1.2 - Oxidation of spent fuel. The oxidation response of spent fuel under repository conditions depends primarily on temperature and time after the spent fuel is exposed to atmospheric oxygen. The oxidation response of spent fuel is a degradation/alteration mode that can significantly increase the potential radionuclide release rate in the repository. This is because the UO_2 phase of spent fuel transforms to a U_4O_9 lattice (slight volume decrease) and then to U_3O_8 (~30% volume increase), increasing the spent-fuel surface

area exposed relative to the original pellet fragment/grain area. The U_3O_8 phase can split the Zircaloy cladding open lengthwise. Dry bath oven tests are in progress to determine spent fuel oxidation response. These are long-term weight gain tests conducted in a hot cell. These tests are primarily providing low-temperature (less than 200°C) oxidation response, but one dry bath recently was set to operate at 255°C to accelerate the oxidation rate. On the basis of information obtained from the dry bath oven tests, thermogravimetric apparatus tests were initiated at a higher range of temperature (250° to 320°C). These two types of tests will provide temperature-time-phase response as UO_2 spent fuel oxidizes to U_4O_{9+x}, to U_3O_8, and finally UO_3.

The dry bath oven tests show an initial oxidation response of UO_2 by a U_4O_{9+x} phase front propagating into the UO_2 spent fuel grains. This U_4O_{9+x} phase has an oxygen-to-uranium metal ratio of ~2.4. The $UO_{2.4}$ is considered a metastable phase structure, and at low temperatures (less than 200°C), a plateau in the oxygen to uranium metal ratio vs. time curve is observed. To assess the stability time of the plateau domain, one dry bath is currently being operated at 255°C. Thus, dry bath oven data are currently being obtained at temperatures of 110°, 130°, 175°, 195°, and 255°C.

The thermogravimetric apparatus tests are complementary to the dry bath tests and can provide higher temperature-time response data. Also, the thermogravimetric apparatus tests provide a better weight gain versus time response data set, which, in conjunction with microscopy, can be used to gain a mechanistic understanding of the time-temperature kinetics and the transition from the $UO_{2.4}$ plateau phase to U_3O_8. On the basis of preliminary scoping thermogravimetric apparatus tests, a test plan and an activity plan were completed. The first test matrix in this activity plan addresses the data needs for the influences of temperature on the $UO_{2.4}$ plateau time interval before the initiation of the U_3O_8 phase transition. The formation of the U_3O_8 phase has significant impacts on spent fuel release rate performance in potential repository environments.

Subactivity 1.5.2.1.3 - Corrosion of zircaloy. No progress was made during the reporting period; this was an unfunded activity.

Subactivity 1.5.2.1.4 - Corrosion of and radionuclide release from other materials in the spent fuel waste form. No progress was made during the reporting period; this was an unfunded activity.

Subactivity 1.5.2.1.5 - Evaluation of the inventory and release of carbon-14 from zircaloy cladding. No progress was made during the reporting period; this was an unfunded activity.

Subactivity 1.5.2.1.6 - Other experiments on the spent fuel waste form. No progress was made during the reporting period; this was an unfunded activity.

Forecast: The flow-through and unsaturated dissolution release rate testing of spent fuels will continue as per the existing test matrices in the activity plans. The oxidation/

degradation spent fuel testing in the oven dry baths and in the thermogravimetric analysis apparatus will continue per the existing test matrices in the activity plans.

5.3.3 Activity 1.5.2.2 - Characterization of the Glass Waste Form

Subactivity 1.5.2.2.1 - Leach testing of glass. Long-term unsaturated tests (drip tests) of two glass compositions (Defense Waste Production Facility and West Valley approved testing material-10) continue in two test series labeled the N2 and N3 series. These tests are being used to determine the types and quantities of radionuclide elements released from waste glasses when subjected to an intermittent dripping water contact scenario. Both soluble and colloidal radionuclide releases of actinides and technetium are being measured. A 304L stainless steel sample holder is also present in these tests to ascertain the influence of the pour canister material on glass waste form behavior.

The Defense Waste Production Facility glass is being tested in the N2 test series, which has been in progress for over nine years as of March 31, 1995, and were sampled on December 19, 1994. The West Valley glass (approved testing material-10) is being tested in the N3 test series, which has been in progress for almost eight years as of March 31, 1995, and were sampled on January 12, 1995. Solution samples from both series were subjected to sequential filtering and the particles are to be analyzed using analytical electron microscopy.

These tests are providing data on radionuclide release mechanisms and degradation/alteration rates of glass waste forms. These data are being used to constrain and guide ongoing model development for glass corrosion. Additional glass waste form testing will be required to model glass degradation/alteration modes and the subsequent dissolution/release of radionuclides as soluble and colloidal species over the range of potential repository environments.

Subactivity 1.5.2.2.2 - Materials interactions affecting glass leaching. The N2 and N3 test series contain stainless steel holders that simulate the presence of the 304L pour canister in the repository. Colloidal-sized iron particles have been identified in the N2 and N3 test solutions, which is important because sorption of radionuclides onto these particles provides a transport mechanism for radionuclides that is not solubility controlled.

Preliminary results from the N3 tests show variability in the extent of iron metal corrosion from the 304L holder. The controls on the extent of metal corrosion are important because this corrosion provides a source of iron colloids for radionuclide transport.

Subactivity 1.5.2.2.3 - Cooperative testing with waste producers. No progress was made during the reporting period; this was an unfunded activity.

Forecast: Degradation/alteration testing of the glass waste form in these long-term unsaturated tests will continue. Analysis of colloids from previous tests will be limited because of restricted funding. Ongoing long-term scoping tests on additional glass compositions will be brought up to quality affecting status as funding becomes available.

5.3.4 Activity 1.5.3.1 - Integrate Scenarios for Release From Waste Packages

Subactivity 1.5.3.1.1 - Develop scenario identifications. The development of the Yucca Mountain Integrating Model (YMIM) code (Gansemer 1995) continued. Information pertaining to this development is provided in Section 5.3.8.

Subactivity 1.5.3.1.2 - Separate scenarios into anticipated and unanticipated categories. No progress was made during the reporting period; this was an unfunded activity.

Subactivity 1.5.3.1.3 - Development of parameters describing the scenarios. Information pertaining to this subactivity is provided in Section 5.3.8.

Subactivity 1.5.3.1.4 - Determine adequacy of design envelope of waste package. No progress was made during this reporting period; this was an unfunded activity.

Forecast: A preliminary list and description will be developed of anticipated features, processes, and events that may have to be considered in analyzing the substantially complete containment requirement. Model development for the features, processes, and events will continue; see the forecast for Section 5.3.8.

5.3.5 Activity 1.5.3.2 - Develop Geochemical Speciation and Reaction Model

Subactivity 1.5.3.2.1 - Develop data base for geochemical modeling. Participants proposed a strategy for qualifying data for the GEMBOCHS database.

A five-year strategy for work in the Thermodynamic Data Determination Task has been developed by the intraproject Solubility Working Group. The work scope includes funding for the United States contribution to the Organization for Economic Coordination and Development/Nuclear Energy Agency Technical Volumes on thermodynamic data. Funding for FY 1995 supports the Organization for Economic Coordination and Development/Nuclear Energy Agency volumes for technetium, neptunium, plutonium and americium. The readiness review process is nearly complete for the laboratory effort to determine thermodynamic constants for Am(III), Pu(V), and U(VI) as a function of temperature.

Two manuscripts describing this work were being prepared. One paper (Johnson and Lundeen, in prep.[a]) describes the standard seven-element suite of thermodynamic data bases distributed with EQ3/6; emphasis is placed on describing the theoretical and empirical algorithms used to calculate thermodynamic properties at elevated pressure-temperature, and the specific modeling applications for which the individual data bases are particularly well suited. The second paper provides a complete set of user documentation and tutorials for the Jewel code (Johnson and Lundeen, in prep.[b]).

The GEMBOCHS data base itself was augmented significantly by incorporation of the CHEMVAL4 and CHEMVAL5 thermodynamic data bases, each of which contain approximately 1,000 chemical species. These stand-alone data bases, which are now available

for use with EQ3/6, are commonly used for comparative radiological assessment calculations in Europe. In addition, incorporation began on the comprehensive NIST (Smith-Martell) data base of critical stability constants for metal complexes (over 4,000 species). Many smaller-scale improvements in GEMBOCHS data (and software) were also completed.

A new Individual Software Plan for the GEMBOCHS system was generated, formally reviewed, and the review comments resolved; the plan was approved and is now in place. A revised Software Configuration Management system was also established.

Related International Work. See Section 5.3.12 for related work (under the heading Thermochemical Data Base) performed under the auspices of the OCRWM international program.

Subactivity 1.5.3.2.2 - Develop geochemical modeling code. This subtask is developing geochemical modeling software (EQ3/6) for analysis and simulation of interactions among water, rock, nuclear waste, and other repository components in the near-field environment, the altered zone, and the far-field environment. In FY 1994, the independent verification and validation activity for the Version 7 series of the software was completed, and Version 7.2a become the first version of EQ3/6 to be certified for use in quality-affecting work. New capabilities for thermodynamic pressure corrections and ion-exchange modeling (incorporating the Gapon and Vanselow models) were added to Version 8.0. This followed the earlier addition of a capability to deal with redox disequilibrium in reaction-path calculations. In FY 1995, the Version 7 software is being maintained, an independent verification and validation activity leading to the certification of Version 8.0 is being conducted, and capabilities for modeling phenomena associated with boiling are being added to the software. These new capabilities will be applied in other work breakdown structure elements, principally those dealing with the geochemistry of the altered zone and the near-field environment. Version 8.0 was set up for in-house beta testing, which may last all or part of the verification and validation period.

The development of EQ3/6 to deal with phenomena associated with boiling is planned as a two-year effort (FYs 1995 and 1996). In FY 1995, the software is being modified to include a capability for dealing with a general multi-component gas phase, with an emphasis on the case of a steam-dominated phase. In boiling systems, the loss (or gain) of other, minor volatile components such as CO_2 may have a major effect on concomitant processes such as mineral deposition. To complete the gas phase submodel, various published models for calculating fugacity coefficients are being examined for their usefulness for application to steam-dominated phases. Calculations of enthalpy and volume balances are being added to the software, but during FY 1995, this will be restricted to the calculations of changes in enthalpies and volumes. In FY 1996, capabilities to use the corresponding balance equations to compute, for example, the change in temperature associated with a given heat input, will be included.

In FY 1995 and FY 1996, the software may be improved to deal with the possibility of formation of concentrated solutions caused by boiling. As time permits, there also may be

some further additions to the ion-exchange modeling capability, such as the addition of the Gaines-Thomas model and a general site-mixing model.

In recent work, the Version 8 input files for EQ3NR and EQ6 have been improved for ease of use. The descriptive strings used in the menu-style input format have been upgraded for succinctness, accuracy, and understandability. Several numerical parameters used by the EQ6 code have been removed from the EQ6 input file and are now simply set in the code itself. A recent minor change was made to allow the pressure to be set to follow the 1.013-bar/steam-saturation curve value even if the data file reference pressure curve is something different, such as a constant 500 bars.

In response to the recent concern in performance assessment about the reported high solubilities of neptunium observed in experimental systems (Nitsche, 1991), calculations were made of likely neptunium mineral solubilities in UE-25 J#13 water (under oxidizing conditions, at 25°C using EQ3/6 Version 7.2a). If the solubility-governing phase is assumed to be $NpO_2(c)$, the predicted concentration is 1.331×10^{-13} molal (87.02% NpO_2^+). Such ground water is vastly undersaturated with other neptunium minerals.

However, if the solubility-governing phase is assumed to be Np_2O_5 (one of the two neptunium solids identified in Nitsche's experiments), the predicted concentration is 2.679×10^{-3} molal, a 10 order of magnitude increase (the speciation of dissolved neptunium is barely changed). The solution is vastly supersaturated with respect to NpO_2, as expected. The UE-25 J#13 water that is saturated with NpO_2 is also very nearly saturated with respect to $NaNpO_2CO_3{:}3.5H_2O$ (the other neptunium phase observed by Nitsche, though with some stoichiometric variation) and $NpO_2OH(am)$. The concentrations of dissolved neptunium corresponding to equilibrium with these phases are 7.791×10^{-4} and 8.202×10^{-4} molal, respectively. The calculated concentrations for Np_2O_5, $NaNpO_2CO_3{:}3.5H_2O$, and $NpO_2OH(am)$ are all close to the values observed by Nitsche (1991).

To summarize, NpO_2 is a very stable phase; solubility equilibrium yields an extremely low concentration of dissolved neptunium. If NpO_2 does not form rapidly (as was apparently the case in Nitsche's experiments), then the concentration of dissolved neptunium is controlled at approximately the 1×10^{-3} molal level by metastable equilibrium with one of the two metastable phases: Np_2O_5 or $NaNpO_2CO_3{:}3.5H_2O$. Whether or not NpO_2 controls the level of dissolved neptunium in a real system appears to be a problem of kinetics. Apparently it does not readily form in UE-25 J#13-like waters at low temperatures (<90°C) and the relatively short time frame of benchtop experiments (60 to 150 days). There is no reason to suspect that the thermodynamic stability of NpO_2 is grossly in error. Considering that the time scales involved for a real repository are so much longer than those that pertain to the benchtop experiments, NpO_2 formation is likely to have an effect in the repository. Some understanding of the kinetics of the process, however, will be necessary if any credit for this can be taken in repository performance assessment. Similar calculations, providing qualitatively the same result, were done by Los Alamos and reported as part of the work for developing the solubility models for the dissolved species concentration limits (see Activity 8.3.1.3.5.1.2).

Examples of very stable (insoluble) minerals which are slow to form in real systems on short time scales, are not unknown in geochemistry. Dolomite ($CaMg(CO_3)_2$) is perhaps the best known example. The dolomite problem has been studied, in part, by conducting experiments at elevated temperatures (150° to 200°C), where the formation of this mineral can be observed (for a review of such work, see Sibley et al., 1994). An approach to the neptunium problem might be to conduct analogous studies.

Forecast: Three accomplishments are expected in the next reporting period. These are a letter report on software maintenance activities, a progress report on the development of capabilities for modeling boiling systems, and a letter report on the independent verification and validation activities and the QA status of the software.

5.3.6 Activity 1.5.3.3 - Generate Models for Release From Spent Fuel

Subactivity 1.5.3.3.1 - Generate release for spent fuel models. The model development for release of radionuclides has been guided primarily by the flow-through dissolution rate data from spent fuel and unirradiated UO_2 testing. Because the water chemistries of these flow-through tests are aggressive, the preliminary models are believed to be upper bounds for actual repository dissolution rates. These flow-through tests have large ratios of water volume to wetted fuel surface area. In providing release rates for more general cases, however, functional forms are multiplicatively coupled in the release model. The functional forms describe the amount of spent fuel area wetted, the spent fuel degradation/alteration-oxidation phase state, the above-mentioned dissolution rate data, and now, a possible dependence on the wetting mode.

The spent fuel area wetted will depend on the failed state of the cladding. For cladding failures with small cracks, significant reduction (several orders of magnitude) in exposed fuel surface area can be attained. This reduces the release rate response proportionally. The surface area reduction models, however, will require future characterization of cladding failures for use in any quality-affecting design analysis, as well as dissolution/release tests to substantiate the modeling concepts. Activities are in progress to provide data for the degradation/alteration oxidation phase state and the dissolution rate data. The last functional form, the wetting mode, has been sub-classified according to the flow-through testing (large flowing water volumes relative to the surface area wetted), the saturated testing (large non-flowing water volumes relative to the surface area wetted), and the unsaturated testing (small water volumes, a film flow mode relative to the surface area wetted). The last testing technique has also been termed the drip test, and only recent and limited test data are available. Results from these tests indicate significant concentrations of colloid formation. The colloid formation and the film flow wetting regime of these unsaturated tests require that new and more complex functional expressions be incorporated into dissolution/release rate models.

Forecast: Extension of the preliminary dissolution/release rate modeling to include solid-liquid interface effects, wetting mode effects, colloidal effects, and thermodynamic

chemical potential terms will continue. A semi-empirical modeling approach for a spent fuel degradation/alteration oxidation response will continue.

Related International Work. See Section 5.3.12 for related work (under the heading Spent Fuel Dissolution Model Development) performed under the auspices of the OCRWM international program.

5.3.7 Activity 1.5.3.4 - Generate Models for Release From Glass Waste Forms

Subactivity 1.5.3.4.1 - Generate release models for glass waste forms. The glass waste form dissolution model is being interfaced to the Yucca Mountain Integrating Model performance assessment model. The present glass dissolution model embodied in the EQ3/6 geochemical modeling code is being simplified by fitting the model results to empirical equations. The primary relationship involves the rate of dissolution of the glass as a function of temperature, pH and dissolved silica concentration. Two additional empirical relationships were also needed for the current YMIM glass submodel: (1) pH vs. the amount of dissolved glass and (2) the ratio of silica released to solution vs. silica contained in alteration phases as a function of surface area to volume ratio in the tests. These latter two relationships allow YMIM to model intermediate behavior between open (flow-through) and closed (bathtub)-type water contact regimes.

Forecast: Work to interface the present glass dissolution model to the YMIM model will continue.

5.3.8 Activity 1.5.3.5 - Waste Package Performance Assessment Model Development

Subactivity 1.5.3.5.1 - Development of system model. The Yucca Mountain Integrating Model code (Lamont, 1994) was developed and a Users Guide published (Gansemer and Lamont, 1995). This code combines summary models of many of the features and processes of the near-field environment and the Engineered Barrier System to calculate container breach times and radionuclide release rates. See Section 5.3.10 for applications. Development was started on the next revision of YMIM to be used in an FY 1995 analysis of the Engineered Barrier System performance and in the FY 1995 Total System Performance Assessment. This version will include several enhancements in container corrosion, near-field thermohydrological environment, and glass waste form processes.

A YMIM verification activity was started in accordance with the YMIM Individual Software Plan. The first stage is to state the program's representational and functional goals and the program's structure, which provides the baseline for review and concurrence by subject-matter experts, for Program implementation, and for test control. This baseline also provides the medium for change control and configuration management at the design-drawing level rather than only at the report and source-code levels. A software-engineering package was selected and acquired to provide graphical and data base representation of the requirements and design, and to provide specific form for review and configuration

management of this level of information. Staff training on the software was completed. A draft version of the YMIM design in this format was developed and is in review.

Subactivity 1.5.3.5.2 - Development of uncertainty methodology. No progress was made during the reporting period; this was an unfunded activity.

Subactivity 1.5.3.5.3 - Water flow into and out of a breached container. No progress was made during the reporting period; this was an unfunded activity.

Forecast: The YMIM model will be further enhanced in preparation for preliminary analyses for technical site suitability and for advanced conceptual design. The next version will be available for project use during the next reporting period. The enhancements will be prioritized for near-term analysis requirements. The YMIM qualification activity will continue.

5.3.9 Activity 1.5.4.1 - Deterministic Calculation of Releases from the Waste Package

In this reporting period, no calculations were performed. See Sections 5.3.10 and 5.6.10 for related calculations.

Forecast: See Section 5.3.10

5.3.10 Activity 1.5.4.2 - Probabilistic Calculation of Releases from the Waste Package

Zircaloy cladding creep strains were predicted from various constitutive equations reported in the literature (Rosen and O'Connell, in prep.), and the reduced effect of the increasing fuel rod gas volume with strain was added to the models. The creep strain is the first step in predicting whether the cladding will undergo creep rupture under the cumulative thermal effects of dry storage and permanent disposal. Knowledge of cladding breach is required to determine the rate of release of radionuclides from the waste packages. There is a variability in the cladding creep strain predictions based on various experimental data sets. Including the increasing-volume effect reduces this variability. Even within a recognized range of variability, useful predictions may be possible, constraining the release rates of radionuclides.

Forecast: Analyses will be performed as a preliminary assessment of the ability of the advanced conceptual design to meet the requirements of substantially complete containment and controlled release of radionuclides. Updated models or analyses will be produced to support the source term component of Total System Performance Assessment. Analyses of the Engineered Barrier System/near-field environment subsystem will be analyzed to support the preliminary Technical Site Suitability assessment. Results will be used as feedback to guide priorities in additional data acquisition and model enhancement activities.

5.3.11 Activity 1.5.5.1 - Determine Radionuclide Transport Parameters

Subactivity 1.5.5.1.1 - Radionuclide distribution in tuff wafers. Adsorption of radionuclides, such as cesium, strontium, uranium and neptunium onto and into the zeolite clinoptilolite is expected to retard their transport through clinoptilolite-bearing formations and/or fractures. Laboratory sorption measurements have shown that clinoptilolite is an effective sink for cesium and strontium. Cesium and strontium adsorption by clinoptilolite can be described by cation exchange and is a relatively rapid and reversible process for systems in which the crystal size of the clinoptilolite is small (on the order of 1 to 2 μm). Preliminary analysis of the experimental data suggests that diffusion rates (on the order of 1×10^{-22} to 1×10^{-17} m^2/s for strontium and cesium, respectively) may be slow enough to limit the attainment of equilibrium between cesium and strontium-bearing ground waters and clinoptilolite for situations in which fluid flow is relatively rapid and clinoptilolite crystals are relatively large (e.g., in fractures). Laboratory sorption measurements over relatively short time scales (weeks to months) suggest that adsorption of uranium and neptunium by clinoptilolite is limited (small partition coefficients) and appears to occur on the external surface of the crystal. Studies are beginning using the same techniques developed for cesium and strontium to directly assess whether there is a potential for intracrystalline adsorption of uranium and neptunium in clinoptilolite, and if so, whether the rates of diffusion are rapid enough to allow clinoptilolite-bearing rocks, such as the Calico Hills Formation, to retard uranium and neptunium movement over repository time scales.

Subactivity 1.5.5.1.2 - Radionuclide distribution in tuff cores. An experimental protocol has been decided on and transport experiments using conservative tracer-bearing solutions have been initiated for samples of Topopah Spring Tuff at ambient, 60° and 90°C. Preliminary results indicate that the experimental apparatus is performing according to expectations. Experiments using conservative tracers are continuing, and experiments using adsorbing tracers (uranium, neptunium) are being planned. A summary of results of characterizing colloids from Nevada Test Site ground waters and fluids that have contacted Topopah Spring Tuff samples in flow experiments indicate that the colloids are primarily layer silicates and silica polymorphs, and are similar for both field and laboratory fluids.

Forecast: Laboratory sorption measurements for cesium and strontium will be completed and the uranium and neptunium studies will continue. Temperature dependence flow studies involving conservative and non-conservative tracer-bearing solutions through Topopah Spring Tuff core samples will continue. Mechanistic modeling studies of radionuclide transport through Topopah Spring Tuff core will be initiated.

5.3.12 Related International Characteristics and Behavior of the Waste Form Work

Thermochemical Data Base

The following is work, related to Subactivity 1.5.3.2.1 (Section 5.3.5), conducted cooperatively with the Nuclear Energy Agency of the Organization of Economic Cooperation and Development under the auspices of the OCRWM international program.

During the previous reporting period, significant progress was made in compiling and reviewing existing thermochemical data. For the planned volume on plutonium and neptunium, both tetra- and hexavalent states, data on the aquo-ions and the hydroxy and carbonate complexes have been assembled and critically reviewed by American and foreign scientists. The draft report for americium was distributed to and reviewed by an external peer review panel; the review panel consisted only of Americans, but was recommended by the Nuclear Energy Agency. Progress was made on the technetium volume by foreign scientists. The data recommended in the final data bases for these radionuclides will be used by YMSCO as part of the thermodynamic data base for the EQ3/6 and possibly other geochemical codes. The corresponding Nuclear Energy Agency data for uranium are already in use. These reviews provide substantially increased confidence in the reliability of data critically needed in performance assessment in calculating solubility and transport.

During this reporting period, progress continued in compiling and reviewing existing thermochemical data. A subcontract was issued to complete the work on plutonium and neptunium data on aquo-ions and the hydroxy and carbonate complexes they form in the tetra and pentavalent states. The draft report of these two volumes should be completed in FY 1996. The comments made by the external peer review panel on the americium volume were by the technical review panel. Publication of the volume should be forthcoming in the near future. An increased effort is being made to complete the draft of the technetium volume by the end of the fiscal year.

Data recommended in the final data bases for these radionuclides, as well as the already published uranium volume, will be used by YMSCO as part of the thermodynamic data base for the EQ3/6 and possibly other geochemical codes. These reviews provide substantially increased confidence in the reliability of data critically needed in performance assessment in calculating solubility and speciation and predicting transport.

Forecast: The americium volume should be published during FY 1995. Work will continue on the plutonium, neptunium and technetium volumes with the expectation they will be ready to submit to external peer review at the end of the year or early in FY 1996.

Spent Fuel Dissolution Model Development

The following is work, related to Subactivity 1.5.3.3.1 (Section 5.3.6), conducted cooperatively with Canada under the auspices of the OCRWM international program.

During the previous reporting period, the original sixteen and eight additional experiments in the UO_{2+x} test matrix were completed. The dehydrated schoepite, $UO_3 \cdot H_2O$, was shown to dissolve much faster than the U_3O_8, particularly at high carbonate concentrations. The results also showed that the dissolution rates of U_3O_8 strongly resemble those of UO_2 under analogous conditions. Raising the temperature to 75°C enhances the rate by a factor of 2 to 4 for the two higher oxides. Initial modeling showed similar response for UO_2 and spent fuel, except for the effect of oxygen. For UO_2 the dissolution data show a half-order response in respect to oxygen at 25° and 75°C. Spent fuel showed no effect in relation to oxygen at room temperature and variable response at 75°C. Modeling was modified to include solid-liquid interface and chemical potential terms. Regression fits with these models were not so robust as earlier ones that relied on classic empirical chemical rate equations for homogeneous solutions and pure polynomial fits. Comparisons, where appropriate, of test results among LLNL, Pacific Northwest Laboratory, and Atomic Energy of Canada Limited showed good agreement. More details were provided by Gray et al., (1994), Steward and Gray (1994), and Rudnicki et al. (1994). These experimental results have direct applicability to dissolution of spent fuel in liquid water, which is the only viable release mechanism for most radionuclides from waste that may be emplaced in Yucca Mountain. They provide a broader data base for both fuel types and water chemistries thereby carrying potential for developing a substantially more robust model for the source term.

During this reporting period, all test series were conducted at 8 ppm dissolved oxygen (20 percent oxygen in the gas phase). The temperature (25° to 75°C), pH (8 to 10) and total carbonate concentration (2×10^{-4} to 2×10^{-2} molar) varied. X-ray Diffraction and nuclear magnetic resonance spectra of the $UO_3 \cdot H_2O$ samples were acquired. Particle size measurements were made with both $UO_3 \cdot H_2O$ and U_3O_8 samples, using both optical microscopy and sedimentation techniques.

The multi-laboratory UO_2 powder dissolution experiments have continued for two and one-half years. For comparison, similar experiments using samples from the same batch of powder were run for shorter times at two other laboratories. The first buffer composition was 0.02 M sodium bicarbonate at a pH of 8, and the second composition a 'standard' saline solution with 0.01 M sodium bicarbonate and 0.1 M sodium chloride saturated with air; the pH was not controlled. After being shut off for several months, they were restarted during summer, 1994. During the subsequent two months, the dissolution rate of the 'carbonate only' experiment increased immediately and dramatically to over 15 $mg \cdot m^{-2} \cdot d^{-1}$. The rates have trended downward since then to values seen previously of about 4 $mg \cdot m^{-2} \cdot d^{-1}$. The dissolution rate in the 'standard saline solution' remained low initially at about 2 $mg \cdot m^{-2} \cdot d^{-1}$, but increased to a value similar to the 'carbonate only' experiment during the last two months of the calendar year. The experiments were momentarily stopped in early January to examine and weigh the UO_2 samples. There was some grain fragmentation, but the grains generally retained their size and sharp edges.

A variety of electrochemical and corrosion science methods, as well as the technique of photothermal deflection spectroscopy, have been used in joint Canadian and American investigations of the mechanisms of oxidative dissolution processes in UO_2. These techniques are leading towards an active-passive kinetics model and away from a grain boundary

explanation. The grain boundaries are more active because of oxygen content, not structural effects. The reactivity of crystalline material can be increased by oxidation. Further oxidation decreases reactivity. An active-passive model is consistent with previous electrochemical and studies and with flow-through studies, which usually show initial high dissolution rates. Such an explanation explains the differences between electrochemical and chemical dissolution studies. The electrochemical studies occur at short times, before a passive film can form. This recent work leads to the conclusion that oxygen stoichiometry is key to the reactivity of UO_2. Changes in oxygen stoichiometry make the crystalline material behave similarly to the sintered material. The work continues to support the contention that dissolution occurs from localized sites, related to oxygen stoichiometry, as opposed to the entire surface.

A joint Canadian and American draft report on factors affecting the dissolution rate of U from UO_2 and spent fuel was prepared to address a milestone on the differences in reactivity between UO_2 and spent fuel. This report identified important parameters that control the dissolution rate of U from UO_2. The UO_2 matrix phase of spent fuel forms the basis for the development of a release model for radionuclides from spent fuel that can be used in waste package design and performance assessment studies. The report discusses results from flow-through leaching experiments, electrochemical experiments and photothermal deflection spectroscopy studies carried out at laboratories in both countries.

Forecast: A model for dissolution of spent fuel, utilizing both the experimental data and enhanced understanding in how to perform the calculations, will be completed.

5.4 CHARACTERISTICS AND CONFIGURATIONS OF THE WASTE PACKAGES (SCP SECTION 8.3.4.3)

No progress was made during the reporting period; this was an out-year study.

Forecast: No activity is planned for FY 1995.

5.5 WASTE PACKAGE PRODUCTION TECHNOLOGIES (SCP SECTION 8.3.4.4)

5.5.1 Design Activity 4.3.1.1 - Waste Package Fabrication Process Development

The objective of this activity is to determine, by using the logical sequence described for this issue, the processes to be used in fabricating the nonwaste form components of the waste packages.

A report on waste package cost estimates was issued, which is discussed under Activity 1.10.2.3.4 (Section 5.1.3).

A design analysis was prepared and issued in response to a request from Waste Acceptance and Storage Transportation Design (CRWMS M&O, 1995). The analysis first examines general limitations upon the multi-purpose canister sizes and weights, as established

by the Multi-Purpose Canister Subsystem Design Procurement Specification, and then concludes that the Mined Geologic Disposal System does not require any additional limitations upon the weight or nominal envelope of the multi-purpose canister. The Mined Geologic Disposal System will design the disposal containers to accommodate all sealed waste-containing multi-purpose canisters that have been produced in accordance with the final production Multi-Purpose Canister Subsystem Design Procurement Specification.

5.5.2 Design Activity 4.3.1.2 - Waste Package Closure Process Development

The objective of this activity is to determine, by using the logical sequence described for this issue, the process to be used in the final closure of the waste package containers.

A technical requirements document on waste package closure was issued (CRWMS M&O, 1995). The document presents the objectives, technical information, and work scope relating to the waste package closure development task and its subtasks. A technical requirements document is issued before soliciting a test plan for the waste package closure development task.

5.5.3 Design Activity 4.3.1.3 - Waste Package Closure Inspection Process Development

The objective of this activity is to determine, by using the logical sequence described for this issue, the process to be used in inspecting the final closure of the waste package containers.

Efforts on production technologies focused on filler material and integrating of fabrication process with multi-purpose canister design. Preparation began on a technical requirements document for nondestructive evaluation of closure welds.

Forecast: The technical requirements document will be completed and issued during the next reporting period.

5.5.4 Design Activity 4.3.1.4 - Remote In-Service-Inspection Development

No progress was made during the reporting period; this was an out-year activity.

Forecast: No work on this activity is planned for FY 1995.

5.5.5 Design Activity 4.3.1.5 - Internal Filler Material Process Development

A design analysis is being prepared in response to a request from Waste Acceptance Storage and Transportation Design (CRWMS M&O, in prep.). The analysis first examines access requirements (both to remove/replace spent nuclear fuel and to add filler materials) as

established by the Multi-Purpose Canister Subsystem Design Procurement Specification. The analysis concludes that to add filler to the multi-purpose canister, the canister would be opened at the Mined Geologic Disposal System by cutting through the cylindrical shell in the vicinity of the shield plug, and the top end and shield plug would be removed, thereby providing access to the entire cross section of the multi-purpose canister. Furthermore, the basket and internals must be designed to provide access to all void spaces within the multi-purpose canister, including void spaces within any flux trap baskets. The void access requirement derives from the criticality control aspect of filler materials.

Forecast: Work on cost estimation and integration of process development with multi-purpose canister design will continue.

5.6 WASTE PACKAGE PERFORMANCE (SCP SECTION 8.3.5.9)

Waste package container designs, as described in the Controlled Design Assumptions Document, currently focus on a multiple barrier approach and include families of materials, other than the copper-base materials and the iron to nickel-base "austenitic" materials, that were the subject of the SCP Conceptual Design (SNL, 1987). Discussions of the progress made on evaluating these "alternate materials" are found under Activity 1.4.2.4 (Section 5.6.6), rather than Activities 1.4.2.2 (Section 5.6.4) and 1.4.2.3 (Section 5.6.5), and Activity 1.4.3.3 (Section 5.6.9) rather than Activities 1.4.3.1 (Section 5.6.7) and 1.4.3.2 (Section 5.6.8). The only option of these "alternate materials" currently being pursued is the "Bimetallic/Single Metal," which is the multiple barrier design.

5.6.1 Activity 1.4.1.1 - Integrate Design and Materials Information (Metal Container)

The current waste package container designs focus on a multiple-barrier approach for both spent nuclear fuel packages and for vitrified high-level waste packages. These designs are "robust" in the sense that (a) multiple barriers provide reinforcement to the containment function, (b) thick sections are used for some of the barrier materials, and (c) some of the barrier materials are very highly corrosion resistant to a wide range of environmental conditions. Materials of construction for the waste package are grouped into three categories according to their projected performance. Configurations of the waste package depend on the thermal load designed for the repository.

Highly Corrosion Resistant Materials

Multiple candidates are presented as corrosion resistant materials that could be used as an inner barrier of a multiple barrier waste package. This group of materials is itself divided into three groups:

1. Nickel-rich Stainless Alloys. These materials are viewed as transition alloys falling between stainless steels and nickel-base alloys. These materials contain 40 to 50 percent nickel plus chromium. They also contain iron, molybdenum and other alloying elements. Candidate materials in this group are Alloy 825 and Alloy G-3.

2. Nickel-base Alloys. These materials can be viewed as an extension of the previous group, in which nickel has replaced iron in the composition. These alloys contain 60 percent or more nickel. Candidate materials in this group are Alloy C-4 and Alloy C-22.

3. Titanium. This group of candidate materials includes Ti Grade 12, which is a "lean" titanium-base alloy containing small additions of nickel and molybdenum, and Ti Grade 16, which contains a small addition of palladium.

Corrosion Allowance Materials

These are materials that are expected to oxidize or corrode at a predictable rate. If these degradation rates are within acceptable limits, the barrier can be made sufficiently thick so that a rather lengthy service lifetime can be obtained. Economical iron-base materials have generally been considered corrosion allowance materials for nuclear waste containers, not only because of their comparatively low cost but also because they can be readily formed and welded in thick sections. Candidate materials in this group are wrought carbon steel, cast carbon steel, and low chromium-molybdenum alloy steel.

Intermediate Materials

A third group of materials was identified, which are referred to as "intermediate" between the corrosion resistant and corrosion allowance groups, because they have some performance characteristics of both groups. Candidate materials are Alloy 400 (UNS N04400) and 70/30 copper-nickel (UNS C71500).

A more complete discussion of these candidate materials, their properties, and their projected performance under a range of possible repository emplacement conditions is presented in a draft report (McCright, in prep.). This draft has been reviewed and is being revised.

A report on engineered materials characterization (Van Konynenburg et al., in prep.) was in DOE review. The report was prepared in three volumes. The first volume describes the engineered materials effort for the YMP, defines terms and outlines the history of selection and characterization of these materials, and summarizes the recent Engineered Barrier System materials characterization workshop. The second volume tabulates design data for engineered materials, and the third volume provides corrosion data, radiation effects on corrosion, and corrosion modeling. The second and third volumes will be evolving documents, with new data added as they become available from additional studies. Initially, volume 3 is devoted to information currently available for environments most similar to those expected in the potential Yucca Mountain repository. This report tabulates existing data (from non-Project

sources) on mechanical and physical properties of the candidate materials, but no additional Project data on these properties was acquired during this period. The existing data were added to the Reference Information Base.

The Metallic Barrier Scientific Investigation Plan (DOE, 1995) was revised, updated, and issued as a controlled document on January 31, 1995. The update is consistent with the current waste package design for a multiple barrier container. The plan describes many technical activities that will be performed in the next several years to support the selection of materials to be used in fabricating the waste package container and to support the performance analysis of the selected materials. The activities can be grouped into four categories: (1) degradation mode surveys and information bases, (2) corrosion testing and physical evaluation, (3) modeling of performance behavior, and (4) materials recommendations. This plan explains how interfaces between the metallic barriers task and other programmatic elements function; it also shows the sequencing of individual activities and how results from the different activities support one another. The preface discusses how the waste package design changes and candidate material evaluations have proceeded through the various revisions of the plan.

Forecast: Integration between the materials evaluation efforts and other aspects of the waste package design effort continue to be emphasized. The Metallic Barrier Scientific Investigation Plan is the main document that will guide the materials evaluation effort for the next several years, and in the coming year this plan will become fully implemented. As new data become available from the testing and modeling activities the Engineered Materials Characterization Report will be periodically updated.

5.6.2 Activity 1.4.1.2 - Integrate Design and Materials Information (Alternate Barriers Investigation)

The purpose of the nonmetallic barriers task is to characterize the behavior of nonmetallic materials, such as ceramics, and to determine degradation rates and mechanisms. One of the barriers of the disposal container may be fabricated from a nonmetallic material. A primary objective of this task is determination of the feasibility of making a nonmetallic barrier as part of a waste package.

Work on alternative barrier approaches to waste package container design ceased at the end of FY 1994. A report (Wilfinger, in prep) on the survey of ceramic materials and processes for fabricating and joining them, either as stand-alone barriers or as thick coatings applied to metal surfaces, was prepared and is currently in review.

There is currently no on-going work on subactivities in this section. If work resumes, progress will be reported accordingly.

Subactivity 1.4.1.2.1 - Survey of alternative barrier designs, materials, and processes to determine feasibility of fabricating a satisfactory waste package. No progress was made during this reporting period; this was an unfunded subactivity.

Subactivity 1.4.1.2.2. - Mechanical properties. No progress was made during this reporting period; this was an unfunded subactivity.

Subactivity 1.4.1.2.3. - Microstructural properties. No progress was made during this reporting period; this was an unfunded subactivity.

Subactivity 1.4.1.2.4 - Thermophysical properties. No progress was made during this reporting period; this was an unfunded subactivity.

Subactivity 1.4.1.2.5 - Nondestructive characterization of the alternate barrier investigations waste package container. No progress was made during this reporting period; this was an unfunded subactivity.

Forecast: When approved, the survey report will be issued. Additional FY 1995 funding is being considered.

5.6.3 Activity 1.4.2.1 - Selection of the Container Material for the License Application Design

Subactivity 1.4.2.1.1 - Establishment of selection criteria and their weighting factors. Criteria and weighting factors for each criterion were selected for the SCP-Conceptual Design materials in the 1987-88 period.

Subactivity 1.4.2.1.2 - Material selection. A quantitative scale for evaluating candidate materials for each criterion was developed for the SCP-Conceptual Design materials in the 1987-88 period.

The results of these activities are being re-evaluated for the candidate materials being considered for multiple barrier waste package containers. Most of the criteria will probably stay the same, but different weighting factors will probably be used to evaluate materials for multiple barriered designs.

Forecast: A draft report on any recommended changes in the selection criteria and weighting factors will be prepared.

5.6.4 Activity 1.4.2.2 - Degradation Modes Affecting Candidate Copper-Based Container Materials

The Controlled Design Assumptions focus entirely on multiple barrier waste package container configurations; therefore, degradation mode activities are reported under Activity 1.4.2.4. The only option currently being pursued under the controlled design assumptions is the "Bimetallic/Single Metal," which is the multiple barrier design. See the discussion in Section 5.6.

5.6.5 Activity 1.4.2.3 - Degradation Modes Affecting Candidate Austenitic Materials

The Controlled Design Assumptions focus entirely on multiple barrier waste package container configurations; therefore, degradation mode activities are reported under Activity 1.4.2.4. See the discussion in Section 5.6.

5.6.6 Activity 1.4.2.4 - Degradation Modes Affecting Ceramic-Metal, Bimetallic/Single Metal, or Coatings and Filler Systems

All the work discussed below is applicable to the bimetallic/single metal case for design alternatives discussed in the SCP (DOE, 1988). See the discussion in Section 5.6.

Subactivity 1.4.2.4.1 - Assessment of degradation modes affecting ceramic-metal systems. No progress was made during the reporting period; this was an unfunded activity.

Subactivity 1.4.2.4.2 - Laboratory test plan for ceramic-metal systems of the alternate barriers investigations. No progress was made during the reporting period; this was an unfunded activity.

Subactivity 1.4.2.4.3 - Assessment of degradation modes affecting bimetallic/single metal systems. The objectives of degradation mode surveys are to (a) compile relevant previously published information about a candidate material and its performance in a number of environments and (b) interpret this body of information in the context of a potential repository in Yucca Mountain. In many instances, the degradation mode survey indicates the ways in which a material can degrade and serves to indicate the rate and kind of degradation in environments that have some similarity to what a metal barrier may experience in the Yucca Mountain setting. In other instances, the lack of information suggests what work will be required to determine the behavior of the candidate material in Yucca Mountain environmental conditions.

Titanium and its alloys are considered for waste package containers because of their excellent corrosion resistance in most aqueous environments. A draft survey report on the degradation modes of titanium (Gdowski, in prep.) was completed in January 1995. The survey included commercially pure titanium, and several "lean" Ti-base alloys, containing less than 1 percent alloying elements.

The degradation mode survey concludes that of the materials reviewed, commercially pure Ti Grade 2 is the most susceptible to crevice corrosion, however, several Ti alloys are likely to be very resistant to crevice corrosion under the expected Yucca Mountain repository conditions.

Hydride-induced cracking of titanium is a possibility, and therefore, further investigation of this phenomenon under credible repository conditions is warranted. One disadvantage of titanium and its alloys is that their strengths decrease rather rapidly with temperature. This is because of the strong temperature dependence of interstitial solute strengthening mechanisms.

The survey recommended that Ti Grades 12 and 16 be considered as candidate materials for one of the barriers in the multiple barrier design for the waste packages in the YMP program.

Forecast: After review and approval, the Titanium Degradation Mode Survey will be published as part of the series on candidate materials. Previous surveys have dealt with copper-base alloys, "austenitic" alloys (stainless steel and Alloy 825), high nickel-chromium-molybdenum alloys (including Alloy C-4 and C-22), and carbon steels, alloy steels, and cast irons as corrosion allowance materials. Additional volumes are planned for Alloy 400 (a nickel-copper alloy) and other nickel-base alloys that have not been previously covered. These are planned for completion in FY 1995. In addition, a Degradation Mode Survey on weldments of high performance materials (nickel-base and titanium-base) is being planned.

Subactivity 1.4.2.4.4 - Laboratory test plan for bimetallic/single metal material systems.

Long-Term Corrosion Studies

The objective of this activity is to determine comprehensive corrosion properties of metallic alloys being considered for waste package structural materials. Three classes of materials are to be addressed: corrosion resistant, corrosion allowance, and intermediate materials (see discussion under Activity 1.4.1.1 in Section 5.6.1). Corrosion properties to be assessed are general corrosion, pitting corrosion, crevice corrosion, intergranular corrosion, stress corrosion cracking, hydrogen embrittlement, and galvanic corrosion. This activity will provide kinetic and mechanistic information about the corrosion degradation of candidate materials. This information will help in materials selection, performance analysis, and model development. Tests are conducted in "bounding environments" to capture the range of environmental conditions and water chemistries that are projected to develop near the container surface over long periods of time. This comprehensive corrosion test is planned for a five-year period (or longer), with periodic removal and inspection of test specimens to measure corrosion degradation as a function of exposure time.

Four bounding water chemistry environments were identified in which these long-term corrosion tests are conducted. The rationale for their use was discussed in the Engineered Materials Characterization Report and the Metallic Barrier Scientific Investigation Plan (discussed in Activity 1.4.1.1). Briefly, the four environments are laboratory-simulated UE-25 J#13 well water, the same simulated UE-25 J#13 well water but with solutes concentrated 20 to 100 times (to simulate water characteristic of the unsaturated zone), the "concentrated" UE-25 J#13 water acidified to pH 2, and the "concentrated" UE-25 J#13 water alkalized to pH 12. The acidified condition represents a "worst case" environment that could arise from microbial activity and possibly the interaction of diesel fuel or other hydrocarbons with steam to form various carboxylic acids. The alkaline condition could result from the reaction of water with concretes, grouts, and other cementitious materials expected to be widely used in the repository construction. Test specimens are exposed to these four water chemistries and the saturated vapor space above the liquid. Some species in the water are expected to volatilize and concentrate in the vapor space. Tests are conducted at 60° and 90°C; these temperatures were selected because previous work in the published literature has

indicated that localized corrosion effects are particularly severe in this temperature range for many materials.

Test specimens, fabricated from all the candidate materials discussed under Activity 1.4.1.1, are configured in flat coupons, coupons with crevices, U-bend stressed specimens, and galvanically coupled specimens. Several thousand specimens are required for the matrix of test conditions. Welded specimens are sometimes used. The activity plan for the long-term corrosion studies gives greater experimental detail on the specimens, environments, and test procedures to be used.

Forecast: The long-term corrosion study is a keystone activity for many of the investigations of the metallic barriers planned for the next several years. Several companion studies will be performed, including tests conducted with measurements of the corrosion potential and determinations of critical potentials for the initiation of different forms of localized corrosion and forms of environmentally assisted cracking. These companion studies are described in the Metallic Barriers Scientific Investigation Plan. The long-term corrosion test specimens are expected to begin exposure before the end of FY 1995.

Thermogravimetric Analysis Studies

The objective of this work is to determine the conditions under which aqueous corrosion processes occur after emplacement of the waste package. These conditions have special significance in an unsaturated zone repository, because the extent of degradation of the candidate material becomes much greater when aqueous corrosion processes begin. The key parameters appear to be humidity, temperature, and surface conditions; the experimental work aims to determine the interrelationship among these parameters. Thermogravimetric analysis is a particularly sensitive technique for using a micro-analytical balance to measure very small changes in weight gain as a material reacts with the environment.

The Cahn 131 unit, which is the apparatus purchased for this investigation, has required several modifications to achieve the uniform humidity control required for these experiments. Subsequent studies on the apparatus have detected thin water films on metal surfaces, and the reversibility of film formation and evaporation as temperatures and humidities change. This preliminary experimental work has been confined to carbon steel and copper specimens, but specimens of other materials have been ordered.

Forecast: The thermogravimetric analysis studies are used to establish the approximate boundaries of the oxidation/corrosion transition and to establish the critical parameters for this transition. An activity plan will be prepared for the work. Planning for longer term oxidation and corrosion studies in controlled humidity chambers will progress as results from the thermogravimetric analysis work are obtained.

Crack Growth Tests

The objectives of this study are to (a) determine the susceptibility of candidate waste package materials to stress corrosion cracking under a variety of environmental, metallurgical,

and mechanical stress conditions relevant to the repository, and (b) provide the experimental data base for predictive models for stress corrosion cracking in the waste package environment. These tests are equally valid for determining the hydrogen embrittlement susceptibility of susceptible materials, if that degradation phenomenon is operating. Stress corrosion cracking and hydrogen embrittlement are important degradation modes that can affect corrosion resistant and corrosion allowance materials. A sensitive crack growth measurement apparatus, which operates under the principle of measuring minute changes in the electrical resistance of the test specimen as a crack propagates, is being used to measure crack growth on pre-cracked compact tension fracture mechanics type of specimens.

Research activities deal with crack growth rate determinations on Alloy 825, Ti Grade 12, Alloy C-4, and Alloy C-22. Crack growth rate tests using standard compact tension fracture mechanics specimens have been conducted on Alloy 825 in an earlier phase of the program. Additional tests began on the other candidate materials and on a new heat of Alloy 825 in FY 1994. These tests are conducted in a simulated UE-25 J#13 well water environment, maintained at 93°C. The specimens have been fatigue cracked in air at room temperature for a pre-crack length of 1.9 mm under a cyclic load with a triangular load shape, load ratio of R = 0.1 to 0.25 (the load ratio R is the maximum stress/minimum stress) and loading frequency of 1 Hz to introduce a sharp starter crack before commencing the crack growth rate tests in the simulated UE-25 J#13 well water environment.

Preliminary data show that the crack propagates faster in the Ti Grade 12 specimen than in both the "Alloy C" specimens by an order of magnitude, under a 0.5-Hz cyclic load and triangular load shape, load ratio of R = 0.5 and stress intensity range of 26 to 28 MPa-$m^{1/2}$ in UE-25 J#13 well water. Growth rates of 1.1×10^{-7}, 0.90×10^{-8}, and 1.1×10^{-8} m/s were observed for the Ti Grade 12, Alloy C-22, and Alloy C-4 specimens, respectively. Because of the inherently faster crack growth rate for the Ti Grade 12 as compared with the nickel-base Alloy C-22 and C-4 specimens, the growing crack is longer in the titanium specimen. The significance of this observation is being analyzed.

Forecast: The crack growth test will be continued for longer time periods at higher stress intensities, and subsequently different R values. Because these would be more aggressive conditions, the crack growth rates should increase. Work is also planned at a second laboratory, using a similar apparatus, to conduct similar types of tests but at different environmental conditions to complement the work currently under way. The second apparatus will undergo preliminary testing to ensure that its operating characteristics are satisfactory.

Microbiologically Influenced Corrosion Studies

The objective of microbiologically influenced corrosion studies is to determine if corrosion is enhanced by the presence and propagation of microorganisms, particularly bacterial species. Metabolism products from these microorganisms can alter the chemical environment significantly, and this effect can occur on a localized level or over a wide area of the container surface. Different types of microorganisms attack different kinds of metal and alloys because of the chemical specificy of the corrosion process. Much of the work proposed for studying microbiologically influenced corrosion effects will be performed by organizations

and personnel having the specialized knowledge and facilities for conducting these kinds of studies. Topics to be addressed include the following:

1. Electrochemical detection of microbiologically influenced corrosion – This part involves developing test procedures to determine microbiologically influenced corrosion susceptibility of steel in water samples ultimately to be taken during exploratory and construction phase of repository operations.

2. Electrochemical stimulation of corrosion by bacterial growth – This part involves determining electrochemical interactions between corrosion and bacterial growth, including cause and mechanism of localized microbiologically influenced corrosion at weld joints.

3. Effects of elevated temperature and nutrient availability on bacterial growth and subsequent microbiologically influenced corrosion – This part involves studying the ability of microbial cultures from Rainier Mesa and Yucca Mountain to revive, grow, and cause corrosion at elevated temperatures.

Forecast: Work will begin on the proposed microbiologically influenced corrosion studies, as indicated in the above discussion.

Subactivity 1.4.2.4.5 - Assessment of degradation modes in coatings and filler systems. No progress was made during the reporting period; this was an unfunded activity.

Subactivity 1.4.2.4.6 - Laboratory test plan for coatings and filler systems of the alternate barriers investigations. No progress was made during the reporting period; this was an unfunded activity.

Forecast: No work is planned in FY 1995 for Subactivities 1.4.2.4.5 and 1.4.2.4.6.

5.6.7 Activity 1.4.3.1 - Models for Copper and Copper Alloy Degradation

The Controlled Design Assumptions focus entirely on multibarrier waste package container configurations; therefore modeling activities are reported under Activity 1.4.3.3. See the discussion in Section 5.6.

5.6.8 Activity 1.4.3.2 - Models for Austenitic Material Degradation

The Controlled Design Assumptions focus entirely on multibarrier waste package container configurations; therefore, modeling activities are reported under Activity 1.4.3.3. See the discussion in Section 5.6.

5.6.9 Activity 1.4.3.3 - Models for Degradation of Ceramic-Metal, Bimetallic/Single Metal, and Coatings and Filler Alternative Systems

The modeling work discussed below applies to the bimetallic/single metal design alternative. See the discussion in Section 5.6.

Pitting Corrosion Model

The objective of the model development activity is to derive predictive tools that will enable using experimental data and analyses to draw long-term assessments of the performance of candidate materials under Yucca Mountain conditions. This work will ultimately describe the performance of the multiple-barrier waste package container, but as a first step in that direction the modeling work has focused on the pitting corrosion of a corrosion resistant barrier, such as one of the nickel-base or titanium-base alloys. While pitting is usually governed by electrochemical, chemical, and occasionally metallurgical parameters, an important aspect of pitting is "stochastic." Much of the modeling work is aimed at developing the stochastic aspect of pitting within the electrochemical and chemical parameters.

A pitting initiation and growth stochastic model has been developed. The most recent work focused on the new capability of the pitting initiation and growth stochastic model to simulate the permanent cessation of growth for "stable" (e.g., macroscopic) pits by including a new stochastic variable η describing the probability that stable pits permanently halt their growth. There are two possible ways to view pit growth with cessation: (1) pit growth is fundamentally stochastic and includes the possibility that pits may permanently stop growing; and (2) pit growth is fundamentally deterministic and continuous, but individual pits may stop growing at different times during exposure. For instance, the kinetics of surface electrochemical reactions may change with time due to small chemical changes in the area surrounding the pit. This can result in the reduction of the electrochemical current so that pit growth can no longer be sustained. The focus of efforts has been on the first possibility, which can be explored using $0 < \eta < 1$, and a pit growth probability γ less than one. The investigation of how permanent pit growth cessation affects the damage function (e.g., the distribution of pit depths) continued by extending previous calculations. Several numerical experiments were performed using different pit growth cessation probabilities for different exposure steps. A nearly static distribution was reached following 4,000 steps of exposure. This distribution exhibits a gradual exponential-type decay in the number of pits vs. their depth, although there is a large variability from one pit depth to the next.

The previous discussion suggests that the ultimate pit distribution is a large number of relatively shallow pits with a smaller number of pits that grow to attain much greater depth. The experimental data suggest that the pit depth distribution following long exposure times is more complex than this; typically, it contains a significant intermediate peak. Of course, a wider combination of γ (and other input) values must be explored to confirm these general observations. Calculations are continuing, using the "deterministic pit growth" option of $\gamma = 1$ (with $0 < \eta < 1$). Again, the major goal is to determine if distributions similar to those observed experimentally can be simulated using this approach.

These results (Henshall, in prep.) were presented at the Materials Research Society XVIII International Symposium on the Scientific Basis for Nuclear Waste Management. The paper will appear in the proceedings of that conference, slated for publication in 1995.

Forecast: Work will continue to refine the pitting corrosion model. Work is under way in the testing and evaluation area that will provide experimental data and, hence, deterministic factors (such as pH, electrochemical potential, temperature, and solution chemistry) for the model. Many of the stochastic features of the pitting model can be successfully applied to models of other degradation modes. As outlined in the Metallic Barrier Scientific Investigation Plan, work on models for the other degradation modes will begin as experimental information on the significant chemical, physical, metallurgical, and, in some instances, mechanical parameters becomes available from the testing activities.

5.6.10 Activity 1.4.4.1 - Estimates of the Rates and Mechanisms of Container Degradation in the Repository Environment for Anticipated and Unanticipated Processes and Events, and Calculation of Container Failure Rate as a Function of Time

The YMIM model (Gansemer and Lamont, 1995) was used to compare the effects of varied repository areal mass densities on containment performance (Gansemer and Lamont, in prep.). The areal mass density, through its heat energy deposited over time, affects the repository temperature and relative humidity fields (Buscheck et al., 1994). In turn, the temperature and humidity affect the corrosion and hence the containment performance of the waste packages. Pitting corrosion of a corrosion-resistant container was examined, by varying the key parameters of the pitting process over a broad range. A higher initial heat loading (110 kW/acre) provides a greater time delay between the decline of repository-ambient temperatures and the return of high relative humidity than the lower initial heat loading (55 kW/acre). Over most of the likely range of pitting process parameters, the temperature-humidity relationship of the 110 kW/acre design is effective in preventing loss of containment function to pitting for most of the repository for over 100,000 yr. This is not true for the 55 kW/acre design. If the uncertainty in the range of the pitting parameters can be halved, this will substantially improve the predicted performance of the 110 kW/acre design.

Forecast: See Section 5.3.10.

5.6.11 Activity 1.4.5.1 - Determination of Whether the Substantially Complete Containment Requirement is Satisfied

No progress was made during this reporting period; this was an unfunded activity. Information pertaining to a predecessor activity is provided under Section 5.3.10.

Forecast: No activity is planned for FY 1995. See Section 5.3.10.

5.6.12 Activity 1.5.5.2 - Radionuclide Transport Modeling in the Near-Field Waste Package Environment

Although originally planned as an out-year activity, considerable progress has been made on this topic in the past six months within the International Program. Simple, semi-analytic bounding models have been developed (Chesnut, 1994a) for estimating the effect of heterogeneity on the transport of radionuclides from a nuclear waste repository to the accessible environment. These simple models provide useful complements to more complex calculations based on detailed mechanistic descriptions of flow and transport, because they can be performed extremely rapidly, and the parameters can possibly be determined by analysis of the cosmogenic isotope data already being obtained as part of site characterization.

The common approach underlying these semi-analytic models is a numerical convolution of a source term function with a ground-water transport function. The source term provides the rate of release of radionuclides from the Engineered Barrier System to the hydrogeologic barrier system, and the ground-water transport function gives the radionuclide breakthrough at the accessible environment as a function of time following the release of a unit pulse from the Engineered Barrier System at time zero. The result of this convolution is a function giving the rate of release to the accessible environment as a function of time. This can be integrated numerically to obtain the cumulative radioactivity released to the accessible environment at any time after emplacement. It can also be used to calculate hypothetical dose rates, when combined with assumptions for the delivery of the dose.

For reasons documented elsewhere (Chesnut, 1994b), the ground-water transport function is believed to be a log-normal function, requiring only three parameters:

t_w, the mean ground-water travel time

σ, a measure of heterogeneity, equal to the standard deviation of the natural logarithm of the travel time

R_F, the retardation factor.

When $\sigma = 0$, transport is completely homogeneous (one-dimensional piston-like displacement). As σ increases, the system becomes progressively more heterogeneous, and transport is dominated by a small number of "fast flow paths." Note that this distribution is in principle deterministic. For a specific system, single values of t_w and σ will bound the travel time distribution that could be measured by a conservative tracer breakthrough curve. Retardation factors must be estimated for each species of interest (only the product $R_F \cdot t_w$ appears in the transport equation).

A "regulatory Engineered Barrier System" is used to illustrate the method–the source term is assumed to follow exactly the NRC subsystem requirements:

- Substantially complete containment of radionuclides for a time t_{cc}, equal to 1,000 yr

- Thereafter, controlled release of each radionuclide at an annual rate, f_I, not to exceed 1 part in 10^5 of its remaining inventory.

This particularly simple source term is a step function for each radionuclide, starting at t_{cc} and continuing until its inventory is exhausted at time t_e. For long-lived radionuclides, t_e is 100,000 + t_{cc}; for short-lived species, t_e is less because some of the inventory decays before it can be released.

Figure 5-1 shows the sensitivity of the normalized accessible environment release to the mean ground-water travel time, for values of σ shown in the legend. For the EPA sum to remain below 1.0 for an infiltration of 1.4 mm/yr, the heterogeneity parameter must be less than about 1.9. In other words, there must be credit for the saturated zone, less heterogeneity than is indicated by the Calico Hills pump test data, a smaller average infiltration rate than is suggested by the current site data, or an Engineered Barrier System that performs better than the existing subsystem requirement, to show compliance with the total system requirement.

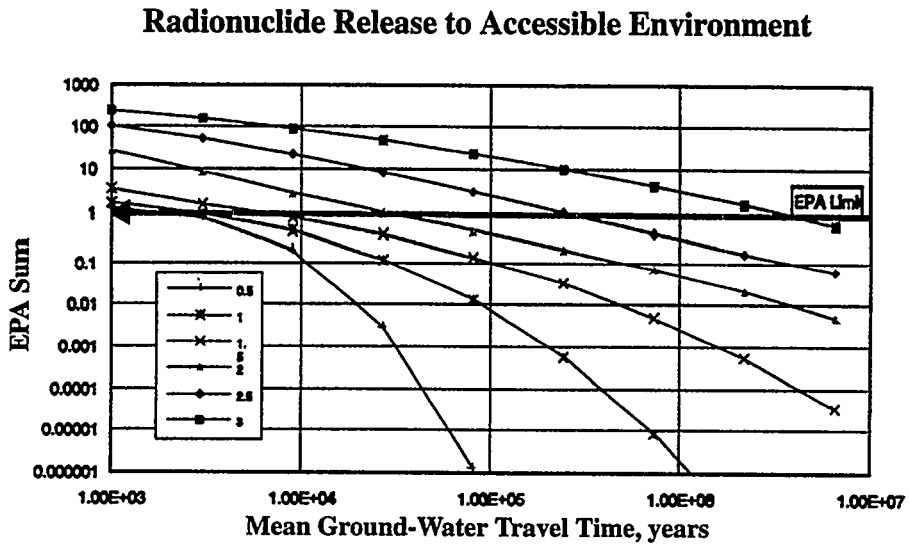

Figure 5-1. Normalized radionuclide release to the accessible environment from convolution of a "regulatory Engineered Barrier System" with a log-normal ground-water transport function. Values of the heterogeneity parameter, σ, are shown in the legend: 0.5 corresponds to a homogeneous soil, 1.6 describes the ground-water flux distribution at Stripa, and 2.2 fits the Calico Hills saturated zone permeability data.

Ultimately, the location of radionuclides as a function of time after emplacement must be determined. That is,

How much of the initial inventory has decayed (the safest fraction)?

How much is still contained within the waste packages (the next safest fraction)?

How much is moving through the geologic control volume?

How much remains in the accessible environment?

The conceptual model described above can be used to answer these questions.

Figure 5-2 shows the distribution of total radionuclides, normalized on the EPA limits for each of the 29 species in the reference inventory. Parameters are chosen to give an EPA sum slightly less than 1.0 for 10,000 yr. The upper curve represents the total normalized radioactivity, taking primary decay into account but ignoring daughters. At emplacement, the total normalized inventory is more than 65,000 (times the EPA release). About 7.4 billion years is required for decay alone to reduce this to 1.0.

The second curve is the total normalized radioactivity minus the normalized radioactivity remaining within the Engineered Barrier System. The region between the two curves represents the portion of the total inventory contained within the Engineered Barrier System.

Finally, the third curve gives the normalized radioactivity that has reached the accessible environment, again allowing for primary decay. The region between the second and third curves represents the inventory contained within the geologic control volume. Note that after 1,000,000 yr, almost all the remaining total radionuclide inventory has reached the accessible environment. Sensitivity studies, exploring order of magnitude changes in the mean ground-water travel time and controlled release fraction, indicate the magnitude of the peak radionuclide inventory remaining in the accessible environment is very insensitive to these model parameter variations.

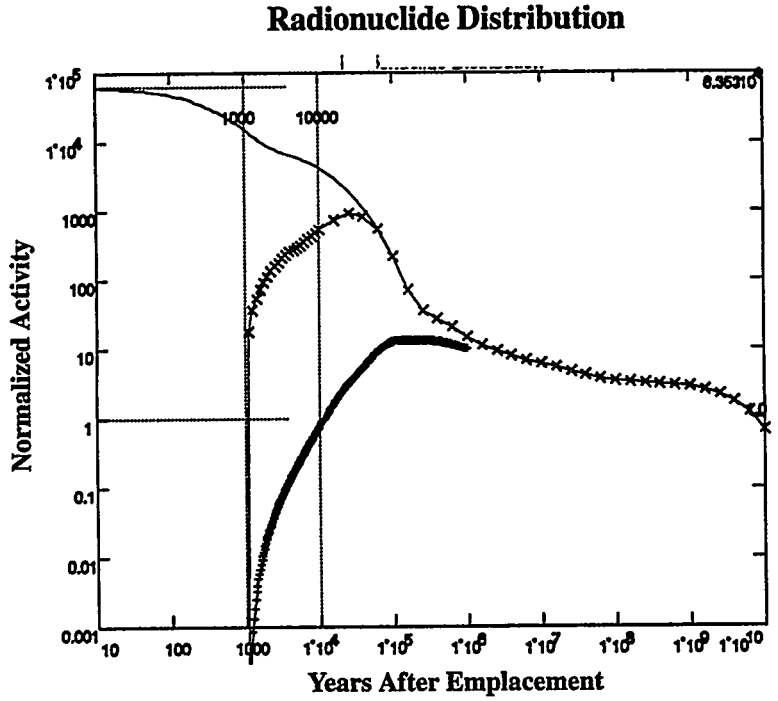

Figure 5-2. Distribution of total radionuclide inventory for the base parameter values. The upper curve is the total, the middle curve is the total minus the Engineered Barrier System inventory, and the lower curve gives the total radionuclide content of the accessible environment.

Related International Work. See Section 5.2.7 for related work (under the heading Effects of Grouting around an Excavation) performed under the auspices of the OCRWM international program.

Forecast: Other Engineered Barrier System release rate functions and ground-water transport functions will be used in the model, and dose rates will be calculated in addition to the EPA sum.

CHAPTER 6 - PERFORMANCE ASSESSMENT

Performance assessment is the set of activities needed for quantitative evaluations of repository system performance to evaluate the suitability of a site, to assess compliance with regulations, and to support the development of a geologic repository. Performance assessment conducts investigations and develops models to examine the performance of the Mined Geologic Disposal System in the preclosure and postclosure phases by using total system and subsystem assessments. Performance assessment verifies, benchmarks, and documents computer codes for assessing the performance of the system's overall waste isolation.

Related International Work. See Section 6.12 for related work [under the heading, Performance Assessment Technology (Verification of SYVAC code)] performed under the auspices of the OCRWM international program.

6.1 WASTE RETRIEVABILITY (SCP SECTION 8.3.5.2)

Section 8.3.5.2 of the SCP, Waste Retrievability, addresses whether the repository be designed, constructed, operated, closed, and decommissioned so that the option of waste retrieval will be preserved as required by 10 CFR 60.111.

A systems study report (CRWMS M&O, 1994i) was written to address the advantages and disadvantages of longer retrievability periods and reported in Progress Report #11 (DOE, 1995m). No further work on this issue was done during the reporting period.

Forecast: No activity is planned for FY 1995.

6.2 PUBLIC RADIOLOGICAL EXPOSURE - NORMAL CONDITIONS (SCP SECTION 8.3.5.3)

No progress was made during the reporting period; this was an out-year activity.

Forecast: The Technical Basis Report for Preclosure Radiation Safety will be started in the next period. The magnitude of the routine radionuclide releases from the operational waste package handling facility will be estimated. This estimate will be made for all operations from multi-purpose canister arrival at the surface facility to final waste package drift emplacement.

6.3 WORKER RADIOLOGICAL SAFETY - NORMAL CONDITIONS (SCP SECTION 8.3.5.4)

The fully coupled neutron-gamma ray transport code MCNP has been procured and installed on a 486 IBM personal computing platform. The installed code has been exercised with the complete set of test problems which covered a spectrum of criticality and radiation

shielding problems of importance to preclosure radiation safety. Since the procurement of the code began, an updated and more accurate cross section data set for MCNP has been released. This new data has been acquired.

Forecast: The most recent cross section data will be loaded for use with the code. The code will be loaded on a second computer as soon as an already procured large capacity hard drive is installed.

Activities outlined in the forecast under Section 6.2 will be extended to cover worker exposure under normal operating conditions at the facility. For worker radiological safety, both direct ionizing radiation and radionuclide exposure will be assessed.

6.4 ACCIDENTAL RADIOLOGICAL RELEASE (SCP SECTION 8.3.5.5)

A simple model has been developed to predict the deformation of robust waste containers from energetic events such as drops and collisions. A relatively simple spreadsheet model is necessary to perform the multiple realizations required by the probabilistic risk assessment approach to preclosure radiation safety.

Planning was conducted to comply with the accelerated schedule for the technical basis report for Preclosure Radiation Safety. An initial outline was drafted and circulated for comment, and is currently being revised.

Forecast: In support of the Technical Basis Report for Preclosure Radiological Safety, evaluation of dose consequences to the maximally exposed individual and the regional population caused by accidental radionuclide releases will begin.

6.5 GROUND-WATER TRAVEL TIME (SCP SECTION 8.3.5.12)

The DOE developed an approach to calculating ground-water travel time that was presented to NRC in a November-December Technical Exchange and was modified based on staff comments made at that exchange. The modified approach was presented at the DOE Technical Program Review in February and to NRC in a Technical Exchange in March 1995. The NRC staff clarified their suggestions made at the previous exchange. The DOE will present the modified approach to the Advisory Committee on Nuclear Waste in April 1995, and will continue to work with the NRC staff to refine the approach. (For additional information on the DOE approach see Chapter 2, Section 2.2.3.2, Issue Resolution. The results of implementation of that approach are discussed below.)

The 1994 ground-water travel time calculations were completed and documented (Arnold et al., in prep). The report describes the development of the geostatistical model domain, the code for modeling unsaturated-zone ground-water flow, and the particle tracker used to evaluate travel times. The emphasis of this work was on simulating the creation of zones of local ground-water saturation in the unsaturated zone based on plausible assumptions

of model parameters and boundary conditions. In addition to baseline analyses on nine realizations of the model domain, sensitivity studies on the effects of variations in model parameters and the domain were made.

The current investigations, the 1995 iteration of ground-water travel time calculations, emphasize the development of alternative conceptual and numerical models (e.g., the dual-permeability model) for unsaturated-zone flow. This work will include both unsaturated- and saturated-zone analyses by the end of FY 1995.

Improvements in the model domain for use in the calculation were implemented during the first half of FY 1995 and continue to be an area of active research. The unsaturated-model domain is being evaluated using (a) information from deterministic geologic models and (b) geostatistical simulation methods. The saturated-zone model domain is being evaluated based on alternative geologic models. Information on the spatial distribution of relevant hydrologic parameters is necessary to perform flow simulations for the travel-time calculation.

A strategy was developed to incorporate uncertainty into the spatial distribution of properties in the unsaturated zone by using multiple realizations of the model domain. Borehole data were used to co-simulate the distributions of matrix porosity and matrix saturated hydraulic conductivity along cross sections use in the flow modeling. The simulations are based on geostatistical analysis of the spatial correlation of matrix porosity. Because borehole data are sparse, a link between the simulation technique and a digital geologic model has been developed to constrain the simulations in regions of higher uncertainty. The spatial distribution of fracture hydraulic properties will be independently simulated. Statistical relationships among parameters defining relative permeability-moisture retention functions and porosity have been derived. These relationships will be used to define the unsaturated-flow parameters in the model domain.

Methods were developed for the upscaling and averaging of hydraulic parameters in the unsaturated-zone model domain for use in the flow simulation. Because hydraulic properties are measured at the laboratory scale and numerical simulations of ground-water flow are necessarily performed at a much larger scale, upscaling relationships are required. A strategy has been developed in which properties are first upscaled to the intermediate, geostatistical-simulation scale and then averaged to derive effective properties at the flow-modeling scale.

Two-dimensional heterogeneous domains are currently being assessed using the equivalent-continuum and dual-permeability models. In addition, equivalent-continuum and dual-permeability models of the region near the unsaturated UE-25 UZ#16 well are being assessed to compare these models with field data and to bound the range of possible infiltration rates.

A comparison has been documented of equivalent continuum and dual permeability models of one-dimensional infiltration through an unsaturated, fractured, heterogeneous domain. Results showed the potential existence of significant flow in fractures in the dual-permeability model, even when the matrix sustained low saturations (Ho, in prep.).

6.5.1 Activity 1.6.2.1 - Model Development

Calculational models for ground-water travel time must address the initiation and propagation of ground-water flow along fast pathways to the accessible environment. The initial model development has investigated the conditions that might lead to initiation of these fast paths. In addition, some of the details concerning how the results of the calculations will be interpreted have also been studied.

The model domain for the saturated zone used in the analysis is much larger than the domain for the unsaturated zone, and fewer data are available at the depth of the saturated zone. For these reasons, the saturated zone model domain is based on deterministic geologic conceptualizations. Alternative geologic models have been evaluated and the travel-time analysis will be based on two alternative geologic model domains. Reinterpretation of the saturated-zone model domain, as presented in Total System Performance Assessment - 1993, has been performed and will be incorporated in flow simulations. The model domain as defined in the digital geologic model will also be used in flow simulations.

Subactivity 1.6.2.1.1 - Development of a theoretical framework for calculational models. No progress was made during the reporting period; this was an unfunded activity.

Related International Work. See Section 5.2.7 for related work (under the heading, Design and Analysis of Disturbed Zone Experiments) performed under the auspices of the OCRWM international program.

Subactivity 1.6.2.1.2 - Development of calculational models. No progress was made during the reporting period; this was an unfunded activity.

Forecast: Alternative conceptual models will be developed; specifically, the dual-permeability model. This will allow comparison of the effects on unsaturated-zone flow of the different conceptual models.

6.5.2 Activity 1.6.2.2 - Verification and Validation

Laboratory-scale and field-scale studies are progressing to obtain process-level information appropriate for verifying and validating numerical representations of natural processes used in ground-water travel time and total system performance assessment calculations.

Subactivity 1.6.2.2.1 - Verification of codes.

Develop and Verify Continuum Joint Model and Code

Continuum models appear to be an efficient technique for modeling jointed rock masses. These models allow the nonlinear closure and sliding behavior of a joint to be combined in an average sense with the behavior of intact rock. Work is under way to

develop models and codes using continuum models of jointed rock masses. A joint model report (Jung and Thorne, in prep.) was approved by DOE. The step-size dependent errors in the F-T algorithm used in the code JAS3D can be eliminated by using a polar decomposition algorithm. Additionally, the damping calculations for the dynamic relaxation method have been modified. A new joint model version of JAS3D uses damping based on the elastic intact material with the optimum (rather than minimum) damping as default. This version converges on all test problems and requires about the same amount of computer time as the conjugate gradient method. Before the joint model is made standard in JAS3D this version of the dynamic relaxation method will be a standard option.

Forecast: Benchmark calculations on the Large Block Test are planned for the second half of FY 1995.

Subactivity 1.6.2.2.2 - Validation of models.

Flow in Discrete Fractures

Development of adequate conceptual models for flow and transport through fractured rock is an essential component of calculation of ground-water travel time, Total System Performance Assessment, and Technical Site Suitability. To support the development of such models, the focus is currently on three areas: (1) understanding the effects of gravity on relative permeability, (2) measuring the relative permeability in cast replicas of natural fractures, and (3) reducing the data obtained from the flow visualization test performed at Fran Ridge during FY 1994.

Work continued on the flow visualization test performed at Fran Ridge in FY 1994. In this test, three dye-tracer experiments were conducted before excavating the country rock surrounding the Large Block Test. During excavation, the flow paths of the tracer were mapped. Excavation, and hence mapping activities, at the site ceased in the fall of 1994. Efforts continued to extract data from the pavement maps acquired during excavation. One of the experiments was run to test the utility of electrical resistance tomography to delineate moisture within fractured rock. Preliminary cross-sections of the fracture network across two planes perpendicular to the electrical resistance tomography probes were prepared and supplied for comparison with their geophysical results.

No new experimental results were obtained in this time period. Laboratory capabilities were refined significantly as a result of the relocation for casting natural fractures (casting in clear epoxy allows visualization of two-phase flow in the fracture). Method improvement efforts have focused on casting and replication of a fracture in a block of Bandelier Tuff, which will be completed during FY 1995. Once casting is completed, aperture characterization can be compared by (a) transport measurements, (b) surface profilometry, (c) thin casts of the aperture field, and (d) casts of the fracture surfaces. During the flow visualization experiments at Fran Ridge, several boulders (Topopah Spring Tuff) containing natural fractures were obtained. Those samples were transported to Beatty, Nevada, and currently await cutting.

Fracture-Matrix Interaction

The absorption of water from a flowing fracture by an unsaturated matrix may play an important role in buffering ground-water travel times. To investigate this issue, a series of physical and numerical experiments are scheduled. The basic goal of this work is to evaluate when and how best to model this imbibition process.

Laboratory facilities were relocated during this period, and following the move, efforts focused on setting up for experiments to be conducted in the second half of FY 1995. An x-ray visualization laboratory for conducting such studies was recently completed and approved for use at the new facilities. The new laboratory will greatly facilitate experimentation, as well as improve control over the experiment.

Significant progress was made toward analyzing a suite of fracture-matrix interaction data collected this past summer. These experiments involved x-ray imaging of matrix imbibition from a vertically oriented slot fracture. In these experiments, the influence of matrix heterogeneity and presence of barrier fractures on imbibition behavior was investigated. To date, staff have completed digitizing the x-ray films and have nearly completed reduction of the data to matrix saturation fields.

Predicting fluid flow and transport behavior in unsaturated, fractured rock is greatly simplified where matrix imbibition can be modeled as a linear function of the square root of time; however, such a treatment implicitly assumes homogenous matrix properties. To investigate matrix heterogeneity, data were analyzed from a simple experiment in which x-ray imaging was used to monitor the imbibition of water from a single slot fracture into a slab of volcanic tuff. The results are currently being documented (Tidwell et al., in prep.). Experimental results show that matrix imbibition follows a linear relationship with the square root of time even though the saturated hydraulic conductivity of the tuff varies by over four orders of magnitude. This result suggests the fracture-matrix interaction terms based on sorptivity will be less sensitive to matrix heterogeneity than originally expected.

Effective Media Property Scaling in Heterogeneous Systems

One of the difficult issues pertaining to the characterization and modeling of rock property characteristics at Yucca Mountain is that measurements are made at scales much smaller than those of the grid blocks used in performance assessment modeling. As such, scaling models are required to transform data from the scale of measurement to the scale at which analysis is being conducted. The goal of this study is to test the current upscaling models through systematic physical experimentation.

Experimental studies were precluded between October 1994 and January 1995 because of the move of the Subsurface Flow and Contaminant Transport Laboratory to new facilities. In February and March 1995, however, the gas permeameter, which is used to acquire multiscale gas permeability data for testing upscaling models, was re-assembled and tested. Additionally, a number of modifications have been made to the permeameter that will

expedite and improve measurement precision. Construction has also begun on a new large tip seal capable of measuring block-scale permeability (blocks are approximately 1 m^3).

Preliminary efforts began for comparing measured up-scaling behavior with various analytic and numerical upscaling models. An extensive literature review was completed and a list of alternative models for testing was compiled. Computer algorithms for many of these models were developed in support of Study 8.3.1.4.3.2, "Three-Dimensional Rock Characteristics Models" (Chapter 3, Section 3.3.7). Strategies are being finalized for implementing comparison studies between measured and modeled upscaling behavior. Preliminary results will be presented at the 1995 High-Level Waste Conference (McKenna and Tidwell, 1995).

Results of these studies are being integrated into performance assessment calculations. Meetings between the staff responsible for testing and travel-time calculations have resulted in a strategy for upscaling rock properties for use in ground-water travel-time calculations. This strategy is currently being documented.

Conduct Nonisothermal Flow Model Development and Validation

Minimal activity has been performed on this task to date. Efforts will begin in late May or June.

Develop/Validate Reactive Transport Model

Final batch adsorption and column experiments to provide data needed to model the caisson experiments were performed. The experiments showed that the adsorption properties of the sand are dominated by two trace components. The extent and rate of nickel adsorption by the sand are pH-dependent; nickel adsorption occurs primarily on the iron oxyhydroxide coatings on the sand, on sites where lithium does not compete. Some of the nickel adsorbs to kaolinite, and competes with lithium for adsorption sites on that mineral. Lithium adsorbs irreversibly, suggesting that kaolinite is the only important phase in the sand with respect to lithium adsorption. Breakthrough curves for nickel and lithium transport in bench-scale columns were consistent with the batch sorption data. Nickel elution profiles from several samplers within the caisson were obtained.

The final report for studies in support of the caisson experiments was completed and was in management review (Siegel et al., in prep.). The studies described in this report should provide a basis for understanding the transport of nickel, lithium, and bromine through porous media similar to the reference sand. Techniques were developed for obtaining parameter values for surface complexation and kinetic adsorption models for rocks and minerals. These should be useful for characterizing other natural materials in support of coupled hydrogeochemical transport calculations.

Integration of Basic Process Understanding Into Performance Assessment Modeling

Approaches to integrating the understanding developed in this laboratory program into performance assessment calculations are being developed through bimonthly meetings with performance assessment and laboratory staff. In addition, an annotated outline was developed for a report of the implications with respect to performance assessment modeling. In particular, the outline provides examples of how recent advances in understanding of small-scale processes in discrete fractures, fracture networks, between fractures and the matrix, and between ensembles of matrix blocks influence formulation of effective permeabilities. Also explored in the outline are how these same small-scale processes could influence large-scale system response in a manner that presently cannot be simulated by classical continuum modeling. The outline was submitted for approval (Glass et al., in prep.).

In line with the integrative effort, it was suggested that the performance assessment group consider using the infiltration experiment performed at Fran Ridge as a test problem in the proposed follow-up to the INTRAVAL program. A draft test problem was prepared and is being considered.

Significance of Short Ground-Water Travel Times

The ground-water travel time regulation was intended to be a simple measure of the geologic quality of a repository site, independent of total system performance. Unfortunately, it is neither independent nor simple.

The standard is not independent because the travel time reflects the distribution of ground-water flux among all pathways connecting the repository to the accessible environment. Since liquid water is believed to be the principal medium for the transport of radionuclides, the radionuclide flux entering the accessible environment will be closely related to the amount and spatial distribution of water flowing from the repository, as well as depending upon the sorption coefficients and solubilities of the radionuclide species released from the Engineered Barrier System.

The ground-water travel time distribution does not represent just the uncertainty in understanding of the geologic system. It is an intrinsic effect of spatial heterogeneity. The travel time issue can be stated as follows: in a heterogeneous system, a non-zero fraction of the total ground-water flow, F(1000), will have a travel time less than or equal to 1,000 yr.

- At Yucca Mountain, observations of tritium from atmospheric weapons testing in the Calico Hills, along with Cl-36 data from such testing, strongly suggest that an unknown fraction of water infiltrating from the surface reaches the water table in a few decades.

- Although water reaching the water table still has to travel about 5 km to reach the accessible environment, it is increasingly difficult to argue convincingly that no water will reach the accessible environment in less than 1,000 yr under pre-emplacement conditions.

- Given that F(1000) > 0, how large can the "fast fraction" be and still allow reasonable assurance of meeting total system performance requirements?

The use of total system performance analysis to evaluate the significance of travel times less than 1,000 yr can be used to address this question. There is no simple way, with large complex models, to separate the contributions of the barrier system and the hydrogeologic system in controlling the release of radionuclides to the accessible environment. However, a "validation" of this separation of Engineered Barrier System and geosphere contributions using performance assessment models was provided with the aid of a simple analytic model for bounding the release of radionuclides to the accessible environment (see Section 5.6.12). The travel-time distribution is assumed to be log-normal (Chesnut, 1994b), with natural log standard deviation, σ, and arithmetic mean, t_w.

The significance of "fast pathways" was assessed by assuming exact compliance with the Engineered Barrier System subsystem requirements (substantially complete containment and controlled release). Release to the accessible environment, normalized by their respective EPA limits, was calculated for a reference inventory of 29 radionuclides using minimum K_d values tabulated. Combinations of the travel-time distribution parameters were chosen so that the EPA sum was exactly 1; other combinations were chosen so that the EPA sum was exactly 10.

Results are shown as the upper and lower curves, respectively, in Figure 6-1. Above the upper curve, the EPA sum is less than 1; regulations require reasonable assurance that the probability is 0.9 or greater that this is true. Compliance also requires reasonable assurance that the probability is at least 0.999 that parameters will lie in the region above the lower curve. Note that for $\sigma \approx 0$ (a completely homogeneous system), a travel time of 1057 yr is sufficient to assure compliance with the total system performance requirement. As the system becomes increasingly heterogeneous (i.e., σ increases), a longer mean travel time is required.

A heterogeneity parameter of $\sigma = 1.6$ fits the inflow flux distribution at Stripa (Neretnieks, 1987), and a value of about 2.2 fits the distribution of hydraulic conductivity obtained from pump tests of the Calico Hills in the saturated zone (Loeven, 1993). A mean ground-water travel time of about 70,000 yr is required to make the EPA sum equal to 1.0 when the heterogeneity parameter is equal to 2.2. Since transport through the unsaturated zone at Yucca Mountain is through the Calico Hills, this degree of heterogeneity should be used in performance calculations until other data become available.

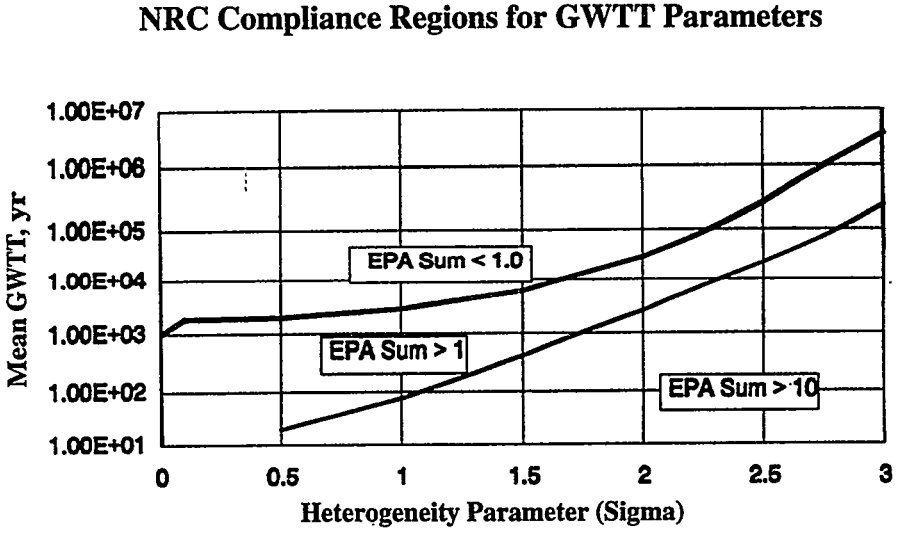

Figure 6-1 Ground-water travel time distribution parameters corresponding to compliance and non-compliance with total system release standards. Along the upper curve the EPA sum is equal to 1.0, and along the lower curve, it is equal to 10.0.

If the infiltration rate is 0.1 mm/yr, as often assumed, the mean travel time from the repository to the water table is 250,000 yr, and there would be no difficulty showing, in the context of this bounding calculation, that the total release standard would be met for σ up to about 2.5. On the other hand, at 1 mm/yr, it must be shown that the system is much more homogeneous, with a σ less than about 1.8. Finally, at 10 mm/yr (a value which cannot be excluded based on available data), the mean travel time would be only 2,500 yr, and it must be shown that σ is less than about 0.8 for total system compliance. A σ value much less than 1.5 seems very unlikely if fractures contribute to the flow and transport in the unsaturated zone below the repository.

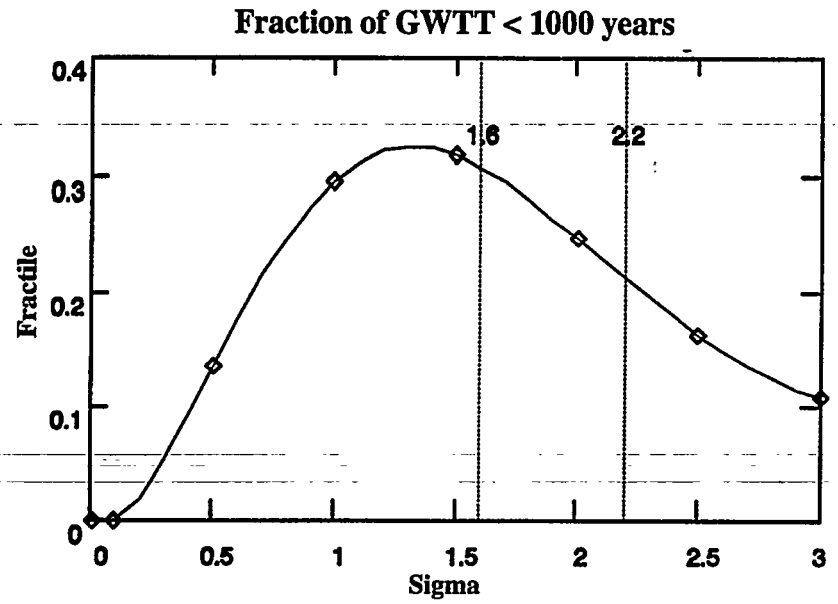

Figure 6-2. The fraction of ground-water flow with a travel time less than or equal to 1,000 years for combinations of t_w and σ given in Figure 6-1.

The question asked above can now be considered: how large can the "fast fraction" be and still allow reasonable assurance of meeting total system performance requirements? Figure 6-2 is a plot of the fraction of ground water having a travel time less than 1,000 yr for the combinations of t_w and σ that result in a value of the EPA sum of 1.0 (from the upper curve in Figure 6-1).

This plot shows that up to about 30 percent of the ground water could have a travel time less than 1,000 yr from the repository to the accessible environment and still permit a demonstration of compliance with the total system release standards. The maximum in this plot indicates that the greatest tolerance to "fast paths" would be obtained for a σ of about 1.3.

These calculations suggest that, in a strongly heterogeneous system with a large mean travel time, a rather large fraction of the total ground-water flux could have a travel time much less than 1,000 yr and still allow satisfactory containment of radionuclides within the geologic control volume.

The observation of bomb-pulse isotopes over most of the depth of the unsaturated zone must be accommodated in any satisfactory analysis of site-scale transport. These observations indicate some transport from the surface essentially to the water table in 40 yr or less. What are the total system performance implications of this rapid transport?

Figure 6-3 shows the fraction of infiltrating water having a travel time less than 40 yr for the same combinations of t_w and σ used above. Note that for σ greater than about 2, more than 1% of the total ground-water infiltration would have a travel time less than 40 yr. For σ less than 1, a negligible fraction would have a travel time less than 40 yr. In other words, to simultaneously account for the observed frequency of occurrence of bomb-pulse material at depth and to demonstrate compliance, the system must not be too homogeneous.

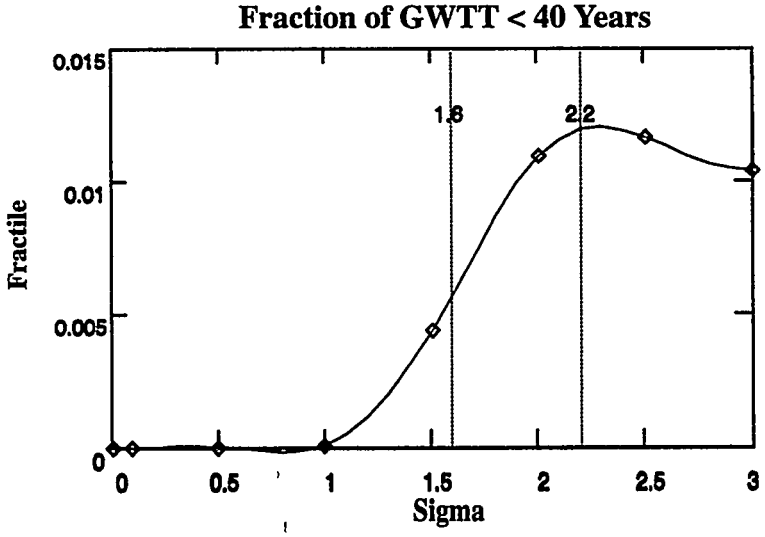

Figure 6-3. The fraction of ground-water flow with a travel time less than or equal to 40 years for combinations of t_w and σ used in Figure 6-1.

Since bomb pulse isotopes have been observed at depth, these calculations suggest that σ is likely to be closer to 2 than to 1, or, alternatively, that the mean ground-water travel time is much shorter than the value required to bound the total system release within the regulatory requirement.

Forecast: Efforts will continue among Project participants to extract fracture network data from the pavement maps obtained from Fran Ridge. That data will be then be made available to both performance assessment and site characterization groups. Experiments investigating the effects of gravity on relative permeability are scheduled to begin in May, with measurement of relative permeability in the fractures scheduled for June. Fracture-matrix studies will focus on analyzing saturation images for the heterogeneous matrix and barrier fracture experiments. Efforts will also be made to perform a new experiment in a tuff slab system cut by a network of rough walled fractures. All work completed under the discrete fracture task will be assimilated and reported under a single report. The primary goal of this report is to document results of laboratory experimentation and, more importantly, to discuss their implications relative to performance assessment modeling. Consistent with these ends, efforts will also be made to assist in implementing discrete-fracture and fracture-matrix flow findings into FY 1995 ground-water travel time calculations.

A series of permeability-sealing experiments on blocks of Yucca Mountain tuff will be completed followed by data analysis. Measured upscaling behavior will be compared with various upscale models, the ultimate goal being to set bounds on the upscale behavior of matrix permeability for tuffs at Yucca Mountain. The results of this effort and the ground-water travel time upscale strategy will be documented in the next six months.

To test many of the assumptions implicit in modeling of nonisothermal flow, physical experiments are to be performed in FY 1996. A series of numerical simulations will be performed to assist in the design and planning of these experiments, including determination of key experimental parameters (e.g., saturations, fracture density, tuff permeability, heater output, and heater placement). Results of these analyses will be documented and submitted.

The final report will be published after comment resolution.

Future work with the log-normal transport function approach will use cosmogenic radiotracer (C-14 and Cl-36) data from the Yucca Mountain site to bound the mean ground-water travel time and heterogeneity parameter.

6.5.3 Activity 1.6.3.1 - Analysis of Unsaturated Flow System

The objective of this activity is to determine which flow paths or sets of flow paths of likely radionuclide travel in the unsaturated zone will be used in ground-water travel time calculations.

Subactivity 1.6.3.1.1 - Unsaturated zone flow analysis. The objective of this subactivity is to determine pre-waste-emplacement unsaturated flow paths from the disturbed zone to the water table. The flow paths will be described in conjunction with Activity 8.3.1.2.2.9.5 and the fastest path of likely radionuclide travel through the unsaturated zone will be identified.

Geohydrologic Data Development

Interactions with field-data investigators and properties-scaling investigators are continuing. Hydrologic properties and other data have been compiled into a local data base in formats that are useful for performance assessment and ground-water travel time modelers. The formats include a local ACCESS data base (primarily hydrologic properties data that represent about 20 percent of all the data that were contained in the old Site and Engineering Properties Data Base with some additions from USGS publications). The remaining 80 percent of the old Site and Engineering Properties Data Base data and additional USGS data (geochemistry, mineralogy, seismology, etc.) have been recovered as ASCII files in a directory format that makes access relatively straightforward but not as convenient as for the data in the ACCESS database.

Subactivity 1.6.3.1.2 - Saturated zone flow analysis. The objective of this subactivity is to determine which flow paths or set of paths of likely radionuclide travel in the saturated zone will be used in ground-water travel time calculations.

No progress was made during the reporting period; this was planned for the second half of FY 1995.

Forecast: The unsaturated zone work should culminate in a data structure that is very convenient for use by performance-assessment and ground-water travel time modelers. Work improving the representation of the saturated zone will be accomplished in conjunction with the ground-water travel time activity reported in Section 6.5.

6.5.4 Activity 1.6.4.1 - Calculation of Pre-Waste-Emplacement Ground-Water Travel Time

Subactivity 1.6.4.1.1 - Performance allocation for Issue 1.6. No progress was made during the reporting period; this was an out-year activity.

Subactivity 1.6.4.1.2 - Sensitivity and uncertainty analyses of ground-water travel time. Sensitivity and uncertainty analyses were conducted as part of Ground-Water Travel Time-94 (Section 6.5) and are documented in Arnold et al. (in prep.).

Subactivity 1.6.4.1.3 - Determination of the pre-waste-emplacement ground-water travel time. The activity described in Section 6.5 is the first step toward making a determination. This was an out-year activity.

Forecast: Additional analyses will be conducted during the remainder of FY 1995.

6.5.5 Activity 1.6.5.1 - Ground-Water Travel Time After Repository Construction and Waste Emplacement

No progress was made during the reporting period; this was an out-year activity.

Forecast: No activity is planned for FY 1995.

6.5.6 Activity 1.6.5.2 - Definition of the Disturbed Zone

Near-field thermomechanical analyses

The thermomechanical code DDA is being applied to the fractured rock near a heated drift to estimate the change in fracture apertures caused by the thermal pulse. When completed, these results will be used to estimate the near-field change in hydraulic

conductivity, which will help define the near-field disturbed zone attributed to thermomechanical effects.

Forecast: This activity will be completed and reported in FY 1995.

6.6 TOTAL SYSTEM PERFORMANCE (SCP SECTION 8.3.5.13)

A revised strategy for waste isolation and containment was formulated during this reporting period. This strategy was developed on the basis of the experiences gained during Total System Performance Assessment - 1991 (Barnard et al., 1992; Intera, Inc., 1993; Eslinger et al., 1993) and Total System Performance Assessment - 1993 (Andrews et al., 1994; Wilson et al., 1994) and the associated sensitivity analyses, included in these analyses as well as the "mini-total system performance assessments" conducted in FY 1994 which were reported in Progress Report #11. The developed strategy was presented to the Nuclear Waste Technical Review Board in September 1994 and January 1995, and was also presented to NRC and their Advisory Committee on Nuclear Waste. The strategy is also described in the Executive Summary of Volume 2 of the Program Plan (DOE, 1994a).

The strategy places primary importance on five key elements of the total system:

1. A favorable environment for the waste package provided by the unsaturated rock mass
2. Robust waste packages to address near-field uncertainties
3. A limited mobilization of the radionuclides within the waste package
4. The slow release of radionuclides through the engineered barriers
5. The slow migration of radionuclides in the geosphere.

Each of these elements is incorporated in the assessment of total system performance.

The key elements of the containment and isolation strategy just described rely on the natural setting to provide a hydrologic environment that limits the contact of water with the waste package materials, therefore extending the life of these engineered materials. In addition, the limited availability of water within the engineered drifts places constraints on the mobilization of radionuclides because of the limited contact of water with the spent fuel once the containment has been breached, as well as limiting the release of radionuclides through the Engineered Barrier System. The strategy therefore relies on the entire system to work in concert, with the natural system providing a favorable environment in which the engineered barriers may perform optimally. The natural system also plays the conventional role as a barrier in limiting the transport of radionuclides released from the engineered barriers to the accessible environment.

The total work effort within the total system performance assessment area during this reporting period can be divided into two components (1) sensitivity analyses, using as a starting point the Total System Performance Assessment - 1993 conceptual models and parameters, to evaluate the significance of different fracture-matrix transport models on the postclosure performance and (2) process modeling and model abstraction for use in Total System Performance Assessment - 1995. The first activity was performed to evaluate the potential effect of various assumptions regarding the relative importance of the Calico Hills hydrostratigraphic unit in limiting radionuclide transport to the accessible environment in support of the Calico Hills Systems Study. The second activity is a necessary precursor to Total System Performance Assessment - 1995. The status of the work performed under these two activities is presented in the following.

Sensitivity Analyses of Alternative Transport Models in the Calico Hills

The Calico Hills hydrostratigraphic unit has frequently been mentioned as the primary geosphere barrier inhibiting the transport of radionuclides in the unsaturated zone from reaching the water table. To test the significance of the Calico Hills as such a barrier, a series of sensitivity analyses have been performed. These analyses started with the base-case conceptual models embodied in Total System Performance Assessment - 1993. Three different types of analyses were conducted. In the first set of analyses, the transport properties of the Calico Hills were fixed at the 10th, 50th, and 90th percentile of the probability density function and all other parameters were sampled from their respective probability density functions. In these analyses, the conceptual models for flow and transport in the Calico Hills (as well as the other hydrostratigraphic units in the unsaturated zone) were treated as an equivalent continuum. In the second set of analyses, the transport models for all unsaturated and saturated zone hydrostratigraphic units were sequentially modified to allow varying degrees of fracture transport in the different welded and nonwelded units. As before, the conceptual representation and parameterization for the waste package and Engineered Barrier System components of the total system were fixed at those assumed in Total System Performance Assessment - 1993. Finally, the third set of analyses varied the degree of fracture-matrix transport coupling (as defined by the effective matrix diffusion coefficient). The results and relevant conclusions based on these analyses will be presented in the final systems study document on the Calico Hills.

Process Modeling and Model Abstraction for Total System Performance Assessment - 1995

The third iteration of total system performance assessment was initiated during the current reporting period. Although the results of Total System Performance Assessment - 1995 are not expected to be available until the next reporting period (see Forecast), the overall objectives of this total system performance assessment iteration as well as the status of the detailed process-level modeling that will feed into the total system performance assessment calculations are presented below.

The general objectives of Total System Performance Assessment - 1995 can be broadly classified into three major categories: (1) incorporate more representative results, and the corresponding uncertainty, from process models into the abstracted models used in total

system performance assessment, (2) test the significance of a range of conservative assumptions incorporated into previous total system performance assessment iterations, with special emphasis on Waste Package/Engineered Barrier System conceptual models, and (3) evaluate a range of potential system and subsystem postclosure performance measures. Each of these objectives is discussed below with the status achieved during the present reporting period.

The direct link between the detailed process model results and the abstracted model inputs required for total system performance assessment was transparent in Total System Performance Assessment - 1993 for a few processes, including the advective thermally driven gaseous flux and C-14 travel times in the unsaturated zone and the saturated zone ground-water velocity and travel times. In Total System Performance Assessment - 1995, the goal is to provide more representative process model inputs derived from the unsaturated zone flow model, a drift-scale thermal hydrology model, and a model for the initiation and rate of humid air and aqueous corrosion of reference waste package designs. In addition to enhancing the representativeness of the process models, the goal is to evaluate the impact of uncertainties in the process model parameters on the predicted behavior of the system, and ultimately to incorporate the effect of this uncertainty on the postclosure performance consequences.

The basis for the unsaturated zone flow model used to abstract results for Total System Performance Assessment - 1995 is a representative cross-section through the three-dimensional flow model described in Wittwer et al. (1995). The two-dimensional model has been tested over a range of possible infiltrations rates, equivalent continuum hydrologic properties, and the definition of the satiated matrix saturation to determine the following:

1. The range in ambient percolation fluxes at the repository horizon

2. The percentage of the total percolation flux likely to be in fractures

3. The advective velocity of the ground water within both the matrix and fractures of each hydrostratigraphic unit.

The results are highly correlated with the applied infiltration rate at the surface and the spatial distribution of that infiltration rate. These results, and the corresponding uncertainty or variability, will be directly incorporated into the Total System Performance Assessment - 1995 analyses. The results from the unsaturated zone flow model will affect both the advective flux through the Waste Package/Engineered Barrier System, as well as the advective velocity through the unsaturated zone. The level of analyses will not allow for distinguishing between uncertainty and variability, and so these factors will be combined in the Total System Performance Assessment - 1995 analyses.

The basis for the drift-scale thermal hydrology model is also a two-dimensional vertical slice through the unsaturated zone flow model, with the thermal hydrologic properties of the hydrostratigraphic units being similar to those used by Buscheck and Nitao (1993). Sensitivity analyses will be conducted with two areal mass loadings (25 and 83 MTU/acre) and two backfill designs, as well as a range of uncertain/variable parameters including the

percolation flux, the hydrologic properties of the Topopah Spring welded tuff, and the vapor diffusion coefficient. These analyses will be similar to those conducted by Lingineni et al. (1995). Multiple deterministic calculations are planned to evaluate the impact of these uncertain and/or variable properties on the transient humidity and temperature adjacent to the waste packages and the water content and aqueous flux within the drift materials. These results, and the corresponding uncertainty/variability, will be directly incorporated into the Total System Performance Assessment - 1995 analyses. The results from the drift-scale thermal hydrology model will affect the initiation and rate of aqueous corrosion of the waste package, the water contact with the waste form, and the advective/diffusive transport through the waste package and other engineered material in the drift.

The model describing the initiation and rate of humid air and aqueous corrosion of candidate waste package designs to be used in Total System Performance Assessment - 1995 has been based on empirical fits, including the corresponding uncertainty in the functional relationships, to observed data from similar materials in similar environments. Specific laboratory testing of candidate materials under actual environments likely to exist in potential repository drifts at Yucca Mountain have not been completed to date. In the absence of such testing, literature data are all that are available. While these data are extensive for corrosion-allowance materials such as mild steel, there is a lack of information on corrosion-resistant materials. Therefore, the model for pitting corrosion of corrosion allowance material used in Total System Performance Assessment - 1995 will be the same as that used in Total System Performance Assessment - 1993. Using the corrosion initiation and rate empirical models, the stochastic pit growth can be calculated and the cumulative distribution of pits penetrating the waste package as a function of time can be determined. From these results, the distribution of initial pits that penetrate each package can be defined. The cumulative area of pits through each waste package also can be defined assuming a nominal pit size of 1 mm^2. These results, and the corresponding uncertainty/variability will be directly incorporated into the Total System Performance Assessment - 1995 analyses. The results from the corrosion initiation and rate models will affect the time the waste packages are breached, as well as the effective waste package surface area through which any dissolved radionuclides can be transported.

In addition to the direct incorporation of more representative results from process models into the Total System Performance Assessment - 1995 analyses, sensitivity analyses will be conducted on a number of assumptions that have been included in previous Total System Performance Assessment iterations. For example, in previous Total System Performance Assessment analyses it was assumed that once the waste package had been breached by the first pit, that (a) the entire waste package surface area was available for release, (b) the entire cladding surface was breached and the entire waste form surface exposed, and (c) the entire waste form surface was covered by a thin liquid film. All these assumptions will be tested in Total System Performance Assessment - 1995. The degraded waste package surface area will be allowed to vary with time due to the cumulative pit penetration distribution. The cladding performance will be incorporated as a sensitivity analysis. The amount of water in contact with the waste form will be assumed to depend on the water content within the waste package. Additional sensitivity analyses will evaluate the potential significance of natural colloids on enhancing the mobility and transport of some

insoluble actinides, and on the significance of a range of fracture-matrix transport representations.

One of the primary benefits of Total System Performance Assessment is the evaluation of the significance of uncertain and/or variable conceptual models and parameters on the predicted performance. This performance may be defined with respect to system or subsystem performance. In Total System Performance Assessment - 1995, a range of performance measures will be evaluated. These include the mean time to waste package breach, the peak release rate from the Engineered Barrier System, the cumulative release of radionuclides at the accessible environment over different time periods (10,000 and 100,000 yr), and the peak individual dose at the accessible environment over different time periods (10,000, 100,000, and 1,000,000 yr). The correlation between the different performance measures can yield insights into the controlling elements of the waste isolation and containment strategy that most significantly affect the overall performance of the system.

Performance Assessment Integration Activities

Efforts continued at a low level to define frameworks for effective and efficient integration of experimental and process-level modeling work into performance assessment work. Integrating the data from process-level work into realistic performance assessments will require significant investigation of coupling among the processes, as well as accounting for changes in scale between relatively homogeneous laboratory systems and the heterogeneous systems expected to exist in actual geological structures. Ongoing laboratory and field experiments are providing useful and important information on aqueous flow through fractures and scaling effects. Studies of nonisothermal effects and site geochemistry were not funded for FY 1995. Work on integration has been delayed because of higher-priority work elsewhere (e.g., the Calico Hills performance assessment calculations).

Forecast: The detailed process models that will be abstracted for input to Total System Performance Assessment - 1995 will be completed in the next reporting period. Following this, the abstracted model results, and the corresponding uncertainty, will be input into the Total System Performance Assessment code RIP. A range of sensitivity and uncertainty analyses will be performed with RIP to evaluate the system and subsystem performance measures. This work will be documented toward the end of the next reporting period.

6.6.1 Performance Assessment Activity 1.1.2.1 - Preliminary Identification of Potentially Significant Release Scenario Classes

Subactivity 1.1.2.1.1 - Preliminary identification of potentially significant sequences of events and processes at the Yucca Mountain repository site. No progress was made during the reporting period; this was an out-year activity.

Subactivity 1.1.2.1.2 - Preliminary identification of potentially significant release scenario classes. The release scenarios reported in Barr et al. (1995) are being screened to develop a

short list of scenarios describing the expected behavior of flow and transport in Yucca Mountain. This list will be used as a baseline for initial performance calculations and later comparison with other scenarios. The screening is essentially complete, and the necessary documentation needs to be written.

Interactions between performance assessment analysts and site investigators have begun in order to develop a Total System Performance Assessment module on the effects of seismic events on repository performance.

Forecast: The reference hydrological cases should be reported in a document to be published during the next few months. In addition, scenarios will be constructed for tectonic processes and human intrusion at Yucca Mountain. Conceptual model development on the tectonic subsystem will be completed early in the third quarter. The models will then be implemented in a numerical form and run as part of Total System Performance Assessment-1995 to assess effects on repository performance. Results will be presented at the FOCUS '95 conference.

6.6.2 Performance Assessment Activity 1.1.2.2 - Final Selection of Significant Release Scenario Classes to be Used in Licensing Assessments

No progress was made during the reporting period; this was an out-year activity.

Forecast: No activity is planned for FY 1995.

6.6.3 Performance Assessment Activity 1.1.3.1 - Development of Mathematical Models of the Scenario Classes

Subactivity 1.1.3.1.1 - Development of models for releases along the water pathways. No progress was made during the reporting period; this was an out-year activity.

Subactivity 1.1.3.1.2 - Development of a model for gas-phase releases. No progress was made during the reporting period; this was an unfunded activity.

Subactivity 1.1.3.1.3 - Development of a model of releases through basaltic volcanism. No progress was made during the reporting period; this was an out-year activity.

Subactivity 1.1.3.1.4 - Development of a model of releases through human intrusion. No progress was made during the reporting period; this was an out-year activity.

Forecast: No activity is planned for FY 1995.

6.6.4 Performance Assessment Activity 1.1.4.1 - The Screening of Potentially Significant Scenario Classes Against the Criterion of Relative Consequences

No progress was made during the reporting period; this was an unfunded activity.

Forecast: No activity is planned for FY 1995.

6.6.5 Performance Assessment Activity 1.1.4.2 - The Provision of Simplified, Computationally Efficient Models of the Final Scenario Classes Representing the Significant Processes and Events Mentioned in Proposed 10 CFR 60.112 and 60.115

No progress was made during the reporting period; this was an unfunded activity.

Forecast: No activity is planned for FY 1995.

6.6.6 Performance Assessment Activity 1.1.5.1 - Calculation of an Empirical Complementary Cumulative Distribution Function

No progress was made during the reporting period; this was an unfunded activity.

Forecast: No activity is planned for FY 1995.

6.7 INDIVIDUAL PROTECTION (SCP SECTION 8.3.5.14)

6.7.1 Activity 1.2.1.1 - Calculation of Doses Through the Ground-Water Pathway

No progress was made during the reporting period; this was an out-year activity.

Forecast: No activity is planned for FY 1995.

6.7.2 Activity 1.2.2.1 - Calculation of Transport of Gaseous Carbon-14 Dioxide Through the Overburden

No progress was made during the reporting period; this was an unfunded activity.

Forecast: No activity is planned for FY 1995.

6.7.3 Activity 1.2.2.2 - Calculation of Land-Surface Dose and Dose to the Public in the Accessible Environment Through the Gaseous Pathway of Carbon-14

No progress was made during the reporting period; this was an out-year activity.

Forecast: No activity is planned for FY 1995.

6.8 GROUND-WATER PROTECTION (SCP SECTION 8.3.5.15)

6.8.1 Analysis 1.3.1.1 - Determine Whether Any Aquifers Near the Site Meet the Class I or Special Source Criteria

No progress was made during the reporting period; this was an out-year activity.

Forecast: No activity is planned for FY 1995.

6.8.2 Analysis 1.3.2.1 - Determine the Concentrations of Waste Products in any Special Source of Ground Water During the First 1,000 Years After Disposal

No progress was made during the reporting period; this was an out-year activity.

Forecast: No activity is planned for FY 1995.

6.9 PERFORMANCE CONFIRMATION (SCP SECTION 8.3.5.16)

No progress was made during the reporting period; this was an unfunded activity.

Forecast: No activity is planned for FY 1995.

6.10 U.S. NUCLEAR REGULATORY COMMISSION SITING CRITERIA (SCP SECTION 8.3.5.17)

No progress was made during the reporting period; this was an out-year activity.

Forecast: No activity is planned for FY 1995.

6.11 HIGHER-LEVEL FINDINGS–POSTCLOSURE SYSTEM AND TECHNICAL GUIDELINES (SCP SECTION 8.3.5.18)

No progress was made during the reporting period; this was an out-year activity.

Forecast: No activity is planned for FY 1995.

6.12 RELATED INTERNATIONAL PERFORMANCE ASSESSMENT WORK

Performance Assessment Technology (Verification of SYVAC code)

The following is work, related to Program 8.3.5 (Chapter 6), conducted cooperatively with Canada under the auspices of the OCRWM international program.

During the previous reporting period, the verification effort for the total system performance assessment code, SYVAC, continued to demonstrate the value of having the entire code development process reviewed externally in depth. The review led to numerous improvements, including the correction of both relatively important errors and a few of significant impact, which had not yet been tested by Atomic Energy of Canada Limited. Kersch and Oliver (1994) provide details of the pilot phase of this task. The same tools developed for the Atomic Energy of Canada Limited work can be used directly for other codes, including models used by the Yucca Mountain Site Characterization Project.

During this reporting period, twenty subroutines of the geosphere model and four of the biosphere model were reviewed. Eight subroutines still need review to complete the current scope of work. Work continued on the documentation requirements of SYVAC3-CC3 and its associated development and support tools, including a users manual for the CC3 model. The CC3 programmers manual was begun. Considerable progress was made on the documentation of support programs that generate input files using data from the CC3 data base. Review of the vault model unit tests was initiated.

Forecast: The review of eight remaining SYVAC subroutines, two of which are large, should be completed. Preliminary results of the vault testing will be presented at the Summer Computer Simulation Conference. The United States involvement in the project will be completed in FY 1996.

CHAPTER 7 - EXPLORATORY STUDIES FACILITY DESIGN AND CONSTRUCTION

Section 8.4.2 of the SCP, presented the rationale for planned testing and described surface testing and the underground test facility. In the SCP underground testing was to be conducted by means of an "Exploratory Shaft Facility." The change to a ramp and drift "Exploratory Studies Facility" means the following description of progress does not closely parallel the SCP structure, and as a result there are not as many references to SCP sections as there are elsewhere in this report.

Throughout this section various design packages are referenced. Table 7-1 identifies and describes the package and shows the status at the end of the reporting period. Figure 7-1 shows the locations of the design packages. Table 7-1 and Figure 7-1 have been updated to reflect the ESF configuration contained in the Civilian Radioactive Waste Management Program Plan (DOE, 1994a). In Table 7-1 the design package numerical identifications have been eliminated beyond Package 2 because of the initiative to streamline the design process and to align the remaining design packages with the ESF configuration contained in the Program Plan.

7.1 EXPLORATORY STUDIES FACILITY DESIGN

Minor modifications were made to the contents of Packages 1E and 2B from those shown in Progress Report #11 (DOE, 1995m). Initiatives were developed and implemented to streamline the design and construction process and align the remaining design packages with the ESF configuration contained in the Program Plan. A value engineering study was completed on the communication system for the ESF pad and the Field Operations Center that will result in a significant cost savings.

Ongoing modifications in the form of Field Change Requests and Change Requests continue to be made against Design Package 1A to support construction. Package 1A consists of the following elements:

- North Portal pad
- Topsoil storage area
- ESF access road
- Sewage collection and treatment system
- North Portal pad water supply system (including the Booster Pump Station)
- Tunnel boring machine starter tunnel
- Rock storage area
- Switchgear building
- North Portal pad power distribution system (partial)

Table 7-1. Design Package Identification and Description

Design Package	Design Package Description	Status
1	North Portal site preparation and surface facilities	
1A	Pad, rock and top soil storage, access road, sewage system, water supply, starter tunnel, switchgear building, power distribution system	Issued
1B	Change house, shop, sewage system, power and water distribution, road grading and paving, site grounding, pad drainage and surface rail modifications, pad grading and paving plan	Issued
1C	Compressed air system, stand-by power, site lighting and grounding	Issued
1D	Site lighting and grounding, muck storage, conveyor access road, fuel storage, equipment foundations, compressed air condensate collection system	Issued
1E	Stand-by power, site grounding, electrical distribution, fuel storage modifications	FY 1995
IDCS	Integrated Data and Control System	Issued
2	North Ramp excavation - starter tunnel to Topopah Spring level	
2A	Conveyor, switchgear, transformers, power centers, subsurface transportation	Issued
2B	Utilities, tunnel ventilation, rail haulage system, mapping platform, control system, safety monitoring and warning system	Issued
2C	Excavation layouts, ground support, utilities, electrical power, site lighting, site grounding, alcoves	FY 1995
	Topopah Spring Level Main Drift	FY 1995
	Ghost Dance Fault Accesses at Topopah Spring Level	Out year
	North Ramp Extension	Out year
	Thermal Test Areas	Out year
	Topopah Spring Level South Ramp	Out year
	South Portal Pad and Facilities	Out year
	Calico Hills Level North Ramp	Out year
	Calico Hills Level Main and Cross Drifts	Out year

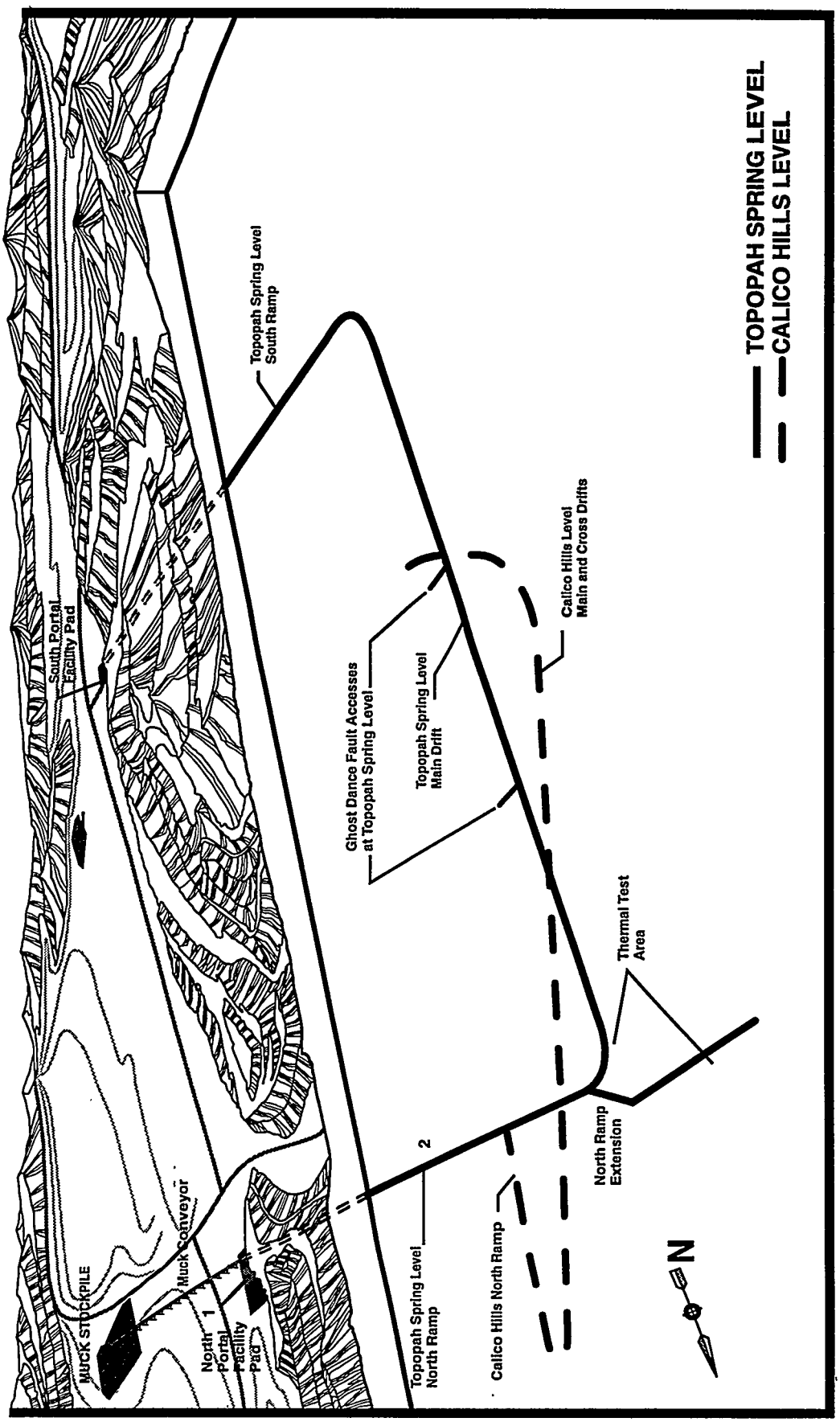

Figure 7-1. Exploratory Studies Facility Design Package Locations

Ongoing modifications in the form of Field Change Requests and Change Requests continue to be made against Design Package 1B to support construction. Design Package 1B consists of the following elements:

- Change house building (contains other services to support portal control)
- Shop building
- Sanitary sewer system
- Power distribution
- Water distribution system
- Subsurface wastewater system
- H-road, site grading, and paving
- Explosive storage area (deleted)
- Site grounding
- Redesign North Portal pad drainage
- Reconfigure North Portal pad for surface rail
- Finish grading and paving plan and surface rail (added by Change Request).

Ongoing modifications in the form of Field Baseline Change Proposals and Baseline Change Proposals continue to be made against Design Package 1C to support construction. Design Package 1C consists of the following elements:

- Compressed air system
- Stand-by power
- Site lighting (partial)
- Site grounding (partial).

Design Package 1D, which was baselined and issued for construction during this period, consists of the following elements:

- Site grounding (continuation)
- Muck storage area
- Conveyor maintenance access road
- Fuel storage system
- Site lighting (continuation)
- Equipment foundations
- Compressed air system condensate collection system.

Design Package 1E, which completed design during this period, consists of the following elements:

- Stand-by/auxiliary power
- Site grounding (continuation)
- ESF electrical distribution (continuation)
- Revised fuel storage system.

The Integrated Data and Control System Design Package, which underwent a 90% Design Review and was baselined and issued for procurement during this period, consists of the following elements:

- Procurement specification for the complete Integrated Data and Control System
- Fiber Distributed Data Interface for the first phase.

A decision was made to use the M&O, through one or more of its team members, as the Integrated Data and Control System Systems Integrator. Discussions are currently under way to implement this decision. This will enhance the Project's ability to accept change to the system in a more timely manner and to minimize costs resulting from change orders to the purchase order with the hardware and software vendors.

Subsurface Design Package 2 for the North Ramp, consisting of Design Packages 2A, 2B, and 2C, was continued and is nearly complete. At this time only the alcove drill and blast specification remains to be completed. Ongoing modifications in the form of Field Change Requests and Change Requests continue to be made against Design Package 2A. Package 2A consists of the following elements:

- Surface and subsurface conveyor
- Electrical switchgear, transformers, and power center
- Subsurface transportation alternatives.

Ongoing modifications in the form of Field Baseline Change Proposals and Baseline Change Proposals continue to be made against Design Package 2B as tunneling progress continues. The control system design was removed from this package and integrated into the Integrated Data and Control System Design Package. Design Package 2B, which was baselined and issued for procurement during this period, consists of the following elements:

- Utility systems
- Tunnel ventilation specification and drawings
- Rail haulage system
- Mapping platform procurement specification
- Excavation, ventilation, and muck storage trade studies
- Control system specification and drawings (now included as part of Integrated Data and Control System Package)
- Life safety monitoring and warning system specifications.

This package contains the appropriate procurement information for these elements.

A value engineering study was completed on the communication system for the ESF pad and the Field Operations Center. The study results included recommendations for a significantly reduced system on the ESF pad based on current needs. The original plan for a fiber optic network to link the ESF pad and Field Operations Center has been modified. The current approach is to use existing microwave capability and existing switching equipment to meet the ESF pad communication needs for the next five years. The value engineering study recommendations are being reviewed by the Architect/Engineer to determine which will be included in a revision to the current ESF pad communications design contained in Design Package 2B. Incorporating the value engineering study recommendations is projected to save approximately $1,000,000.

Design Package 2C, which underwent a 90% Design Review during this period, was issued as segments to support the procurement and construction schedule for the initial phase of tunnel boring machine operations. Three additional segments, which cover tunnel boring machine excavation to the end of the North Ramp, were baselined and issued during this period. Ongoing modifications in the form of Field Baseline Change Proposals and Baseline Change Proposals continue to be made against Design Package 2C as tunneling progresses. Design Package 2C consists of the following elements:

- North Ramp to Topopah Spring Level excavation and ground support
- Remaining utility systems for North Ramp
- Electrical power, lighting, and grounding
- Associated test and operational support alcoves.

This package primarily contains construction and installation details for these elements, as well as the elements in Design Packages 2A and 2B.

During this reporting period, an alternative approach for designing and installing ESF construction utilities was proposed based on discussions between the Architect/Engineer, DOE, the Construction Management Organization, and the Constructor. The objective of the proposal was to enhance tunnel boring machine productivity by installing construction utilities only and to defer costs associated with procuring and installing of Architect/Engineer designed permanent systems. Pending final approval of this approach by DOE, the Architect/Engineer is proceeding with the design package for the Topopah Spring Level Main Drift (formerly labeled 8A). This package covers primarily the excavation layouts for the remainder of the Topopah Spring loop and will use ground control, drilling and blasting, and other standard drawings and specifications from Design Package 2C. To improve overall efficiency of the design/construction approach, the Constructor has been given responsibility for planning the construction utility systems, including compressed air, water, waste water, electric power and control systems, and ventilation. The construction systems will comply with all construction controls imposed by Architect/Engineer specifications. The construction utilities will be designed to support both construction and site characterization testing needs, and on completion of the construction phase will be upgraded or replaced to meet standards of the Architect/Engineer designed permanent systems. The Design Package 2C electrical and mechanical systems designs will be reviewed and if necessary reconfigured to support the Program Plan.

PROGRESS REPORT #12

Design for the Topopah Spring Level Main Drift Package is continuing and currently consists of the following elements:

- Topopah Spring level main drift excavation layouts and ground support
- Associated operational support alcoves
- Conveyor system support structures.

The Topopah Spring Level Main Drift Package design details are being developed with input from the Constructor, Test Coordination Office (Los Alamos) and USGS. The Architect/ Engineer interfaces with SNL and USGS in planning for future design validation activities.

During this reporting period, an initiative was started to streamline the design process. The bulk of the design for the underground portion of the ESF was performed as part of the design of the North Ramp (Design Package 2). This included analyses of the various systems and preparation of standard specifications and drawings. The remaining portions of the underground facility will use these analyses and standard specifications and drawings. In addition, specific general arrangement and detail drawings and specifications for each portion of the underground facility will be developed as required.

Because the bulk of the underground design was reviewed during the development of the North Ramp design, the 50% and 90% Design Reviews have been eliminated. They will be replaced with one external review for each of the design packages for the remaining portions of the underground facility. This process will shorten the development time for releasing designs for the remaining portions of the facility, but will not sacrifice the quality of the products. Organizations such as NRC, Nuclear Waste Technical Review Board, State of Nevada, and Affected Counties will be invited to observe the external reviews.

As part of this initiative, we will no longer refer to design packages by number. Design packages will be referred to by the physical scope of the design package. For example, Design Package 8A will simply be referred to as the Topopah Spring Level Main Drift Design Package. This will eliminate confusion over the contents of a particular design package. The design packages that remain to be released for construction are as follows:

- Topopah Spring Level Main Drift (formerly Design Package 8A)
- Ghost Dance Fault Accesses at Topopah Spring Level (formerly part of Design Package 8)
- North Ramp Extension (formerly part of Design Package 8)
- Thermal Test Areas (formerly part of Design Package 9)
- Topopah Spring Level South Ramp (formerly Design Package 4)
- South Portal Pad and Facilities (formerly Design Package 3)

- Calico Hills Level North Ramp (formerly Design Package 5)

- Calico Hills Level Main and Cross Drifts (formerly Design Package 7).

The Topopah Spring Level Main Test Area (formerly Design Package 9) no longer exists as a defined area. The tests that were to have been performed in this area have been relocated to various locations along the Topopah Spring Level Main Drift and North Ramp Extension. The Optional Shaft (formerly Design Package 10) is no longer part of the Program Plan.

The 69 kV temporary power system upgrades were completed. The remaining design work for breaker addition and replacement at Canyon and North Portal substations is nearing completion. The design is scheduled to be released the end of April 1995. After the release, the breaker addition and replacement will be initiated, with planned completion in FY 1995.

One item originally planned for FY 1995, which will slip into FY 1996, is the voltage correction capacitors at Stockade Wash substation. Because of funding constraints DOE/ Nevada Test Site has canceled the Stockade Wash substation upgrade. The location of the voltage correction capacitor banks will be changed to Valley substation, which is a better location technically. This requires a design for Valley substation to accommodate the capacitors. Raytheon Services Nevada has begun preparing a schedule and cost estimate for this design for DOE approval. The capital funds for the capacitor banks will be reallocated to purchase a replacement transformer for the one on loan from Nevada Power Company at the North Portal substation. The current transformer is scheduled for return to Nevada Power Company September 30, 1995.

Forecast: Design Package 1E is scheduled to undergo a design review, be baselined, and issued for construction early in the fourth quarter of FY 1995. The Architect/Engineer will support procurement, which is scheduled to begin on the first portions of the Integrated Data and Control System Package in the third quarter of FY 1995. The initial Integrated Data and Control System procurement will consist of a surface work station, ethernet, and the first five Data Acquisition Stations to support the SNL construction monitoring activities and the USGS alcove work. Design of the following additional Design Package 1 and 2 items will be completed, baselined, and issued for construction by Change Request in the third quarter of FY 1995:

- Local controls for water and Compressed Air System
- North Portal pad perimeter fencing
- North Portal lightning protection
- Modifications to switchgear building for Integrated Data and Control System
- Sanitary sewage treatment.

The remaining segment of Design Package 2C, design of alcoves and alcove utilities, is scheduled to be baselined and issued for construction early in the third quarter of FY 1995. Design Package 2B utility systems and life safety monitoring and warning system drawings and specifications, which were initially issued for procurement only, are scheduled to be issued for construction during the second half of FY 1995.

A revision to the Design Package 2B communications design for the ESF pad and Field Operations Center is scheduled to begin in the third quarter of FY 1995 to incorporate accepted value engineering study recommendations.

The Topopah Spring Level Main Drift Design Package is scheduled for design completion in the third quarter of FY 1995 and external review and issue for construction in the fourth quarter of FY 1995. The Ghost Dance Fault Accesses at Topopah Spring Level Design Package is scheduled to begin design in the third quarter of FY 1995.

Design will begin in the third quarter of FY 1995 to incorporate voltage correction capacitors at the Valley substation as part of the Nevada Test Site power system upgrades to the ESF site. The design is scheduled to be completed in the first quarter of FY 1996, which will result in the procurement and installation of the capacitors in the second quarter of FY 1996.

7.2 Exploratory Studies Facility Seismic Design

A technical assessment of the ESF seismic design inputs began in FY 1993. No work was performed on this task during the reporting period. The technical assessment examined the seismic design basis for the ESF using a two-phase approach. First, the assessment team was to review the Exploratory Shaft Seismic Design Basis Working Group Report (Subramanian et al., 1990) to determine if the proposed seismic design basis was still appropriate given the current configuration of the ESF and the current understanding of seismic hazards at Yucca Mountain. Second, if the proposed basis could no longer be supported, the team was to recommend a new seismic design basis.

A review of Subramanian et al. (1990) resulted in three main comments:

1. Assumptions related to the configuration of the ESF are now inappropriate given the new configuration involving ramps and drifts.

2. Conclusions based on geologic data available at the time of the report need to be revised using new information gathered since that time.

3. The multiple levels of conservatism recommended in the report are inappropriate.

On the basis of this evaluation, the assessment team concluded that the proposed seismic design basis could no longer be supported. Hence, the technical assessment team implemented the second phase of its charter: to recommend seismic design inputs appropriate for design of the ESF at Yucca Mountain.

As part of the process to develop these inputs, a probabilistic assessment of vibratory ground motion hazard at Yucca Mountain was performed (DOE, 1994g). The results of the probabilistic assessment yield values of peak horizontal acceleration and velocity as a function of their annual probability of being exceeded. The results also provide the information

needed to determine a design basis earthquake and associated response spectrum. This approach incorporates the time dependence of earthquake occurrence, allows uncertainties in assessment inputs to be explicitly incorporated in the analysis, and evaluates hazard from potential sources of future seismicity.

The resulting values of mean peak horizontal acceleration with various annual probabilities of being exceeded are as follows:

Annual Probability of Being Exceeded	Mean Peak Horizontal Acceleration (g)	Average Return Period (yr)
2×10^{-3}	0.19	500
1×10^{-3}	0.27	1,000
5×10^{-4}	0.37	2,000
1×10^{-4}	0.66	10,000

Because the purpose of the ESF is to facilitate underground exploration and testing to support a site suitability evaluation for Yucca Mountain, the technical assessment team recommended that seismic design loading for the facility should be based on a hazard with a 90% probability of not being exceeded in 50 yr (or a return period of roughly 500 yr). Seismic design inputs, therefore, were developed for the hazard with an annual probability of being exceeded of 2×10^{-3}.

Disaggregation of the probabilistic seismic hazard assessment indicates that for annual exceedance probabilities greater than about 1×10^{-4} (return periods of less than 10,000 yr), the primary source of ground motion hazard at the site is a background earthquake. At an exceedance level of 2×10^{-3}, the mean magnitude and distance of contributing earthquakes is M 5.7 at a source-to-site distance of 9 km. Response spectra were developed for such an earthquake using three approaches: (1) probabilistic equal-hazard, (2) empirical deterministic, and (3) stochastic deterministic. The recommended design response spectrum envelops the three approaches.

Peak velocity for design was determined using the band-limited white noise approach and random vibration theory. The velocity was derived to be consistent with the recommended design spectrum. For the 2×10^{-3} exceedance probability level, the design peak velocity is 12 cm/sec.

The technical assessment team also evaluated the effect on ground motion caused by depth of burial below the surface. Both stochastic and empirical approaches were used. For design, a step-function that envelops the results of the two approaches was recommended.

To evaluate the need for seismic design inputs for surface fault displacement, a simpler analysis was performed. The recurrence intervals for surface displacement on faults within

and near the site were compared with the approximately 50- to 100-yr expected life of the ESF. Because the recurrence intervals for surface fault displacement are large, the technical assessment team concluded that design did not need to accommodate fault displacement.

On the basis of the recommendation of the technical assessment team, and considering other information, the ESF Design group developed a graded approach for seismic design of temporary and permanent items. This approach uses the philosophy in DOE Standard 1020 in which structures, systems, and components with larger adverse consequences of failure are designed more conservatively. This approach is often referred to as the performance goal-based approach.

Seismic design within a performance goal-based framework requires that structures, systems, and components be classified into performance categories. Items within a single performance category have a similar target for performance that is established on the basis of the adverse consequences of their failure. The target is expressed as an annual probability of failure that the design should not exceed. Performance categories established in DOE Standard 1021 range from performance category-0, for which the structures, systems, and components are unimportant from safety, mission, and cost perspectives and for which seismic design is not required, to performance category-4, for which the structures, systems, and components performs a safety function in a highly hazardous facility and for which seismic design should provide an annual probability of failure that does not exceed 1×10^{-5}.

Temporary ESF items are evaluated as equivalent to performance category-1 items within the DOE Standard 1021 framework. The ESF surface and subsurface items are only planned to be functional during the ESF maintainable service life of 25 yr, and thus are not important to radiological safety or waste isolation. Temporary items are only considered important to worker safety. Within the DOE Standard 1021 framework, items in performance category-1 are designed for a ground motion with a 2×10^{-3} annual probability of being exceeded to achieve a performance goal of 1×10^{-3}. The value of mean horizontal acceleration determined from the probabilistic hazard assessment for this annual probability of exceedance is 0.19g. Design for the controlling earthquake associated with this ground motion level would be reasonable for temporary ESF items.

Although the value of 0.19g is derived from a site-specific analysis, ESF designers decided to design temporary ESF items more conservatively. The Nevada Test Site is classified as Uniform Building Code Zone 3 in Appendix C of DOE Standard 1020. Because Yucca Mountain is located on the boundary of the Nevada Test Site, ESF temporary items will be designed conservatively for a mean horizontal acceleration of 0.30g consistent with Uniform Building Code Zone 3.

Depth reduction factors from the ESF Seismic Design Inputs Report are considered to directly apply to the selection of appropriate subsurface ground motions. These factors are multipliers used to reduce the surface acceleration values for subsurface design. The ground motion reduction factors for acceleration are summarized as follows:

Depth (m)	Peak Acceleration Horizontal	Vertical
0-100	1.00	1.00
100-200	0.60	0.70
200-400	0.50	0.60
>400	0.50	0.50

The design response spectrum for temporary ESF items is based on the one developed in the ESF Seismic Design Inputs Report. The response spectrum presented in that report for a mean horizontal ground acceleration with an annual probability of exceedance of 2×10^{-3} (0.19g) was normalized and scaled to the selected design acceleration value of 0.30 g.

Permanent ESF items could potentially be incorporated within the repository if one is built at Yucca Mountain. A methodology for seismic design of a repository at Yucca Mountain is being developed as the second in a series of topical reports addressing seismic hazard assessment and seismic design issues (see Section 3.13). Pending development and implementation of that methodology, a preliminary evaluation of ESF permanent items has classified them as, at most, equivalent to performance category-3 within the DOE Standard 1020 framework. Damage to ESF permanent items (openings, ground support, linings, and operational seals) from a seismic event poses only low risk of radiation exposure to the public during the preclosure period. This risk is judged to be lower than that from damage to a reactor hot cell and its filtered ventilation system. Specific considerations include the following:

- There will be no direct handling of radioactive materials underground
- Storage of radioactive materials will be in dedicated emplacement drifts
- During transport underground, there will be no direct handling or storage of radioactive materials
- Radioactive waste will always be contained within protective waste packages that will be designed to survive severe drift damage.

Also, the repository facility will not need to be continuously operated. Following a seismic event, operations could be suspended while crews inspect the openings and complete minor maintenance and repair to ground support systems. Ground support systems will, nonetheless, be designed to withstand the design-basis earthquake without either disrupting operations or causing rockfalls that may damage equipment or expose personnel to bodily injury. This evaluation of ESF permanent items is consistent with earlier evaluations which suggest that repository structures, systems, and components are likely to be, at most, equivalent to performance category-2 or performance category-3. In addition, ESF permanent items are being designed such that items can be upgraded, if appropriate, for repository seismic design.

Mean horizontal ground accelerations, based on the analysis supporting the ESF Seismic Design Inputs Report for annual probabilities of exceedance equivalent to those for performance category-2 and performance category-3 within the DOE Standard 1020 framework are 0.27g and 0.37g, respectively. Depth reduction factors to take into account the attenuation of ground motion with depth are again considered appropriate for determining seismic design values.

ESF design based on the described approach has been analyzed using input ground motion values corresponding to an acceleration of 0.4g. For example, ESF Design Package 2C was analyzed using inputs at all depths based on maximum horizontal and vertical ground accelerations of 0.40g. For quasi-static analyses of the North Ramp, ground motion inputs were an acceleration of 0.40g and a velocity of 40 cm/sec. Also for the North Ramp, dynamic analyses were performed consisting of a P-wave analysis and a combined P-wave and S-wave analysis. Unsupported and rock-bolt supported openings were analyzed. Combined loadings included in situ, thermal (where appropriate), and seismic. These analyses add an additional conservatism to the ESF seismic design.

Forecast: The assessment of Subramanian et al. (1990) and the ESF Seismic Design Inputs Report will be combined to form the review record of the technical assessment. The completed review record will be submitted.

7.3 EXPLORATORY STUDIES FACILITY CONSTRUCTION

This reporting period marked significant progress in ESF construction. The tunnel boring machine continued excavating late in the last period of FY 1994 and has achieved many key milestones. Construction began on several key surface facilities, and several key items related to construction were procured.

The Phase I (initial test excavation) operations, which began in September 1994, were completed in October 1995. This phase consisted of a 12.2-m (40-ft) trial excavation to test the operation of the tunnel boring machine under low load conditions. Phase II (shakedown) operations began after Phase I operations concluded and were completed in late December 1994. In this phase, the tunnel boring machine was operated under increasing load to shake down the system under sustained operating conditions. Also in this phase the tunnel was mapped without a mapping platform. At the end of Phase II the mapping platform was assembled, installed, and checked out in the tunnel boring machine trailing gear. Phase III (limited operations) operations began in December 1994 and continued throughout the period. This phase added a fully operational mapping platform. The tunnel muck was handled using locomotives and muck cars and ground support, consisting of steel sets and lagging or rock bolts and welded wire fabric was required by ground conditions and safety considerations. Phase III will end with the installation and checkout of the surface/subsurface conveyor system. Progress slowed significantly during excavation through the Bow Ridge Fault in late January and early February 1995. This was caused by loose, blocky ground and the requirement to implement special construction methods to fill the voids resulting from excavation in these ground conditions. In spite of the slow progress through the fault zone,

the tunnel boring machine was 34-m (111.8 ft) ahead of schedule at Station 5+49.4-m (18+02.5 ft) at the end of March 1995.

The following two milestones were achieved during the first half of FY 1995:

1. Excavation of 30-m (98.7 ft) of the North Ramp by tunnel boring machine - Level 2 Project milestone (late November 1994)

2. Excavation of North Ramp to Station 3+75-m (12+33.6 ft) - Level 3 Project milestone (early March 1995)

Surface construction began on the following surface facilities during this reporting period:

- Conveyor service road
- Subsurface power center
- Perimeter security fencing
- Electrical duct banks
- Booster pump station
- Water storage tanks (on top of Exile Hill)
- Water line from UE-25 J#13 to the booster pump station
- Change house building
- Surface conveyor.

Surface construction continued on the following surface facilities during this reporting period:

- Water line from the water storage tanks on top of Exile Hill to the North Portal pad
- Water line from the booster pump station to tanks on top of Exile Hill
- Sanitary sewer system
- Switchgear building
- Booster pump station.

The following major procurements were made during this reporting period to support surface and subsurface construction:

- Surface/subsurface conveyor
- Steel sets and lagging
- Shell and heating ventilation and air condition system for the change house building
- Transformers to support surface facilities and the conveyor system.

Forecast: Installation and checkout of the surface/subsurface conveyor system is scheduled for completion in the third quarter of FY 1995. Phase IV (full operations) tunnel boring machine operations will begin after the checkout of the conveyor system. This operation consists of tunneling with the muck being handled using the conveyor system and should significantly increase the daily advance rates to the 20-30-m (65-100 ft) per day range

depending on ground conditions. Alcove No. 2 (Bow Ridge Fault Test Alcove) at Station 1+68.2-m (5+53.3 ft) is scheduled for completion late in the third quarter of FY 1995. Alcove No. 3 presently planned at Station 8+86-m (29+14.5 ft) is scheduled for completion late in the fourth quarter of FY 1995. Excavation on Alcove No. 4, presently planned at Station 10+61-m (34+90.1 ft), is scheduled to begin the end of the fourth quarter of FY 1995. All alcove excavation is planned to use drilling and blasting.

Alcove No. 2 construction and conveyor installation will be performed concurrent with tunnel boring machine tunneling operations. Because of this coordinated effort construction schedules will be maintained for the remainder of FY 1995.

Because excavation progress is projected to remain ahead of schedule through the remainder of FY 1995, the initiatives, discussed in Section 7.1 of this document, for an alternative approach for design and installation of ESF construction utilities, and streamlining the design process were implemented during the reporting period and will continue to assure timely delivery of the design packages to support subsurface construction.

The initial portions of the Integrated Data and Control System, which are currently being procured, are scheduled for delivery and installation at the end of the fourth quarter of FY 1995.

The following surface construction items are scheduled to be completed in the second half of FY 1995:

- Muck storage area
- Conveyor service road
- Perimeter security fencing
- Electrical duct banks
- Subsurface waste water
- Sanitary sewer system
- Water line from UE-25 J#13 to the booster pump station
- Water line from the booster pump station to tanks on the top of Exile Hill
- Water line from the water storage tanks on top of Exile Hill to the North Portal pad.

This will complete a significant portion of the surface construction at the ESF North Portal pad.

7.4 RELATED INTERNATIONAL EXPLORATORY STUDIES FACILITY CONSTRUCTION WORK

Development of Capability for Integration of Construction and Testing Related to the Exploratory Studies Facility

The following is work conducted cooperatively with Sweden under the auspices of the OCRWM international program.

This task provides for exchanges of ideas regarding interaction between construction management strategies and test controls, application of test design, performance of instruments, test progress reporting, and QA process in the underground environment that are jointly beneficial.

Two technical exchange visits by YMP participants were coordinated with DOE, one with USGS participation. The first visit was a workshop on tunnel boring machine operations sponsored by the Swedish Nuclear Fuel and Waste Management Company. The second visit allowed direct viewing and technical information exchanges of the Swedish underground facilities and experiments at the Hard Rock Laboratory, the Central Interim Storage Facility for Spent Nuclear Fuel, and the Forsmark site for final repository for radiogenic operational waste. The Swiss Grimsel experimental site and proposed Wellenberg site for intermediate and low level radioactive waste storage were also visited.

Product exchanges for the period included illustrations and drawings that demonstrate test and construction progress and measurement results of the field deployment of a Laser-Induced Breakdown Spectroscopy system that provides real-time elemental analysis of the tunnel wall and drilling cuttings.

Forecast: Several instrumentation systems unique to the United States program will be deployed and evaluated, which will allow their value to both programs to be assessed. These efforts include additional Laser-Induced Breakdown Spectroscopy measurement of dust particles produced during aircoring, muck produced by the tunnel boring machine, and coming off tunnel walls. This will allow real time identification of elements and will identify changes in the rock compositions and fracture filling. A RAMAN LIDAR measurement system to detect gases and water vapor as they escape from fractures and openings in either the underground or surface environment will be deployed and evaluated. Continued review of Swedish Nuclear Fuel and Waste Management Company reports, and comparison with other international program reports and correspondence, will provide valuable information on underground operations construction and testing interfaces.

APPENDIX A

Matrix Mapping the SCP to the Annotated Outline and Requirements Documents

APPENDIX A

Because of the changes reflected in the Program Plan and because of increasing site and engineering knowledge, some aspects of the detailed program outlined in the Site Characterization Plan (SCP) have changed. In Chapters 1 through 7, the SCP described the site and summarized repository and waste package designs. In Chapter 8, Section 8.3.1 described site testing plans, while programs for repository (Section 8.3.2), seals (Section 8.3.3), and waste package (Section 8.3.4) were presented in terms of approaches to meeting design requirements, site information needed for design, and the design activities to be performed to develop the design basis. Performance assessment approaches for preclosure and postclosure evaluations were presented in Section 8.3.5, and site information needed and activities to be conducted were also described. The Site Characterization Program Baseline represents a subset of information extracted from the SCP that has undergone controlled revisions since 1988. Similarly, study plans provide expansions of test plans in Section 8.3.1 and have been systematically revised, with changes documented in the Site Characterization Program Baseline and summarized in previous progress reports.

To better describe and document the changes currently occurring in the program, Table 1 was compiled to map the general content of the SCP to the requirements or planning documents that provide the basis for the current program, as well as to appropriate sections of the Annotated Outline for the License Application where the information will be presented. The level of detail provided in this table reflects the status of the design and performance assessment programs, which are currently being reviewed and refocused as new strategies resulting from the Program Plan are implemented. Also lending itself to a more generalized treatment is the site descriptive material that was contained in Chapters 1-5 of the SCP. This information will be fully reflected in upcoming revisions to Section 3.1 of the License Application Annotated Outline.

Changes to the objectives of site studies, as well as to the activity structure within studies, have previously been documented in both the Site Characterization Program Baseline and the Site Design and Test Requirements Document. Currently, the Site Design and Test Requirements Document is the single document presenting the current study plan objectives for the program. Table 2 presents a compilation of ongoing changes and modifications to site program studies and activities since the SCP was issued. This matrix identifies where studies and activities have been combined, deleted, or modified. Some changes shown in Table 2 have not been formally completed, but are included in this compilation for completeness.

Under the Program Plan, the site characterization program initially focuses on the scientific investigations and engineering activities needed to support a Technical Site Suitability evaluation in 1998. Thus, the activities conducted through 1998 emphasize improved understanding of hydrologic processes and expanded knowledge about the geologic framework of the site. If the site appears suitable, the focus of site characterization will shift to acquiring additional site characterization data to support advanced waste package and repository design activities and developing the analyses needed to determine overall site suitability in 2000. Similarly, this information, together with that used to support the 1998 Technical Site Suitability evaluation, will serve as the basis for a license application in 2001.

Consistent with the Program Plan, major reliance will be placed on containment by the engineered barriers for the 2001 application, while additional data obtained between 2001 and 2008 will improve confidence in performance of natural barriers. This underlying strategy provides the rationale for some of the changes in sequencing and scope of design, performance assessment, and site studies and activities.

Although many site investigations needed to evaluate suitability will be continued to support the licensing process, several will be completed, or nearly so, when the Technical Site Suitability evaluation is made in 1998. The results of these investigations will be incorporated into the license application annotated outline. Data collection, engineering activities, and analyses conducted after the 1998 evaluation will focus on the primary objective of submitting a successful License Application to the U.S. Nuclear Regulatory Commission (NRC) in 2001.

Additional information regarding long-term performance will be provided in the phases after the initial license application. The initial license application for construction authorization will be followed later by an updated application for a license to receive and possess spent nuclear fuel and high-level waste in about 2008, and a final application for a license amendment to close the repository. Additional applications for license amendments to permit changes in design or operating conditions may be submitted as needed.

Repository and waste package design information and plans are under development with Advanced Conceptual Design activities providing some information. The focus in repository design has been to ensure that interfaces to the Exploratory Studies Facility (ESF) are adequately defined and developed. For regulatory control, the Civilian Radioactive Waste Management System Requirements Document establishes the technical requirements for the entire program (including waste acceptance, storage, and transportation). The Mined Geologic Disposal System Requirements Document is the controlling document for the Yucca Mountain Site Characterization Project. It defines the Program-level requirements for designing the repository, the engineered barrier system, the ESF, and surface-based testing facilities.

The next level is Project documentation, which establishes design requirements and specifications for the repository, for the facilities at the site to support site characterization, and for the engineered barrier system. These design requirements documents are the Repository Design Requirements Document, the Site Design and Test Requirements Document, and the Engineered Barrier Design Requirements Document.

Under the Site Design and Test Requirements Document, are more specific documents for controlling the site characterization activities. These documents address the ESF and the facilities supporting surface-based testing. The Exploratory Studies Facility Design Requirements Document describes the functions to be performed by and the design requirements for facilities, underground openings, utilities, and services of the ESF. The Surface-Based Testing Facilities Requirements Document identifies requirements for facilities needed to support sampling and testing to be carried out from the ground surface.

In Sections 8.3.2 through 8.3.5, the SCP described approaches that would be taken to demonstrate compliance with design and performance requirements (issue resolution strategies) for each major 10 CFR Part 60 requirement. These approaches were expected to be revised as site knowledge increased and results from performance assessment and modeling activities became available. Similarly, implementing the Program Plan is likely to result in the need to revise some of these approaches. The process of resolving Site Characterization Analysis open items results in important feedback from NRC staff and potential revisions to original plans, for example for the proposed approach for meeting the requirement for substantially complete containment by the waste package. Similarly, focused interactions with NRC staff on topics, such as the approach to defining and calculating ground-water travel time, have provided the basis for improving the approaches described in the SCP. To date, the general changes to the approaches have been summarized in appropriate sections of progress reports. The Department of Energy is currently considering whether changes to approaches for demonstrating compliance have become substantive enough to warrant more-detailed documentation to serve as supporting references for future progress reports.

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Table 1. Matrix of SCP Chapters and Sections

SCP Chapter/Section	LA AO[a] Section	Requirements Document or Planning Document	Comments
1 - Geology	3.1, 3.1.1, 3.1.1.1, 3.1.1.2, 3.1.1.3	Not applicable	The Annotated Outline for the License Application will update the site descriptive materials presented in Chapters 1-5 of the SCP
2 - Geoengineering	3.1.1.2.7	Not applicable	Same as 1
3 - Hydrology	3.1.2, 3.1.2.1, 3.1.2.2, 3.1.2.3	Not applicable	Same as 1
4 - Geochemistry	3.1.3, 3.1.3.1, 3.1.3.2	Not applicable	Same as 1
5 - Climate	3.1.4, 3.1.4.1, 3.1.4.2, 3.1.4.3	Not applicable	Same as 1
6 - Conceptual Design of a Repository	4.0, 4.1, 7.0	Site Characterization Program Baseline (SCPB)	Revision 14 of the SCPB will substantially change the scope of the document; this revision will describe the conceptual design of the repository at a summary level of detail
		Initial Summary Report for Advanced Conceptual Design (ACD)	See Chapters 7 and 8 in the Summary Report for ACD
		Repository Design Requirements Document (RDRD)	Contains design basis requirements

Table 1. Matrix of SCP Chapters and Sections

SCP Chapter/Section	LA AO[a] Section	Requirements Document or Planning Document	Comments
6 - Conceptual Design of a Repository (continued)		Controlled Design Assumptions (CDA)	The CDA documents management decisions and/or assumptions, based on best available information or engineering judgment, and provides references to plans and schedules to substantiate the assumptions; appropriate assumptions are also listed in the RDRD as requirements with a "to be verified" (TBV) designation
7 - Waste Package	4.1, 5.1	SCPB	Revision 14 of the SCPB will substantially change the scope of the document; this revision will describe the conceptual design of the waste package at a summary level of detail
		Initial Summary Report for ACD	See Chapter 6 of ACD Summary Report
		Engineered Barrier Design Requirements Document (EBDRD)	Contains design basis requirements
		CDA	The appropriate assumptions from this document are also listed in the EBDRD as requirements with a TBV designation
8 - Site Characterization Program			
8.0 - Introduction		Program Plan Vol. 2	Introductory material updated in Program Plan
8.1 - Rationale		SCPB Program Plan, Vol 2	Summary information on Rationale for Site Characterization Program and general approach to issue resolution remains applicable and will be updated as appropriate

Table 1. Matrix of SCP Chapters and Sections

SCP Chapter/Section	LA AO[a] Section	Requirements Document or Planning Document	Comments
8.2 - Issues		SCPB Program Plan, Vol 2	Summary information on Issues-based approach remains applicable and will be updated as appropriate
8.3 - Planned Tests, Analyses, and Studies	1.6	Site Design and Test Requirements Document (SDTRD)	SDTRD provides study plan objectives for site program
8.3.1 - Site Program	1.6	SDTRD	SDTRD provides study plan objectives for site program; See Table A-2 for compilation of changes to studies and activities
8.3.2 - Repository Program	4.1, 4.2, 4.3, 4.4, 4.5, 7.0	RDRD EBDRD	Sections 3.2 and 3.7 of the RDRD and EBDRD capture the repository requirements; revisions to SCP repository design activities occur as the design program moves forward and are/will be documented in this and future Progress Reports
8.3.3 - Seal Program	4.1.2, 4.3	RDRD EBDRD	Sections 3.7 of the RDRD and 3.2 of the EBDRD capture the seal requirements; revisions to SCP seal design activities will occur as the design program moves forward and will be documented in future Progress Reports
8.3.4 - Waste Package	4.1, 5.0, 5.1.1, 5.2	EBDRD	Section 3.7 of the EBDRD captures the waste package requirements; revisions to SCP waste package design activities occur as the design program moves forward and are/will be documented in this and future Progress Reports

Table 1. Matrix of SCP Chapters and Sections

SCP Chapter/Section	LA AO[a] Section	Requirements Document or Planning Document	Comments
8.3.5 - Performance Assessment Program: Preclosure	2.5, 4.1, 4.2, 4.3, 4.4, 4.5, 5.1, 5.2, 6.0, 7.0	RDRD EBDRD	Sections 3.2 of the RDRD and EBDRD cover preclosure performance assessment requirements; revisions to SCP preclosure performance assessment activities will occur to support the interim site suitability milestone for Radiological Safety and repository design activities, and are/will be documented in this and future Progress Reports
8.4 - Planned Site Preparation Activities		ESFDR, SCPB	SCPB Rev. 14 will provide a summary level description of the Exploratory Facilities Design and document interfaces to the Geologic Repository Operation Area
8.5 - Milestones, Decision Points, and Schedule		Program Plan Vol. 2	Detailed schedules and milestones for Program Plan activities for Fiscal Year 1996 and out-years are under development; Annual Plans and Technical Implementation Plans are tools that are being used to document detailed planning basis for site characterization, design, and performance assessment activities in support of Program Plan
8.6 - Quality Assurance Program	10.2	Quality Assurance Requirements Document (QARD)	The QARD and the procedures that implement it have replaced the Quality Assurance Plan that served as the basis for Section 8.6
8.7 - Decontamination and Decommissioning	4.1.1.11, 4.1.2.6, 4.1.3.9	RDRD, ESFDR	Requirements for decommissioning are captured in RDRD and ESFDR

a License Application Annotated Outline

Table 2. Matrix of SCP Programs, Investigations, Studies, and Activities

SCP Program/Investigation/Study/Activity		Comments	SDTRD[a] Section	LA AO[b] Section	PR[c] Section
8.3	Planned Tests, Analyses, and Studies	N/A			N/A
8.3.1	Site Program	N/A	3.2.1.1	1.6	Ch. 3
8.3.1.1	Program: Site Overview	N/A			N/A
8.3.1.2	Program: Geohydrology	N/A	3.2.1.2	3.1.2	3.1
8.3.1.2.1	Investigation: Studies to Provide a Description of the Regional Hydrologic System	N/A	3.2.1.2.A		N/A
8.3.1.2.1.1	Study: Characterization of the Meteorology for Regional Hydrology	Ongoing	3.2.1.2.A.1	3.1.4, 3.1.4.1	3.1.1
8.3.1.2.1.2	Study: Characterization of Runoff and Streamflow	Ongoing	3.2.1.2.A.2	3.1.2.1, 3.1.2.1.1	3.1.2
8.3.1.2.1.3	Study: Characterization of the Regional Ground-Water Flow System	Ongoing	3.2.1.2.A.3	3.1.2.2	3.1.3
8.3.1.2.1.4	Study: Regional Hydrologic System Synthesis and Modeling	Ongoing	3.2.1.2.A.4	3.1.2.2	3.1.4
8.3.1.2.2	Investigation: Studies to Provide a Description of the Unsaturated Zone Hydrologic System at the Site	N/A	3.2.1.2.B		N/A

Table 2. Matrix of SCP Programs, Investigations, Studies, and Activities

SCP Program/Investigation/Study/Activity		Comments	SDTRD[a] Section	LA AO[b] Section	PR[c] Section
8.3.1.2.2.1	Study: Characterization of Unsaturated-Zone Infiltration	Ongoing	3.2.1.2.B.1	3.1.2.3	3.1.5
8.3.1.2.2.2	Study: Water Movement Test	Ongoing	3.2.1.2.B.2	3.1.2.3	3.1.6
8.3.1.2.2.3	Study: Characterization of Percolation in the Unsaturated-Zone Surface-Based Study	Ongoing	3.2.1.2.B.3	3.1.2.3	3.1.7
8.3.1.2.2.4	Study: Characterization of the Yucca Mountain Percolation in the Unsaturated Zone in the Exploratory Studies Facility	Ongoing Act. 8.3.1.2.2.4.6 - Tests transferred to other activities. Testing in the Calico Hills Formation will be part of other ESF test activities. Act. 8.3.1.2.2.4.9 - Deleted. Testing is no longer planned in an exploratory shaft. This activity comprised tests specific to a shaft.	3.2.1.2.B.4	3.1.2.3	3.1.8

Table 2. Matrix of SCP Programs, Investigations, Studies, and Activities

SCP Program/Investigation/Study/Activity		Comments	SDTRD[a] Section	LA AO[b] Section	PR[c] Section
8.3.1.2.2.5	Study: Diffusion Tests in the Exploratory Studies Facility	Ongoing	3.2.1.2.B.5	3.1.2.3	3.1.9
8.3.1.2.2.6	Study: Characterization of Gaseous-Phase Movement in the Unsaturated Zone	Ongoing	3.2.1.2.B.6	3.1.2.3	3.1.10
8.3.1.2.2.7	Study: Hydrochemical Characterization of the Unsaturated Zone	Ongoing	3.2.1.2.B.7	3.1.2.3	3.1.11
8.3.1.2.2.8	Study: Fluid Flow in Unsaturated, Fractured Rock	Ongoing	3.2.1.2.B.8	3.1.2.3	3.1.12
8.3.1.2.2.9	Study: Site Unsaturated-Zone Modeling and Synthesis	Ongoing	3.2.1.2.B.9	3.1.2.3	3.1.13
8.3.1.2.3	Investigation: Studies to Provide a Description of the Saturated Zone Hydrologic System at the Site	N/A	3.2.1.2.C	3.1.2.3	N/A
8.3.1.2.3.1	Study: Characterization of the Site Saturated-Zone Ground-Water Flow System	Ongoing	3.2.1.2.C.1	3.1.2.3	3.1.14
8.3.1.2.3.2	Study: Characterization of the Saturated-Zone Hydrochemistry	Ongoing	3.2.1.2.C.2	3.1.2.3	3.1.15

Table 2. Matrix of SCP Programs, Investigations, Studies, and Activities

SCP Program/Investigation/Study/Activity		Comments	SDTRD[a] Section	LA AO[b] Section	PR[c] Section
8.3.1.2.3.3	Study: Saturated-Zone Hydrologic System Synthesis and Modeling	Ongoing	3.2.1.2.C.3	3.1.2.3	3.1.16
8.3.1.3	Program: Geochemistry	N/A	3.2.1.3	3.1.3	3.2
8.3.1.3.1	Investigation: Studies to Provide the Information on Water Chemistry Within the Potential Emplacement Horizon and Along Potential Flow Paths	N/A	3.2.1.3.A		N/A
8.3.1.3.1.1	Study: Ground-Water Chemistry Model	Ongoing	3.2.1.3.A.1	3.1.3.2	3.2.1
8.3.1.3.2	Investigation: Studies to Provide the Information on Mineralogy, Petrology, and Rock Chemistry Within the Potential Emplacement Horizon and Along potential Flow Paths	N/A	3.2.1.3.B		N/A
8.3.1.3.2.1	Study: Mineralogy, Petrology, and Chemistry of Transport Pathways	Ongoing	3.2.1.3.B.1	3.1.3.2	3.2.2
8.3.1.3.2.2	Study: History of Mineralogical and Geochemical Alteration of Yucca Mountain	Ongoing	3.2.1.3.B.2	3.1.3.2	3.2.3
8.3.1.3.3	Investigation: Studies to Provide the Information Required on Stability of Minerals and Glasses	N/A	3.2.1.3.C		N/A

Table 2. Matrix of SCP Programs, Investigations, Studies, and Activities

SCP Program/Investigation/Study/Activity		Comments	SDTRD[a] Section	LA AO[b] Section	PR[c] Section
8.3.1.3.3.1	Study: Natural Analog of Hydrothermal Systems in Tuff	This study is no longer planned. This study is not site characterization work, would not substitute for site-specific data, and has utility only in reducing uncertainties in EQ3/6 applications. Overlaps work planned in Studies 8.3.4.2.4.1 and 8.3.1.20.1.1	3.2.1.3.C.1	3.1.3.2	3.2.4
8.3.1.3.3.2	Study: Kinetics and Thermodynamics of Mineral Evolution	Ongoing	3.2.1.3.C.2	3.1.3.2	3.2.5
8.3.1.3.3.3	Study: Conceptual Model of Mineral Evolution	Work scope of this study has been combined with Study 8.3.1.3.3.2	3.2.1.3.C.3	3.1.3.2	3.2.6
8.3.1.3.4	Investigation: Studies to Provide the Information Required on Radionuclide Retardation by Sorption Processes Along Flow Paths to the Accessible Environment	N/A	3.2.1.3.D		N/A
8.3.1.3.4.1	Study: Batch Sorption Studies	Ongoing Incorporates Study 8.3.1.3.4.3	3.2.1.3.D.1	3.1.3.2	3.2.7
8.3.1.3.4.2	Study: Biological Sorption and Transport	Ongoing	3.2.1.3.D.2	3.1.3.2	3.2.8
8.3.1.3.4.3	Study: Development of Sorption Models	Work scope of this study has been combined with Study 8.3.1.3.4.1	3.2.1.3.D.3	3.1.3.2	3.2.9

Table 2. Matrix of SCP Programs, Investigations, Studies, and Activities

SCP Program/Investigation/Study/Activity		Comments	SDTRD[a] Section	LA AO[b] Section	PR[c] Section
8.3.1.3.5	Investigation: Studies to Provide the Information Required on Radionuclide Retardation by Precipitation Processes Along Flow Paths to the Accessible Environment	N/A	3.2.1.3.E		N/A
8.3.1.3.5.1	Study: Dissolved Species Concentration Limits	Ongoing	3.2.1.3.E.1	3.1.3.2	3.2.10
8.3.1.3.5.2	Study: Colloid Behavior	Out-Year	3.2.1.3.E.2	3.1.3.2	3.2.11
8.3.1.3.6	Investigation: Studies to Provide the Information Required on Radionuclide Retardation by Dispersive, Diffusive, and Advective Processes Along Flow Paths to the Accessible Environment	N/A	3.2.1.3.F		N/A
8.3.1.3.6.1	Study: Dynamic Transport Column Experiments	Ongoing	3.2.1.3.F.1	3.1.3.2	3.2.12
8.3.1.3.6.2	Study: Diffusion	Ongoing	3.2.1.3.F.2	3.1.3.2	3.2.13

Table 2. Matrix of SCP Programs, Investigations, Studies, and Activities

SCP Program/Investigation/Study/Activity		Comments	SDTRD[a] Section	LA AO[b] Section	PR[c] Section
8.3.1.3.7	Investigation: Studies to Provide the Information Required on Radionuclide Retardation by all Processes Along Flow Paths to the Accessible Environment	N/A	3.2.1.3.G		N/A
8.3.1.3.7.1	Study: Retardation Sensitivity Analysis	Ongoing	3.2.1.3.G.1	3.1.3.2	3.2.14
8.3.1.3.7.2	Study: Demonstration of Applicability of Laboratory Data to Repository Transport Calculations	Ongoing	3.2.1.3.G.2	3.1.3.2	3.2.15
8.3.1.3.8	Investigation: Studies to Provide the Information Required on Retardation of Gaseous Radionuclides Along Flow Paths to the Accessible Environment	N/A	3.2.1.3.H		N/A
8.3.1.3.8.1	Study: Gaseous Radionuclide Transport Calculations and Measurements	This study is no longer planned. Already covered under Study 8.3.1.2.2.6 and Act. 8.3.1.3.7.1.3 Awaiting EPA Section 801 Rulemaking	3.2.1.3.H.1		3.2.16
8.3.1.4	Program: Rock Characteristics	N/A	3.2.1.4		3.3
8.3.1.4.1	Investigation: Development of an Integrated Drilling Program and Integration of Geophysical Activities	N/A	3.2.1.4.A		N/A
8.3.1.4.1.1	Activity: Development of an Integrated Drilling Program	This study is no longer planned.	3.2.1.4.A.1.a		3.3.1

Table 2. Matrix of SCP Programs, Investigations, Studies, and Activities

SCP Program/Investigation/Study/Activity		Comments	SDTRD[a] Section	LA AO[b] Section	PR[c] Section
8.3.1.4.1.2	Activity: Integration of Geophysical Activities	Ongoing	3.2.1.4.A.1.b		3.3.2
8.3.1.4.2	Investigation: Geologic Framework of the Yucca mountain Site	N/A	3.2.1.4.B		N/A
8.3.1.4.2.1	Study: Characterization of the Vertical and Lateral Distribution of Stratigraphic Units Within the Site Area	Ongoing	3.2.1.4.B.1	3.1.1.2.2	3.3.3
8.3.1.4.2.2	Study: Characterization of the Structural Features Within the Site Area	Ongoing	3.2.1.4.B.2	3.1.1.2.3	3.3.4
8.3.1.4.2.3	Study: Three-Dimensional Geologic Model	Ongoing	3.2.1.4.B.3	3.1.1.2	3.3.5
8.3.1.4.3	Investigation: Development of Three-Dimensional Models of Rock Characteristics at the Repository Site	N/A	3.2.1.4.C		N/A
8.3.1.4.3.1	Study: Systematic Acquisition of Site-Specific Subsurface Information	Ongoing	3.2.1.4.C.1	3.1.1, 3.1.1.2.7	3.3.6
8.3.1.4.3.2	Study: Three-Dimensional Rock Characteristics Models	Ongoing	3.2.1.4.C.2	3.1, 3.1.1	3.3.7
8.3.1.5	Program: Climate	N/A	3.2.1.5		3.4
8.3.1.5.1	Investigation: Studies to Provide the Information Required on Nature and Rates of Change in Climatic Conditions to Predict Future Climates	N/A	3.2.1.5.A	3.1.4.3	N/A

Table 2. Matrix of SCP Programs, Investigations, Studies, and Activities

SCP Program/Investigation/Study/Activity		Comments	SDTRD[a] Section	LA AO[b] Section	PR[c] Section
8.3.1.5.1.1	Study: Characterization of Modern Regional Climate	Ongoing	3.2.1.5.A.1	3.1.4.1	3.4.1
8.3.1.5.1.2	Study: Paleoclimate Study: Lake, Playa, and Marsh Deposits	Ongoing	3.2.1.5.A.2	3.1.1.2.2.5, 3.1.2.3.10	3.4.2
8.3.1.5.1.3	Study: Climatic Implications of Terrestrial Paleoecology	Ongoing	3.2.1.5.A.3	3.1.4.2	3.4.3
8.3.1.5.1.4	Study: Analysis of the Paleoenvironmental History of the Yucca Mountain Region	Ongoing	3.2.1.5.A.4		3.4.4
8.3.1.5.1.5	Study: Paleoclimate-Paleoenvironmental Synthesis	Planned for FY 1995	3.2.1.5.A.5	3.1.2.2.7	3.4.5
8.3.1.5.1.6	Study: Characterization of the Future Regional Climate and Environments	Ongoing	3.2.1.5.A.6	3.1.4.3	3.4.6
8.3.1.5.2	Investigation: Studies to Provide the Information Required on Potential Effects of Future Climatic Conditions on Hydrologic Characteristics	N/A	3.2.1.5.B		N/A
8.3.1.5.2.1	Study: Characterization of the Quaternary Regional Hydrology	Ongoing	3.2.1.5.B.1	3.1.2.2.7, 3.1.2.3.10, 3.1.4.2	3.4.7

Table 2. Matrix of SCP Programs, Investigations, Studies, and Activities

SCP Program/Investigation/Study/Activity		Comments	SDTRD[a] Section	LA AO[b] Section	PR[c] Section
8.3.1.5.2.2	Study: Characterization of the Future Regional Hydrology Due to Climate Changes	Out-Year	3.2.1.5.B.2	3.1.4.3	3.4.8
8.3.1.6	Program: Erosion	This work is completed. Any additional work will be performed under Study 8.3.1.5.1.4.	3.2.1.6	3.1.1.2.1	3.5
8.3.1.7	Program: Rock Dissolution	N/A	3.2.1.7		N/A
8.3.1.8	Program: Postclosure Tectonics	N/A	3.2.1.8		3.6
8.3.1.8.1	Investigation: Studies to Provide the Information Required on Direct Releases Resulting from Volcanic Activity	N/A	3.2.1.8.A		N/A
8.3.1.8.1.1	Study: Probability of Magmatic Disruption of the Repository	Ongoing	3.2.1.8.A.1	3.1.1.2, 3.1.1.3	3.6.1
8.3.1.8.1.2	Study: Physical Processes of Magmatism and Effects on the Repository	Ongoing	3.2.1.8.A.2	3.1.1.3, 4.5	3.6.2

Table 2. Matrix of SCP Programs, Investigations, Studies, and Activities

SCP Program/Investigation/Study/Activity		Comments	SDTRD[a] Section	LA AO[b] Section	PR[c] Section
8.3.1.8.2	Investigation: Studies to Provide the Information Required on Rupture of Waste Packages due to Tectonic Events	N/A	3.2.1.8.B		N/A
8.3.1.8.2.1	Study: Tectonic Effects: Evaluations of Changes in the Natural and Engineered Barrier Systems Resulting from Tectonic Processes and Events	Ongoing Incorporates Investigations 8.3.1.8.3 & 8.3.1.8.4 and Study 8.3.1.8.5.3	3.2.1.8.B.1	3.1.1.3, 5.2.2, 6.2.2	3.6.3
8.3.1.8.3	Investigation: Studies to Provide the Information Required on Changes in Unsaturated and Saturated Zone Hydrology due to Tectonic Events	N/A	3.2.1.8.C		N/A
8.3.1.8.3.1	Study: Analysis of the Effects of Tectonic Processes and Events on Average Percolation Flux Rates Over the Repository	Work scope of this study has been combined with Study 8.3.1.8.2.1	3.2.1.8.C.1	6.2.2	3.6.4
8.3.1.8.3.2	Study: Analysis of the Effects of Tectonic Processes and Events on Changes in Water-Table Elevation	Work scope of this study has been combined with Study 8.3.1.8.2.1	3.2.1.8.C.2	3.1.1.3, 6.3, 6.3.2	3.6.5
8.3.1.8.3.3	Study: Analysis of the Effects of Tectonic Processes and Events on Local Fracture Permeability and Effective Porosity	Work scope of this study has been combined with Study 8.3.1.8.2.1	3.2.1.8.C.3	3.1.1.3	3.6.6
8.3.1.8.4	Investigation: Studies to Provide the Information Required on Changes in Rock Geochemical Properties Resulting from Tectonic Events	N/A	3.2.1.8.D		N/A

Table 2. Matrix of SCP Programs, Investigations, Studies, and Activities

SCP Program/Investigation/Study/Activity		Comments	SDTRD[a] Section	LA AO[b] Section	PR[c] Section
8.3.1.8.4.1	Study: Analysis of the Effects of Tectonic Processes and Events on Rock Geochemical Properties	Work scope of this study has been combined with Study 8.3.1.8.2.1	3.2.1.8.D.1	3.1.3	3.6.7
8.3.1.8.5	Investigation: Studies to Provide the Information Required by the Analysis and Assessment Investigations of the Tectonics Program	N/A	3.2.1.8.E		N/A
8.3.1.8.5.1	Study: Characterization of Volcanic Features	Ongoing	3.2.1.8.E.1	3.1.1.1.3.2, 3.1.1.2.3.5	3.6.8
8.3.1.8.5.2	Study: Characterization of Igneous Intrusive Features	Ongoing Act. 8.3.1.5.2.1 - Deleted. The technique yields results too ambiguous and too general to be useful. Act. 8.3.1.5.2.2 - Data will be collected under Study 8.3.1.8.1.2.	3.2.1.8.E.2	3.1.1.2	3.6.9
8.3.1.8.5.3	Study: Investigation of Folds in Miocene and Younger Rocks of the Region	Unfunded This study relies on available data, no unique data to be acquired by this study. Work scope transferred to Study 8.3.1.8.2.1	3.2.1.8.E.3	3.1.1.2.3	3.6.10
8.3.1.9	Program: Human Interference	N/A	3.2.1.9		3.7

Table 2. Matrix of SCP Programs, Investigations, Studies, and Activities

SCP Program/Investigation/Study/Activity		Comments	SDTRD[a] Section	LA AO[b] Section	PR[c] Section
8.3.1.9.1	Investigation: Studies to Provide the Information Required on Natural Phenomena and Human Activities that might Degrade Surface Markers and Monuments	N/A	3.2.1.9.A		N/A
8.3.1.9.1.1	Study: An Evaluation of Natural Processes that Could Affect the Long-Term Survivability of the Surface Marker System at Yucca Mountain	Ongoing No Study Plan. No unique data to be acquired by this study. Data will come from Studies 8.3.1.8.1.2, 8.3.1.8.2.1, 8.3.1.5.1.4 & Erosion Topical Report.	3.2.1.9.A.1	7.10	3.7.1
8.3.1.9.2	Investigation: Studies to Provide the Information Required on Present and Future Value of Energy, Mineral, Land, and Ground-Water Resources	N/A	3.2.1.9.B		N/A
8.3.1.9.2.1	Study: Natural Resource Assessment of Yucca Mountain, Nye County, Nevada	Ongoing	3.2.1.9.B.1	3.1.1.1.5, 3.1.1.2.5	3.7.2
8.3.1.9.2.2	Study: Water Resource Assessment of Yucca Mountain, Nevada	Ongoing	3.2.1.9.B.2	3.1.2.1.7, 3.1.2.1.8, 3.1.2.2.8	3.7.3
8.3.1.9.3	Investigation: Studies to Provide the Information Required on Potential Effects of Exploiting Natural Resources on Hydrologic, Geochemical, and Rock Characteristics	N/A	3.2.1.9.C		N/A

Table 2. Matrix of SCP Programs, Investigations, Studies, and Activities

SCP Program/Investigation/Study/Activity		Comments	SDTRD[a] Section	LA AO[b] Section	PR[c] Section
8.3.1.9.3.1	Study: Evaluation of Data Needed to Support an Assessment of the Likelihood of Future Inadvertent Human Intrusion at Yucca Mountain as a Result of Exploration and/or Extraction of Natural Resources	Ongoing No study plan. No unique data to be acquired by this study. Study 8.3.1.9.2.1 will be a major direct input to this study.	3.2.1.9.C.1	3.1.1.1.5	3.7.4
8.3.1.9.3.2	Study: An Evaluation of the Potential Effects of Exploration for, or Extraction of, Natural Resources on the Hydrologic Characteristics at Yucca Mountain	Out-Year No study plan. No unique data to be acquired by this study. Study 8.3.1.9.2.2 will supply inputs to computer modeling and bounds for sensitivity analysis.	3.2.1.9.C.2	3.1.2.1.8, 3.1.1.1.5, 3.1.1.2.5	3.7.5
8.3.1.10	Program: Population Density and Distribution	N/A	3.2.1.10	9.2	N/A
8.3.1.11	Program: Land Ownership and Mineral Rights	N/A	3.2.1.11	9., 9.1	N/A
8.3.1.12	Program: Meteorology	N/A	3.2.1.12		3.8
8.3.1.12.1	Investigation: Studies to Provide Data on Regional Meteorological Conditions	N/A	3.2.1.12.A		N/A

Table 2. Matrix of SCP Programs, Investigations, Studies, and Activities

SCP Program/Investigation/Study/Activity		Comments	SDTRD[a] Section	LA AO[b] Section	PR[c] Section
8.3.1.12.1.1	Study: Characterization of the Regional Meteorological Conditions	To begin in FY 1995 No study plan. Material intended for inclusion in this study plan was combined with other studies in the Scientific Investigation Implementation Plan.	3.2.1.12.A.1	3.1.4.1	3.8.1
8.3.1.12.1.2	Study: Plan for Synthesis of Yucca Mountain Site Characterization Project Meteorological Monitoring	The work scope of this study was combined with other studies in the Scientific Investigation Implementation Plan for Study 8.3.1.12.1.1.	3.2.1.12.A.2	3.1.4.1	3.8.2
8.3.1.12.2	Investigation: Studies to Provide Data on Atmospheric and Meteorological Phenomena at Potential Locations of Surface Facilities	N/A	3.2.1.12.B		N/A
8.3.1.12.2.1	Study: Meteorological Data Collection at the Yucca Mountain Site	Ongoing	3.2.1.12.B.1	3.1.4.1.2, 3.1.4.1.3	3.8.3
8.3.1.12.3	Investigation: Studies to Provide Data on the Location of Population Centers Relative to Wind Patterns in the General Region of the Site	Ongoing The work scope of this investigation was combined with other studies in the Scientific Investigation Implementation Plan for Study 8.3.1.12.1.1.	3.2.1.12.C	4.2.1.27, 4.5.1.3, 7.2.4, 7.2.5	3.8.4

Table 2. Matrix of SCP Programs, Investigations, Studies, and Activities

SCP Program/Investigation/Study/Activity		Comments	SDTRD[a] Section	LA AO[b] Section	PR[c] Section
8.3.1.12.4	Investigation: Studies to Provide Data on Potential Extreme Weather Phenomena and Their Recurrence Intervals	N/A	3.2.1.12.D	3.1.4.1.1, 3.1.4.1.3, 4.1.1, 4.1.1.9, 4.1.3.3	N/A
8.3.1.12.4.1	Study: Characterize the Potential Extreme Weather Phenomena and Their Recurrence Intervals	The work scope of this study was combined with other studies in the Scientific Investigation Implementation Plan for Study 8.3.1.12.1.1.	3.2.1.12.D.1	3.1.4.1	3.8.5
8.3.1.13	Program: Offsite Installations	N/A	3.2.1.13	4.2, 4.3, 4.4	3.9
8.3.1.13.1	Investigation: Determination of Nearby Industrial, Transportation, and Military Installations and Operations (Nuclear and Nonnuclear)		3.2.1.13.A		N/A
8.3.1.13.1.1	Activity: Identify Near-Site Activities		3.2.1.13.A.1.a	4.3, 4.4	N/A
8.3.1.13.1.2	Activity: Characterize Nuclear Fuel Cycle Facilities in the Area		3.2.1.13.A.1.b	4.3, 4.4	N/A
8.3.1.13.1.3	Activity: Characterize all Nuclear Facilities not Associated with the Nuclear Fuel Cycle near the Yucca Mountain Site		3.2.1.13.A.1.c	4.3, 4.4	N/A
8.3.1.13.2	Investigation: Potential Impacts of Nearby Installations and Operations		3.2.1.13.B	4.3, 4.4	N/A

Table 2. Matrix of SCP Programs, Investigations, Studies, and Activities

SCP Program/Investigation/Study/Activity		Comments	SDTRD[a] Section	LA AO[b] Section	PR[c] Section
8.3.1.13.2.1	Activity: Evaluate Near-Site Activities		3.2.1.13.B.1.a	4.3, 4.4, 7.2	N/A
8.3.1.13.2.2	Activity: Evaluation of the impact of Nuclear Fuel Cycle Operations Near the Yucca Mountain Site and Las Vegas		3.2.1.13.B.1.b	4.3, 4.4	N/A
8.3.1.13.2.3	Activity: Evaluate the impact of all Nuclear Facilities not Associated with the Nuclear Fuel Cycle Near the Yucca Mountain Site		3.2.1.13.B.1.c	4.3, 4.4, 7.2	N/A
8.3.1.13.2.4	Activity: Evaluate the impact of Ground Motion from Nuclear Testing Activities at the Nevada Test Site		3.2.1.13.B.1.d	3.1.1.2.4, 6.2.2	N/A
8.3.1.14	Program: Surface Characteristics	N/A	3.2.1.14		3.10
8.3.1.14.1	Investigation: Studies to Provide the Topographic Characteristics of Potential Locations of Surface Facilities	N/A	3.2.1.14.A		N/A
8.3.1.14.2	Investigation: Studies to Provide Soil and Rock Properties of Potential Locations of Surface Facilities	N/A	3.2.1.14.B	3.1.1.2.7	N/A
8.3.1.14.2.1	Study: Exploration Program	Ongoing	3.2.1.14.B.1	3.1.1.2.7, 4.1.1	3.10.1
8.3.1.14.2.2	Study: Laboratory Tests and Material Property Measurements	Ongoing	3.2.1.14.B.2	3.1.1.2.7, 4.1.1	3.10.2
8.3.1.14.2.3	Study: Field Tests and Characterization Measurements	Ongoing	3.2.1.14.B.3	3.1.1.2.7, 4.1.2, 4.1.3	3.10.3

Table 2. Matrix of SCP Programs, Investigations, Studies, and Activities

SCP Program/Investigation/Study/Activity		Comments	SDTRD[a] Section	LA AO[b] Section	PR[c] Section
8.3.1.15	Program: Thermal and Mechanical Rock Properties	N/A	3.2.1.15		3.11
8.3.1.15.1	Investigation: Studies to Provide the Required Information for Spatial Distribution of Thermal and Mechanical Properties	N/A	3.2.1.15.A		N/A
8.3.1.15.1.1	Study: Laboratory Thermal Properties	Ongoing	3.2.1.15.A.1	3.1.1.2.7	3.11.1
8.3.1.15.1.2	Study: Laboratory Thermal Expansion Testing	Ongoing	3.2.1.15.A.2	3.1.1.2.7	3.11.2
8.3.1.15.1.3	Study: Laboratory Determination of Mechanical Properties of Intact Rock	Ongoing	3.2.1.15.A.3	3.1.1.2.7	3.11.3
8.3.1.15.1.4	Study: Laboratory Determination of the Mechanical Properties of Fractures	Ongoing	3.2.1.15.A.4	3.1.1.2.7	3.11.4
8.3.1.15.1.5	Study: Excavation Investigations	Ongoing	3.2.1.15.A.5	3.1.1.2.7	3.11.5
8.3.1.15.1.6	Study: In Situ Thermomechanical Properties	Ongoing	3.2.1.15.A.6	3.1.1.2.7	3.11.6
8.3.1.15.1.7	Study: In Situ Mechanical Properties	Ongoing	3.2.1.15.A.7	3.1.1.2.7	3.11.7
8.3.1.15.1.8	Study: In Situ Design Verification	Ongoing Incorporates scope of work from Act. 8.3.1.15.2.1.2	3.2.1.15.A.8	3.1.1.2.7	3.11.8
8.3.1.15.2	Investigation: Studies to Provide the Required Information for Spatial Distribution of Ambient Stress and Thermal Conditions	N/A	3.2.1.15.B		N/A

Table 2. Matrix of SCP Programs, Investigations, Studies, and Activities

SCP Program/Investigation/Study/Activity		Comments	SDTRD[a] Section	LA AO[b] Section	PR[c] Section
8.3.1.15.2.1	Study: Characterization of the Site Ambient Stress Conditions	No study plan. Act. 8.3.1.15.2.1.1 - Deleted Proposed techniques would be redundant with other planned approaches. Act. 8.3.1.15.2.1.2 - Transferred to Study 8.3.1.15.1.8.	3.2.1.15.B.1	3.1.1.2.7	3.11.9
8.3.1.15.2.2	Study: Characterization of the Site Ambient Thermal Conditions	Ongoing	3.2.1.15.B.2	3.1.1.2.7	3.11.10
8.3.1.16	Program: Preclosure Hydrology	N/A	3.2.1.16		3.12
8.3.1.16.1	Investigation: Flood Recurrence Intervals and Levels at Potential Locations of Surface Facilities	N/A	3.2.1.16.A	3.1.2.1.4, 3.1.2.1.5, 4.1	N/A
8.3.1.16.1.1	Study: Characterization of Flood Potential of the Yucca Mountain Site	Ongoing	3.2.1.16.A.1	3.1.2.1.5	3.12.1
8.3.1.16.2	Investigation: Location of Adequate Water Supplies	N/A	3.2.1.16.B		N/A
8.3.1.16.2.1	Study: Location of Adequate Water Supply for Construction, Operation, Closure, and Decommissioning of a Mined Geologic Disposal System at Yucca Mountain, Nevada	Out-Year No study plan. Activities do not require a study plan, will be based on data gathered in other studies.	3.2.1.16.B.1	3.1.2.2.8, 3.1.2.2.9, 3.1.2.3.9, 4.1.1.6	3.12.2
8.3.1.16.3	Investigation: Ground-Water Conditions within and above the Potential Host Rock	N/A	3.2.1.16.C		N/A

Table 2. Matrix of SCP Programs, Investigations, Studies, and Activities

SCP Program/Investigation/Study/Activity		Comments	SDTRD[a] Section	LA AO[b] Section	PR[c] Section
8.3.1.16.3.1	Study: Determination of the Preclosure Hydrologic Conditions of the Unsaturated Zone at Yucca Mountain, Nevada	Unfunded	3.2.1.16.C.1	3.1.2.3.4	3.12.3
8.3.1.17	Program: Preclosure Tectonics	N/A	3.2.1.17		3.13
8.3.1.17.1	Investigation: Studies to Provide the Required Information on Volcanic Activity that could Affect Repository Design or Performance	N/A	3.2.1.17.A		N/A
8.3.1.17.1.1	Study: Potential for Ash Fall at the Site	No study plan. All activities rely on data from other studies.	3.2.1.17.A.1	3.1.1.2.3.5, 3.1.1.3	3.13.1
8.3.1.17.2	Investigation: Studies to Provide the Required Information on Fault Displacement that could Affect Repository Design or Performance	N/A	3.2.1.17.B		N/A
8.3.1.17.2.1	Study: Faulting Potential at the Repository	No study plan. Combined with Study 8.3.1.17.3.6	3.2.1.17.B.1	3.1.1.2.3, 3.1.1.3	3.13.2
8.3.1.17.3	Investigation: Studies to Provide the Required Information on Vibratory Ground Motion that could Affect Repository Design or Performance	N/A	3.2.1.17.C		N/A

Table 2. Matrix of SCP Programs, Investigations, Studies, and Activities

SCP Program/Investigation/Study/Activity		Comments	SDTRD[a] Section	LA AO[b] Section	PR[c] Section
8.3.1.17.3.1	Study: Relevant Earthquake Sources	Ongoing	3.2.1.17.C.1	3.1.1.1.4, 3.1.1.2.4	3.13.3
8.3.1.17.3.2	Study: Underground Nuclear Explosion Sources	No study plan. All activities rely on available data. This work is essentially complete	3.2.1.17.C.2	3.1.1.2.4	3.13.4
8.3.1.17.3.3	Study: Ground Motion from Regional Earthquakes and Underground Nuclear Explosions	Ongoing	3.2.1.17.C.3	3.1.1.2.4	3.13.5
8.3.1.17.3.4	Study: Effects of Local Site Geology on Surface and Subsurface Motions	This work is completed.	3.2.1.17.C.4	3.1.1.2.4	3.13.6
8.3.1.17.3.5	Study: Ground Motion at the Site from Controlling Seismic Events	Out-Year	3.2.1.17.C.5	3.1.1.2.4	3.13.7

Table 2. Matrix of SCP Programs, Investigations, Studies, and Activities

SCP Program/Investigation/Study/Activity		Comments	SDTRD[a] Section	LA AO[b] Section	PR[c] Section
8.3.1.17.3.6	Study: Probabilistic Seismic Hazards Analyses	Ongoing	3.2.1.17.C.6	3.1.1.2.4, 3.1.1.2.4.3	3.13.8
8.3.1.17.4	Investigation: Preclosure Tectonics Data Collection and Analysis	N/A	3.2.1.17.D		N/A
8.3.1.17.4.1	Study: Historical and Current Seismicity	Ongoing	3.2.1.17.D.1	3.1.1.1.4	3.13.9
8.3.1.17.4.2	Study: Location and Recency of Faulting Near the Prospective Surface Facilities	Ongoing Act. 8.3.1.17.4.2.1 is completed	3.2.1.17.D.2	3.1.1.2.3, 3.1.1.2.4	3.13.10
8.3.1.17.4.3	Study: Quaternary Faulting Within 100 km of Yucca Mountain, Including the Walker Lane	Ongoing	3.2.1.17.D.3	3.1.1.1.3, 3.1.1.1.4	3.13.11
8.3.1.17.4.4	Study: Quaternary Faulting Proximal to the Site Within Northeast-Trending Fault Zones	Ongoing Act. 8.3.1.17.4.4.3 - Transferred to Study 8.3.1.17.4.6.	3.2.1.17.D.4	3.1.1.1.3, 3.1.1.2.3	3.13.12
8.3.1.17.4.5	Study: Detachment Faults at or Proximal to Yucca Mountain	Ongoing	3.2.1.17.D.5	3.1.1.1.3, 3.1.1.2.3	3.13.13
8.3.1.17.4.6	Study: Quaternary Faulting Within the Site Area	Ongoing	3.2.1.17.D.6	3.1.1.2.3.2, 3.1.1.2.4	3.13.14

Table 2. Matrix of SCP Programs, Investigations, Studies, and Activities

SCP Program/Investigation/Study/Activity		Comments	SDTRD[a] Section	LA AO[b] Section	PR[c] Section
8.3.1.17.4.7	Study: Subsurface Geometry and Concealed Extensions of Quaternary Faults at Yucca Mountain	No study plan. Work scope transferred to Studies 8.3.1.4.2.1 & 8.3.1.17.3.6	3.2.1.17.D.7	3.1.1.2.3	3.13.15
8.3.1.17.4.8	Study: Stress Field Within and Proximal to the Site Area	Out-Year	3.2.1.17.D.8	3.1.1.2.4, 3.3.1.2.3	3.13.16
8.3.1.17.4.9	Study: Tectonic Geomorphology of the Yucca Mountain Region	No study plan. Work scope transferred to Studies 8.3.1.5.1.4, 8.3.1.17.4.3, and 8.3.1.17.4.12	3.2.1.17.D.9		3.13.17
8.3.1.17.4.10	Study: Geodetic Leveling	Ongoing	3.2.1.17.D.10	3.1.1.1.3, 3.1.1.2.3	3.13.18
8.3.1.17.4.11	Study: Characterization of Regional Lateral Crustal Movement	No study plan. Work scope transferred to Study 8.3.1.17.4.10	3.2.1.17.D.11	3.1.1.1.3, 3.1.1.2.3	3.13.19
8.3.1.17.4.12	Study: Tectonic Models and Synthesis	Ongoing	3.2.1.17.D.12	3.1.1.2.4, 3.1.1.3	3.13.20

a Site Design and Test Requirements Document
b License Application Annotated Outline
c Progress Report

APPENDIX B

Site Characterization Program Baseline History

Site Characterization Program Baseline History (Page 1 of 2)

Revision	Issued	Revisions
0	2/22/91	Initial Issue
1	4/5/91	Updated information related to the Exploratory Studies Facility. Incorporated changes to program planning resulting from the "Exploratory Studies Facility Alternatives Study: Final Report."
2	10/2/91	Revised plans for testing in Site Characterization Plan Section 8.3.1.14. Consolidated all of the anticipated studies under Investigation 8.3.1.14 into one Study Plan (8.3.1.14.2).
3	2/7/92	Changes to the objectives of Activities 1 and 4 in Study Plan 8.3.1.2.1.4 and Activity 4 in Study Plan 8.3.1.2.3.2. Added three drillholes to Study Plan 8.3.1.2.3.1. Deleted requirement for tagging surface dust suppression water with chemical tracer.
4	3/13/92	Incorporated changes in the objectives of Activities 1 and 3 in Study Plan 8.3.1.2.3.2.
5	7/15/92	Corrected references to integration of geophysical activities.
6	7/15/92	Updated Section 8.4 to be consistent with current Exploratory Studies Facility concept.
7	7/15/92	Deleted Activity 8.3.1.4.2.1.6 to eliminate redundancy.
8	9/24/92	Reorganized waste package near-field environment program.
9	10/2/92	Changed scope of the Site Characterization Program Baseline to delete activity descriptions that are controlled in the study plans; placed parameter tables in separate controlled document; removed hypothesis testing tables and analyses supporting test control from the Site Characterization Program Baseline. Changes made to Activities 8.3.1.2.2.4.6, 8.3.1.5.2.1.2, 8.3.1.5.2.2.1, 8.3.1.5.2.2.2, 8.3.1.5.2.2.3; changes made to Studies 8.3.1.3.7.2, 8.3.1.8.1.1, 8.3.1.8.1.2, 1.10.4.3; and changes made to Investigation 8.3.1.7.1.
10	1/14/93	Documented changes made to Study 8.3.1.2.2.4; Activities 8.3.1.8.5.2.2, 8.3.1.15.2.2, 8.3.1.17.4.3.2, 8.3.1.17.4.4.3; and Section 8.3.5.13.

Site Characterization Program Baseline History (Page 2 of 2)

Revision	Issued	Revisions
11	8/3/94	Revised Investigation 8.3.1.8.2. Revised the objectives of Activities 8.3.1.8.5.2.1, 8.3.1.8.5.2.3, and 8.3.1.17.3.1. Documented editorial changes to Section 8.4.
12	1/20/95	Revised the objectives of Studies 8.3.1.5.1.6 and 8.3.1.15.1.5. Revised 8.4 in response to NRC comments and revised ESF/Repository interface drawings described in CR 94/035M2.

APPENDIX C

Interim Evaluations in the Site Suitability Evaluation Process

Interim Evaluations in the Site Suitability Evaluation Process (Page 1 of 3)

Interim Evaluation Completion Date	Technical Basis Report	Higher-Level Finding Regulatory Assessment	Guideline Reference
Surface Processes (FY 1995)	Available information on erosion, surface characteristics, and hydrology	Postclosure Erosion Qualifying Condition and Disqualifying Condition	§960.4-2-5
		Preclosure Surface Characteristics Qualifying Condition	§960.5-2-8
		Preclosure Hydrology Qualifying Condition and Disqualifying Conditions	§960.5-2-10
Tectonics (FY 1997)	Existing information on faulting, seismicity and volcanology; seismic design bases	Preclosure Tectonics Qualifying Condition and Disqualifying Condition	§960.5-2-11
		Postclosure Tectonics Disqualifying Condition	§960.4-2-7
Preclosure Radiological Safety (FY 1997)	Available information on population density and distribution, site ownership and control, meteorology, offsite installations and operations; repository design concepts; dose assessment calculations	Preclosure radiologic safety system guideline Qualifying Condition	§960.5-1(a)
		Population Density and Distribution Qualifying Condition and Disqualifying Condition	§960.5-2-1
		Site Ownership and Control Qualifying Condition	§960.5-2-2
		Meteorology Qualifying Condition	§960.5-2-3
		Offsite Installations and Operations Qualifying Condition and Disqualifying Condition	§960.5-2-4

Interim Evaluations in the Site Suitability Evaluation Process (Page 2 of 3)

Interim Evaluation Completion Date	Technical Basis Report	Higher-Level Finding Regulatory Assessment	Guideline Reference
Geochemistry and Rock Characteristics (FY 1997)	Available information on rock and mineral distribution, mineral alteration history, ground-water chemistry, sorption characteristics, rock mechanical properties, and natural resources; repository design concepts	Postclosure Human Interference Disqualifying conditions Preclosure rock characteristics Qualifying and Disqualifying Condition The postclosure qualifying conditions for geochemistry, rock characteristics, and human interference will be considered under the regulatory assessment for Total System Performance Assessment	§960.4-2-2 §960.4-2-3 §960.4-2-8 §960.5-2-9
Reasonably Available Technology (FY 1997)	Preceding technical basis reports for surface characteristics, rock characteristics, hydrology, and tectonics; repository design concepts	Preclosure Systems guideline for ease and cost of siting, construction, operations, and closure Qualifying Condition	§960.5-2-8, 5-2-9, 5-2-10, and 5-2-11
Geohydrology and Transport (FY 1998)	Potential climate change impacts on radionuclide transport, geochemistry impacts on radionuclide transport, ground-water travel time along radionuclide transport pathways	Postclosure Geohydrology Disqualifying Condition	§960.4-2-4 §960.4-2-3 §960.4-2-1

Interim Evaluations in the Site Suitability Evaluation Process (Page 3 of 3)

Interim Evaluation Completion Date	Technical Basis Report	Higher-Level Finding Regulatory Assessment	Guideline Reference
Total System Performance Assessment (FY 1998)	Total System Performance Assessment - 1997 and the preceding technical basis documents for geohydrology, geochemistry, rock characteristics, climate, and tectonics; waste package and repository design concepts	Postclosure System Guideline Qualifying Condition: System and Subsystem Requirements of 10 CFR Part 60 and 40 CFR Part 191	§960.4-1
		Postclosure Qualifying Conditions for Geohydrology, Geochemistry, Rock Characteristics, Climate, Human Interference, and Tectonics	§960.4-2-1 §960.4-2-2 §960.4-2-3 §960.4-2-4 §960.4-2-7
Technical Site Suitability Evaluation (FY 1998)	Collation of preceding technical basis documents	Technical Site Suitability Determination; collation of preceding regulatory assessments	Not a 10 CFR Part 960 Requirement
Prepare Site Recommendation Report and Affirm Previous Findings (FY 2000)	Environmental, socioeconomic and transportation technical basis from Final Environmental Impact Statement: All preceding technical basis documents and current data and analyses	Preclosure Environmental Quality Systems Guideline Qualifying Condition	§960.5-1-2
		Environmental Quality Qualifying and Disqualifying Condition	§960.5-2-5
		Socioeconomic Qualifying and Disqualifying Conditions	§960.5-2-6
		Transportation Qualifying Condition	§960.5-2-7
		Site Recommendation Report	§960.3-2-4

APPENDIX D

Interactions with the U.S. Nuclear Regulatory Commission and Other Organizations

Interactions with the U.S. Nuclear Regulatory Commission and Other Organizations (Page 1 of 5)

Organization	Date	Type	Location	Subject/Purpose
NRC	10/7/94	Technical Meeting	Washington, D.C. and Las Vegas, NV (Videoconference)	Discussion of NRC concerns related to the Extreme Erosion Topical Report and Seismic Topical Report I (probabilistic seismic hazard assessment).
NRC	11/1/94	Management Meeting	Rockville, MD	DOE response to NRC concerns related to ESF design control and QA.
NRC	11/7/94	Technical Meeting	Las Vegas, NV	Bi-monthly discussion of the status of ESF design and construction activities.
NRC	11/8-9/94	Technical Exchange	Las Vegas, NV	Discussion of the DOE field heater experiments associated with coupled thermal-hydrologic-mechanical-chemical processes
NRC	11/9/94	Site Visit	Yucca Mountain, NV	Tour of the Fran Ridge Large Block Test.
NRC	11/29/94	Technical Exchange	Denver, CO	Discussion of ground-water flow mechanisms in the unsaturated zone.
NRC	11/30/94 - 12/1/94	Technical Exchange	Denver, CO	Discussion of site data, modeling, and regulatory aspects of the ground-water travel time requirement.
NRC	12/2/94	Management Meeting	Washington, D.C. and Las Vegas, NV (Videoconference)	NRC comments on the DOE Five-Year Plan and the Program Approach.
NRC	12/6/94	Management Meeting	Washington, D.C. and Las Vegas, NV (Videoconference)	Bi-monthly discussion of management issues, including topical report annotated outlines and transmittals of information to NRC.

Interactions with the U.S. Nuclear Regulatory Commission and Other Organizations (Page 2 of 5)

Organization	Date	Type	Location	Subject/Purpose
NRC	12/7/94	Technical Exchange	Rockville, MD	DOE presentations on the status of waste package design and materials testing, and discussion of the substantially complete containment requirement.
NRC	1/17/95	Management Meeting	Washington, D.C. and Las Vegas, NV (Videoconference)	Discussion of the DOE waste isolation and containment strategy as reflected in the Program Approach.
NRC	1/19/95	Site Visit	Yucca Mountain, NV	Tour of the site for the NRC Nuclear Safety Research Review Committee on Waste.
NRC	1/24/95	Technical Meeting	Rockville, MD	Bi-monthly discussion of the status of ESF design and construction activities.
NRC	1/26/95	Technical Exchange	Washington, D.C. and Las Vegas, NV (Videoconference)	Discussion of NRC concerns related to Seismic Topical Report I and the annotated outline for Seismic Topical Report II (seismic design methodology).
NRC	2/8/95	Management Meeting	Washington, D.C. and Las Vegas, NV (Videoconference)	Bi-monthly discussion of management issues, including the NRC policy on harassment and intimidation.
NRC	3/20/95	Technical Meeting	Washington, D.C. and Las Vegas, NV (Videoconference)	Bi-monthly discussion of the status of ESF design and construction activities.
NRC	3/29/95	Technical Exchange	Washington, D.C. and Las Vegas, NV (Videoconference)	Discussion of the DOE calculational approach to pre-waste emplacement ground-water travel time.

Organization	Date	Type	Location	Subject/Purpose
ACNW	10/18-19/94	68th Meeting	Las Vegas, NV	Discussion of pneumatic testing, electronic data transfer, the impact of the Program Approach on saturated and unsaturated zone activities, and the Waste Isolation Pilot Plant system prioritization approach.
ACNW	10/20/94	Site Visit	Yucca Mountain, NV	Tour of field activities associated with the hydrology program.
ACNW	10/21/94	Working Group	Las Vegas, NV	Discussion of uses and limitations of ground-water dating methods.
ACNW	11/10/94	69th Meeting	Las Vegas, NV	Discussions with the Director of the NRC Division of Waste Management and a meeting with NRC; topics included NRC research activities and the impact of the DOE Program Approach.
ACNW	1/18-19/95	70th Meeting	Rockville, MD	Discussion of the NRC materials research program, rock mechanics, and the draft NRC Probabilistic Risk Assessment Policy and Implementation Plan; discussions with the Director of the NRC Division of Waste Management.

Organization	Date	Type	Location	Subject/Purpose
ACNW	2/21-22/95	71st Meeting	Rockville, MD	Discussions with the Director of the NRC Division of Waste Management on ground-water travel time and key technical uncertainties; discussions with the Director of the NRC Office of Research on the "hot" repository concept and the multi-purpose canister; discussion of proposed EPA standards for land disposal of low-level waste, model validation, and guidelines for the Licensing Support System.
ACNW	3/15-16/95	72nd Meeting	Rockville, MD	Presentations by DOE on the waste containment strategy in the Program Approach and on the Engineered Barrier System; presentations by NRC, the State of Nevada, and ACNW consultants on ground-water travel time.
NWTRB	10/12/94	Fall Full Board Meeting	Las Vegas, NV	Discussion of three main areas related to site suitability: the process by which DOE will assess site suitability; the main technical site-suitability issues at Yucca Mountain and DOE priorities regarding exploration, testing, and data collection; and the roles assigned to natural and engineered barriers.

Interactions with the U.S. Nuclear Regulatory Commission and Other Organizations (Page 5 of 5)

Organization	Date	Type	Location	Subject/Purpose
NWTRB	11/17-18/94	Combined Meeting of Structural Geology and Geoengineering Panel and Hydrogeology and Geochemistry Panel	Washington, D.C.	Discussion of several areas related to thermal management of a high-level waste repository, including alternative thermal management strategies, ***in situ*** thermal testing needs, performance analysis, and the DOE process for making a thermal management decision.
NWTRB	1/10-11/95	Winter Full Board Meeting	Beatty, NV	Discussions included the DOE environmental monitoring program at Yucca Mountain; the DOE strategy for developing the Environmental Impact Statements for the multi-purpose canister and for the repository; the integration of the repository Environmental Impact Statement with Yucca Mountain site characterization studies; the DOE socioeconomic program; and the DOE waste isolation strategy development.

APPENDIX E

Status of NRC Site Characterization Analysis Open Items

Status of Site Characterization Analysis Open Items (Page 1 of 27)

Item ID	Item Description	Status	Action Description
Objection 1	Adequacy of Title I design control process.	Closed 11/2/92	NRC letter lifting Objection 1. NRC considers this objection closed.
Objection 2	Acceptability of DOE Quality Assurance Program.	Closed 11/2/92	NRC letter lifting Objection 2. NRC considers this objection closed.
Comment 1	A systematic, iterative approach to identify and collect data during site characterization to support a license application not demonstrated to be in place.		Submit a supplemental response to the NRC. This response will be used to close Comments 10, 18, 49, and 60.
Comment 2	Performance Assessment: Confidence in performance.		Submit a supplemental response to the NRC.
Comment 3	Reliance on expert judgment to supply licensing information.		Supplemental response submitted to the NRC on 7/12/93. Awaiting NRC concurrence.
Comment 4	Rationale for the testing needs; integration of testing with design and performance assessment needs.		Develop parametric calculations to refine parameter goals. Develop plans for collecting all necessary data. Supply NRC with the information in semiannual progress reports. Submit a supplemental response to the NRC.
Comment 5	Waste Package: Interpretation of substantially complete containment.	Closed 7/11/94	NRC Evaluation of DOE response. NRC considers this comment closed.
Comment 6	Performance Assessment: Hypothesis Testing Table and alternative conceptual models.		Submit a supplemental response to the NRC.
Comment 7	Use of expert judgment versus peer review.		Supplemental response submitted to the NRC on 7/12/93. Awaiting NRC concurrence.

Status of Site Characterization Analysis Open Items (Page 2 of 27)

Item ID	Item Description	Status	Action Description
Comment 8	Alternative Tectonic Models.		Study Plan 8.3.1.17.4.12, Rev. 1 "Tectonic Models and Synthesis" needs to be completed and approved. Submit a supplemental response to the NRC.
Comment 9	Use of expert judgment during the development of Hypothesis Testing Table.		Submit a supplemental response to the NRC.
Comment 10	Assessment of significance of site hydrologic characteristics.		Resolve concerns in Comment 1. Resolution of Comment 1 will address the cross-issues for this comment.
Comment 11	No hypothesis on the thermal effects of waste emplacement in the hydrologic environments presented.		Submit a supplemental response to the NRC.
Comment 12	Porous flow in the Calico Hills unit.	Closed 11/2/92	NRC letter lifting Objection 1. NRC considers this comment closed.
Comment 13	Surface Hydrology: Surface water gaging station locations and the natural infiltration measurements.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 14	Hydrologic properties of the tuffaceous beds of the Calico Hills nonwelded unit.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 15	Solitario Canyon horizontal borehole activity is inadequate to discriminate between the hypotheses that faults are barriers to fluid flow in non-welded tuff units or faults are conduits for liquid-water flow.	Closed 9/15/94	NRC evaluation of SP 8.3.1.2.2.4. NRC considers this comment closed.

Item ID	Item Description	Status	Action Description
Comment 16	Characterization of the hydrologic properties of the Calico Hills unit.	Closed 11/2/92	NRC letter lifting Objection 1. NRC considers this comment closed.
Comment 17	Multi-purpose borehole testing near the shafts.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 18	Initial hydrologic modeling studies are not supported by planned studies.		Resolve concerns in Comment 1. Resolution of Comment 1 will address cross-issues for this comment.
Comment 19	Saturated Zone: Work is not adequate for saturated zone characterization.		Develop and submit plan to define sufficient testing of the saturated zone. Submit a supplemental response to the NRC.
Comment 20	Saturated Zone: Potentiometric surface will not adequately be defined.		Submit a supplemental response to the NRC.
Comment 21	Saturated Zone: Tc-199 and I-129 are not included to be characterized in the ground water flow and radionuclide analysis background concentrations.		Supplemental response submitted to the NRC on 1/7/93. Awaiting NRC concurrence.
Comment 22	Saturated Zone: Hydrochemical samples.		Supplemental response submitted to the NRC on 1/7/93. Awaiting NRC concurrence.
Comment 23	Unsaturated Zone: Evaluation of radionuclide concentrations on fracture surfaces.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 24	Approaches are not sufficient for determining reliable thermodynamic properties.		Receive Study Plan from Los Alamos National Laboratory.

Item ID	Item Description	Status	Action Description
Comment 25	Waste Package: Rationale on additional testing on waste and interactions between and among radionuclides on sorption.		Submit Study Plan 8.3.4.2.4.1 "Characterization of Chemical and Mineralogical Changes in Post-Emplacement Environment" to NRC. Submit a supplemental response to the NRC.
Comment 26	Sorption Batch Studies.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 27	Batch Sorption Measurements.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 28	Sorption on Particulates and Colloids.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 29	Biological Sorption and Transport.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 30	Solubility Modeling.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 31	Some parameters and conditions under fracture flow are not planned and need to be determined.		Submit a supplemental response to the NRC.
Comment 32	Rock characteristics program: Geophysical integration is insufficient.		Geophysical Integration Group needs to develop a plan to implement integration. Submit a supplemental response to the NRC.
Comment 33	Engineering rock parameters are not adequately integrated to develop 3-D rock characteristics models.		Study Plan 8.3.1.4.3.1 "Systematic Acquisition of Site Specific Data" submitted to the NRC on 1/11/93. Prepare Study Plan 8.3.1.4.2.3 "Three-Dimensional Geologic Modeling" and submit to the NRC. Submit a supplemental response to the NRC.

Status of Site Characterization Analysis Open Items (Page 5 of 27)

Item ID	Item Description	Status	Action Description
Comment 34	Drilling Program: It is unclear how data from various drill holes will be used in support of various studies, how uncertainties in core retrieval and data analyses will be handled, and how the large volume of existing information will be used to plan the drilling program.		Submit a supplemental response to the NRC.
Comment 35	Adequacy of lithological, structural, and drifting activities to characterize the site.	Closed 11/2/92	NRC letter lifting Objection 1. NRC considers this comment closed.
Comment 36	Rationale for investigation 8.3.1.4.2 may not be accurate for the perimeter drift defining lower concentrations of faults.		Supplemental response submitted to the NRC on 6/16/94. Awaiting NRC concurrence.
Comment 37	Identification of blast fractures.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 38	Characterization of faults in the subsurface.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 39	Systematic Drilling Program: No assessment is provided to support the estimated maximum range of statistical correlation for porosity and air permeability.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.

Item ID	Item Description	Status	Action Description
Comment 40	Systematic Drilling Program: Spacing of the 30 sample borehole pairs in a range of up to 10,000 feet may represent a lower bound for geostatistical analysis.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 41	Systematic Drilling Program: Tight clustering of sample locations SD-8 and SD-12 has not been justified.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 42	Adequacy of evaluation of escarpment retreat.		Supplemental response submitted to the NRC on 7/23/92. Awaiting NRC concurrence.
Comment 43	Adequacy of numerical goals in erosion, post-closure tectonics, and pre-closure tectonics performance assessment tables.	Closed 2/17/95	Ltr. Bell to Milner, "NRC Review of the DOE Responses to Site Characterization Analysis Comments 42 and 43."
Comment 44	Waste Package: Overall goal is not consistent with substantially complete containment.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 45	Volcanic rate calculations independent of underlying volcanic-tectonic processes.		Supplemental response submitted to the NRC on 7/12/93. Awaiting NRC concurrence.
Comment 46	Postclosure Tectonics.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 47	Waste Package: Relationship of postclosure tectonics to the waste package and the EBS requirements.		Supplemental response submitted to the NRC on 6/9/93. Awaiting NRC concurrence.

Item ID	Item Description	Status	Action Description
Comment 48	Use of fault slip rates on the repository facilities are not conservative.		Prepare and issue topical report "Seismic Design Criteria" in accordance with the Seismic Hazards Issue Resolution Group's Issue Resolution Action Plan. Submit a supplemental response to the NRC.
Comment 49	Volcanism: Results from investigations on basaltic volcanism may fail to meet overall system performance.	Closed 9/14/94	NRC evaluation of SP 8.3.1.8.1.2. NRC considers this comment closed.
Comment 50	Effects of faulting may be underestimated.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers the comment closed.
Comment 51	Adequacy of Geophysics program to determine deep and shallow crustal features.		Geophysical Integration group needs to develop a plan to implement integration.
Comment 52	Use of Geophysics to identify volcanic/igneous features.		Completed assessment by independent consultant of planned and potential geophysical studies that contribute to resolution of volcanism issue. Consultant's preliminary findings were submitted to the NRC on site representative. Submit a supplemental response to the NRC.
Comment 53	Adequacy of natural resource assessment; consideration of ore deposition models.		Supplemental response submitted to the NRC on 2/5/93 in SP 8.3.1.9.2.1. NRC Ltr. 2/18/94 Holonich to Shelor partially closing SCA Comment 53. Awaiting NRC concurrence.
Comment 54	Inconsistencies in Site Characterization Plan Chapter 8.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.

Item ID	Item Description	Status	Action Description
Comment 55	Adequacy of geostatistical approach to geomechanical and thermal properties.		The review of Performance Allocations for Activity 8.3.1.15 "Rock Characteristics Program" needs to be completed. Submit a supplemental response to the NRC.
Comment 56	Validation of models for mechanical and thermal properties.		Submitted SP 8.3.1.15.1.5, Rev. 1 "Excavation Investigations," to NRC on 5/5/94. Submit 8.3.1.15.1.6 "In Situ Thermomechanical Properties," and 8.3.1.15.1.7, "In Situ Mechanical Properties" to the NRC. The Review of Performance Allocations for Activity 8.3.1.15 "Rock Characteristics Program" needs to be completed. Submit a supplemental response to the NRC.
Comment 57	Design verification does not consider alternative methods of excavation.	Closed 11/2/92	NRC letter lifting Objection 1. NRC considers comment closed.
Comment 58	Descriptions in the in situ design verification section do not include tests to verify design reports.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 59	Description of tectonic and igneous events do not allow for determination of actual investigations to be conducted, and sequencing of activities.		Submit a supplemental response to the NRC.
Comment 60	Performance Assessment: Adequacy of preclosure design and performance goals and characterization parameters.		Resolve concerns in Comment 1. Resolution of Comment 1 will address cross-issues of this comment.

Item ID	Item Description	Status	Action Description
Comment 61	Assumption that future faulting will follow previous faulting.		Submit a supplemental response to the NRC.
Comment 62	The studies of faulting at the surface facilities do not indicate how DOE is proposing to use standoff distances.		Submit a supplemental response to the NRC.
Comment 63	Use of pre-existing and unavailable information for the preclosure tectonics program and the surface facilities.		Submit a supplemental response to the NRC which will describe where in the study plan and the "Test and Evaluation Plan" the concerns of the NRC are addressed.
Comment 64	Adequacy of faults study for design and performance.		Submit a supplemental response to the NRC.
Comment 65	Use of domains to define areas of faulting potential.	Closed 7/31/91	NRC evaluation of DOE response. NRC considers this comment closed.
Comment 66	Release via a single event 10,000 year cumulative slip earthquake.		Complete detailed study to show the facility can conservatively withstand an event exceeding the design basis ground motion. Submit a supplemental response to the NRC.
Comment 67	Data on earthquakes having a cutoff of a magnitude 5.5 may not be sufficient to support an evaluation of the effects of site geology on surface and subsurface motion.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 68	Adequacy of treatment on detachment faulting affects.		Prepare Study Plan 8.3.1.17.4.12, Rev. 1 "Tectonic Models and Synthesis" and submit to the NRC. Submit a supplemental response to the NRC.

Item ID	Item Description	Status	Action Description
Comment 69	Synthesis of data on the northwest trending faulting.		Prepare Study Plan 8.3.1.17.4.12 "Tectonic Models and Synthesis" and submit to the NRC. Submit supplemental response to the NRC.
Comment 70	Blast control procedures are less important to post-closure performance are not justified.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 71	Adequacy of technologies in assessing faulting for construction, operation, and closure.		Submit a supplemental response to the NRC.
Comment 72	Adequacy of the seal program.	Closed 11/2/92	NRC letter lifting Objection 1. NRC considers this comment closed.
Comment 73	Performance Assessment: Adequacy of required backfill hydraulic conductivity.		Resume work on the seals program investigation. Prepare the study plan for the measurement of the hydraulic conductivity (there is no numeric designator for this SP yet). Submit a supplemental response to the NRC.
Comment 74	Testing of Seal Components: No indication is given as to whether and when the testing to evaluate the behavior of selected sealing components under in situ test conditions will be initiated.		Prepare Study Plan 8.3.3.2.2.3 "In Situ Testing of Seal Components." Submit a supplemental response to the NRC.
Comment 75	Definition of and inconsistent use of geologic setting.	Closed 12/30/93	NRC Evaluation of DOE Responses. NRC considers this comment closed.

Status of Site Characterization Analysis Open Items (Page 11 of 27)

Item ID	Item Description	Status	Action Description
Comment 76	NRC reviews cannot be relied on as peer reviews.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 77	Adequacy of considerations of retrieval operations in evaluating the effects of credible accidents on radiological exposure.		Evaluate the effects of credible accidents on radiological exposures during retrieval operation of the Advanced Conceptual Design. Submit a supplemental response to the NRC.
Comment 78	10 CFR Part 20 requirements need to be considered for postclosure.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 79	Waste Package: Adequacy of waste package corrosion tests for the repository.		Complete the reviews and revisions of Study Plan 8.3.4.2.4.1 "Characterization of Chemical and Mineralogical Changes in the Post Emplacement Environment" and submit to the NRC. The Lawrence Livermore National Laboratory report, "Metal Barrier Selection and Testing," LLNL SIP CM-01, Rev. 2 was submitted to the NRC on 1/31/95. Submit a supplemental response to the NRC.
Comment 80	Performance goals consistent with interpretation and intent of substantially complete containment.	Closed 3/7/95	NRC Evaluation of supplemental response. NRC considers this item closed.
Comment 81	Waste Package: Adequacy of program in stress corrosion cracking behavior of waste packages.		The metals barriers scientific investigation plan was submitted to the NRC on 1/31/95. Evaluation of the extended dry concept with drift emplacement needs to be completed which may make this concern moot. The metals barrier scientific investigation must be initiated and preliminary results released. Submit a supplemental response to the NRC.

Item ID	Item Description	Status	Action Description
Comment 82	Waste Package: There is an inadequate discussion on how the waste package performance may be verified at the time of license application.		Prepare Study Plan 8.3.4.2.4.4 "Engineered Barrier System Field Test" and submit to the NRC. Submit a supplemental response to the NRC.
Comment 83	The term "uniform corrosion" is misleading.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 84	Issue resolution strategy and testing package for the waste package and Engineering Barrier System do not take into account the full range of likely natural conditions that might affect performance of the barrier.		Consider the effect of unanticipated processes and events on the overall system in the ongoing issue resolution process. Submit a supplemental response to the NRC.
Comment 85	Performance Assessment: Temporal changes in the state of stress due to corrosion of the container is not accounted for.		The metals barriers scientific investigation plan to be completed. Evaluation of the extended dry concept with drift emplacement needs to be completed which may make this concern moot. The metals barrier scientific investigation must be initiated and preliminary results released. Submit a supplemental response to the NRC.
Comment 86	Waste Package: Degradation modes of copper-based alloys do not appear to agree with scientific literature.		Complete the degradation modes surveys for candidate materials and test plans for promising materials. Submit a supplemental response to the NRC.

Item ID	Item Description	Status	Action Description
Comment 87	Waste Package: Adequacy of effects of dissimilar metal contacts causing corrosion.		Advance the waste package design which will narrow the waste package option down to three designs.Describe the use of data from galvanic testing in the waste package design plan. Submit a supplemental response to the NRC.
Comment 88	Waste Package: Assumption of reduced uncertainties because of the unsaturated zone.		The Lawrence Livermore National Laboratory scientific investigation SIP-CM-01 (Rev. 1), "Metal Barrier Selection and Testing" was submitted to the NRC on 1/31/95.
Comment 89	Waste Package: Construction materials may change the local pH and affect the corrosion of the metal containers and the leach rates of radionuclides from the glass.		Prepare Study Plan 8.3.4.2.4.5 "Manmade Materials" and submit to the NRC. Submit a supplemental response to the NRC.
Comment 90	Waste Package: Consideration of varying oxygen concentrations on the corrosion of metal containers.		Provide details on how the effects of oxygen on the waste package will be considered. These details will be described in the metal barriers investigation plan. Complete evaluation of the drift emplacement alternative. This alternative would make this concern moot. Submit a supplemental response to the NRC.
Comment 91	Waste Package/Performance Assessment: Consideration of alternative canisters for C-14 releases.		Evaluate and describe performance of alternative waste package designs to be considered in Advanced Conceptual Design. Review the new Environmental Protection Agency standards when they become available. Alternative waste package scenarios need to be developed. A robust design may make this concern moot. Submit a supplemental response to the NRC.

Item ID	Item Description	Status	Action Description
Comment 92	Disturbed Zone: Boundary definition does not include properties affected by heat generated by waste emplacement.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers the comment closed.
Comment 93	Performance Assessment: Will the site meet the performance objective for prewaste emplacement.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 94	Performance Assessment: Assumption about features, events, processes related to the hydraulic systems in the modeling strategy.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 95	Performance Assessment: Logic used to develop and screen scenarios and its implementation appear to be deficient.		Supplemental Response submitted to the NRC on 5/27/93. Awaiting NRC concurrence.
Comment 96	Adequacy of the use of Kd for modeling heterogeneous medium.		Study Plans 8.3.1.3.4.1 "Sorption Study" and 8.3.1.3.4.3 "Development of Sorption Models" were submitted to the NRC on 8/26/94; Study Plan 8.3.1.3.5.1 "Dissolved Species Concentration Limit" was submitted to the NRC on 9/17/93. Submit a supplemental response to the NRC.
Comment 97	Adequacy of evidence to eliminate iodine as an important radionuclide.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.

Item ID	Item Description	Status	Action Description
Comment 98	Performance Assessment: Appropriateness of weighting Complementary Cumulative Distribution Functions by expert judgment.		Continue the development of the alternative conceptual models. Address the Complementary Cumulative Distribution Functions through the iterative TSPA process. Prepare and provide the NRC with documentation on the TSPA and sensitivity studies (related to schedule in Comment 9). Submit a supplemental response to the NRC.
Comment 99	Performance Assessment: Quantification of all releases.		DOE/NRC Technical Exchange on Scenarios and Complementary Cumulative Distribution Functions.
Comment 100	Performance Assessment: Adequacy of considerations of faulting release scenarios.	Closed 2/8/93	NRC evaluation of DOE responses. The NRC considers this comment closed.
Comment 101	Performance Assessment: Appropriateness of equation used to estimate the partial performance for the 4th scenario class involving release along the water pathway.		Supplemental response submitted to the NRC on 10/11/94. Awaiting NRC concurrence.
Comment 102	Performance Assessment: Adequacy of Ross sequences in comparison to the hydrologic flow model.		Submit a supplemental response to the NRC.
Comment 103	Performance Assessment: Ross sequences address anticipated conditions and not scenarios.		Submit a supplemental response to the NRC.

Item ID	Item Description	Status	Action Description
Comment 104	Performance Assessment: Ross sequences address spent fuel but not vitrified waste form.	Closed 2/8/93	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 105	Performance Assessment: Rationale for elimination of scenarios.		Supplemental response submitted to the NRC on 5/27/93. Awaiting NRC concurrence.
Comment 106	Performance Assessment: Missing coupling term for calculation of liquid phase radionuclide transport.	Closed 2/8/93	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 107	Performance Assessment: Awaiting time in calculation is OK but care needs to be taken in the empirical Complementary Cumulative Distribution Functions in approximating.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 108	Performance Assessment: Use of the Estimated Partial Performance Measures to screen scenarios and establish goals.	Closed 2/8/93	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 109	Performance Assessment: Adequacy of treatment of coupling time between matrix and fracture flow in hypothesis testing tables.		Continue Total System Performance Analysis activity which will continue to analyze the coupling times for the transfer of radionuclides between matrix and fracture flow. Submit a supplemental response to the NRC.
Comment 110	Performance Assessment: Adequacy of dealing with human intrusion in the Complementary Cumulative Distribution Function.	Closed 2/8/93	NRC evaluation of DOE responses. NRC considers this comment closed.

Item ID	Item Description	Status	Action Description
Comment 111	Inconsistencies exist in the Site Characterization Plan on Total System Performance.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 112	Adequate discussion of state variables as constants or as random variables.	Closed 2/8/93	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 113	Consistency of definition of Complementary Cumulative Distribution Function and the unit step function.	Closed 2/8/93	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 114	The term "independent" is used instead of "mutually exclusive."	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 115	Adequacy of expanding of Complementary Cumulative Distribution Function in terms of scenario classes.		Submitted a supplemental response to the NRC on 5/27/93. Awaiting NRC concurrence.
Comment 116	Individual exposures via potable water may need to be expanded.		Issuance by the Environmental Protection Agency of a new standard (40 CFR 191) for individual exposure standards per the Energy Policy Act of 1992. Revise issue resolution strategy for Site Characterization Plan Issue 1.2. Prepare additional response to NRC. Submit revised issue resolution strategy and response to NRC.

Item ID	Item Description	Status	Action Description
Comment 117	Individual exposure rate of C-14 may need to consider advective and diffusive flow rates.		Submit a supplemental response to the NRC.
Comment 118	The monitoring and testing activities should include long-term in situ and long-term waste package activities.		Determine testing requirements after site characteristics have advanced far enough to define the performance program. Submit a supplemental response to the NRC.
Comment 119	Performance Confirmation: The information presented is insufficient to determine if the confirmation program meets the requirements of 10 CFR 60.		Conduct NRC/DOE interaction on the performance confirmation program. Prepare Study Plan 8.3.3.2.2.3 "In Situ Testing of Seal Components" and then submit to the NRC for acceptance. Prepare Study Plan 8.3.1.15.1.6 "In Situ Thermo-mechanical Properties" and submit to the NRC. Prepare Study Plan 8.3.4.2.4.4 "Engineered Barrier Field Tests" and submit to the NRC. Submit a supplemental response to the NRC.
Comment 120	Model and computer code validation studies.		Prepare and provide to the NRC the model and computer code validation strategy. Submit a supplemental response to the NRC.
Comment 121	Exploratory Shaft Facility: Adequacy of seismic design of Exploratory Shaft Facility.		Exploratory Studies Facility Design Requirements submitted on 9/9/94.
Comment 122	Demonstration and acceptability of the dry coring method.		Supplemental response submitted to the NRC on 3/30/94. Awaiting NRC concurrence.
Comment 123	Assessment of effects of ventilation on the Exploratory Shaft Facility.	Closed 6/21/94	NRC evaluation of DOE responses. NRC considers this comment closed.

Item ID	Item Description	Status	Action Description
Comment 124	Potential causes for a reduction in the drainage capacity.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 125	Existing data used in the licensing process needs to be qualified.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 126	Items covered by 10 CFR Part 60 (G) are incomplete.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 127	Design Acceptability Analysis.	Closed 11/2/92	NRC letter lifting Objection 1. NRC considers this comment closed.
Comment 128	Requirements applicable to the Exploratory Shaft Facility.	Closed 11/2/92	NRC letter lifting Objection 1. NRC considers this comment closed.
Comment 129	Design Acceptability Analysis and the Exploratory Studies Facility Design Requirements do not consider 10 CFR 60 requirements.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 130	Only 22 of fifty-two (52) requirements applicable to the Exploratory Shaft Facility were focused on in the Title I design. The rigor and completeness of the Design Acceptability Analysis are questioned.		Prepare a supplemental response after the ESFDR document is issued. The response will identify where in the ESFDR document the 29 requirements are addressed and discuss how the 30th requirement is addressed by the SCP.
Comment 131	Design Acceptability Analysis.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 132	Design Acceptability Analysis.	Closed 11/2/92	NRC letter lifting Objection 1. NRC considers this comment closed.

Item ID	Item Description	Status	Action Description
Comment 133	Design Acceptability Analysis.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Question 1	Integration of mapping efforts.	Closed 12/30/93	NRC evaluation of DOE responses. NRC considers this question closed.
Question 2	Performance Assessment: Relation between mechanical and hydraulic apertures.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question 3	Repository Design: Rationale used for selecting the total repository area is not presented.		Supplemental response submitted to the NRC on 5/17/94. Awaiting NRC concurrence.
Question 4	Adequacy of temperature logging to evaluate anomalously low heat flow.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question 5	Adequacy of vertical boreholes for evaluation of faults and fractures.		Submitted supplemental response to the NRC on 6/16/94. Awaiting NRC concurrence.
Question 6	Meaning of statement in last paragraph page 8.3.1-75.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question 7	Face mapping of exploratory drifts restricted to areas of anomolous conditions.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question 8	Rock Properties: Level of detail and uncertainty in 3D model.		Submitted Study Plan 8.3.1.4.3.1 "Systematic Acquisition of Site-Specific Subsurface Information" to the NRC for review on 1/19/93. Submit Study Plan 8.3.1.4.3.2 "Three-Dimensional Rock Characteristics Models" to the NRC for review. Submit a supplemental response to the NRC.

Status of Site Characterization Analysis Open Items (Page 21 of 27)

Item ID	Item Description	Status	Action Description
Question 9	Systematic Drilling Program: Adequacy of sampling same sequences for rock properties.		Submitted Study Plan 8.3.1.4.3.1 "Systematic Acquisition of Site-Specific Subsurface Information" to the NRC for review on 1/19/93. Submit a supplemental response to the NRC.
Question 10	How will 3D block model account for variability in the block?	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question 11	Rationale to start drilling prior to approval of study plans.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question 12	Rationale for exclusion of lunar crater basaltic field as natural analog.		Submitted supplemental response to the NRC on 6/9/93. Awaiting NRC concurrence.
Question 13	Basis for statements made about the migration, structural boundaries, and stage of volcanism.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question 14	Natural Resources: Adequacy of evaluation of previous mining and drilling leases.	Closed 2/18/94	NRC evaluation of DOE responses. NRC considers this question closed.
Question 15	Resource exploration and mineral resource potential.	Closed 2/18/94	NRC evaluation of DOE responses. NRC considers this question closed.
Question 16	Methods for determining the impact of ground motion from underground nuclear explosions.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question 17	Rock Properties: Activities to investigate effects on	Closed 4/21/93	NRC evaluation of DOE responses. NRC considers this question closed.
Question 18	Allowable movements on joints related to rock mass strength.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.

Item ID	Item Description	Status	Action Description
Question 19	Side Looking Airborne Radar (SLAR).	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question 20	Repository Design: Discussion of vertical or horizontal emplacement.		Supplemental response submitted to the NRC on 6/16/94. Awaiting NRC concurrence.
Question 21	Process to assure the parameters for performance goal C2 (radiation shielding of rock) is comprehensive enough and expected values realistic.		Further develop the advanced conceptual design. Submit a supplemental response to the NRC.
Question 22	Parameters related to repository construction and operation.		Supplemental response submitted to the NRC on 3/30/94. Awaiting NRC concurrence.
Question 23	Computer code verification and validation.		Submit a supplemental response to the NRC.
Question 24	Justification that the shaft liner does not provide structural support for the formation.	Closed 7/31/94	NRC evaluation of DOE responses. NRC considers this question closed.
Question 25	Heterogeneous air flow characteristics for seal program.		Supplemental response submitted to the NRC on 4/13/93. Awaiting NRC concurrence.
Question 26	Inconsistency between tentative Design Goals and Design Performance Goals.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question 27	Storage capacity at base of shaft for attaining the tentative design goals.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.

Status of Site Characterization Analysis Open Items (Page 23 of 27)

Item ID	Item Description	Status	Action Description
Question 28	ES-1 penetration of the Calico Hills Unit: Impacts of the current sealing program and issue resolution strategy 4.4.		Prepare seal design concepts (Sandia National Laboratories). Conduct performance assessment of seal program. Submit a supplemental response to the NRC.
Question 29	Justification that references sited present results representative of conditions at Yucca Mountain.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question 30	Waste Package: Water quality as related to waste package design.		The metal barriers scientific investigation plan was submitted to the NRC on 1/31/95. Complete evaluation of the drift emplacement alternative needs. Submit a supplemental response to the NRC.
Question 31	Waste Package: Integrity of spent fuel cladding.		Supplemental response submitted to the NRC on 9/16/92. Awaiting NRC concurrence.
Question 32	Waste package: Container "similarity" for borosilicate glass waste vs. spent fuel.		Advance the waste package design and narrow the waste package options down to three designs. Submit a supplemental response to the NRC.
Question 33	Waste Package: Emplacement hole drainage concerns.		Evaluate water-vapor interface, crevice corrosion, and galvanic corrosion testing in the metal barriers scientific investigation plan during Advanced Conceptual Design. Complete evaluation of the drift emplacement alternative. This alternative would make this concern moot. Submit a supplemental response to the NRC.
Question 34	Waste Package/ Performance Assessment: Meaning of undetected defective closures.		Submit a supplemental response to the NRC.

Item ID	Item Description	Status	Action Description
Question 35	Waste Package: Acceptance criteria for helium leak results.	Closed 11/8/94	NRC Staff evaluation of Supplemental response. NRC considers this item closed.
Question 36	Waste Package: Contact of canisters with corrosive elements during shipping and handling.		Advance the waste package design and narrow options down to three designs. Submit a supplemental response which will further address the issue of eliminating corrosion elements during manufacture of the container to the NRC.
Question 37	Waste package: Basis for 10-cm of free fall for canister and contents.	Closed 3/7/95	NRC evaluation of DOE responses. NRC considers this question closed.
Question 38	What is the basis for the 1-mm thinning criterion for waste package scratching.		Submitted a supplemental response to the NRC on 7/12/93. Awaiting NRC concurrence.
Question 39	Waste Package: Defining "unusual process history" of canister.		Advance the design of the waste package. Submit a supplemental response to the NRC.
Question 40	Waste Package: Basis for factor of 2 on borehole liner in comparison to container material.		Study effects of water containing liner corrosion products on degradation of the container in accordance with the metal barriers scientific investigation plan. Submit a supplemental response to the NRC.
Question 41	Repository: Consideration of 10 CFR 60.132 (a) in resolution of Issue 2.4.		Conduct engineering studies to evaluate the waste throughput requirements. Submit a supplemental response to the NRC.
Question 42	Repository: Assumption of stability of vertical emplacement hole.		Advance the Advanced Conceptual Design. Drift emplacement may make this comment moot. Submit a supplemental response to the NRC.

Status of Site Characterization Analysis Open Items (Page 25 of 27)

Item ID	Item Description	Status	Action Description
Question 43	Waste Package: Anticipated operational occurrences considered part of normal conditions on the preclosure design and analysis.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question 44	Waste Package/Performance Assessment: Basis for assumed numbers of breached assemblies or canisters.		Provide information on failures of waste forms in multiple locations. Prepare and provide the NRC with documentation on the Total System Performance Assessment. Advance the Advanced Conceptual Design and narrow options to two candidate designs. Submit a supplemental response to the NRC.
Question 45	Waste Package: Investigation of particulate source terms, retention factors, and plate-out of waste package during accident conditions.		NRC requested preliminary MGDS/ESF postclosure safety analysis for review. Supplemental response submitted to the NRC on 7/1/94. Awaiting NRC concurrence.
Question 46	Waste Package: Basis for stricter containment of long half-life isotopes.	Closed 7/11/94	NRC evaluation of DOE response. NRC considers this question closed
Question 47	Waste Package: Assumption on breached waste containers.	Closed 3/7/95	NRC Evaluation of DOE Response. NRC Considers this question closed.
Question 48	Waste Package: Selection of peer review panel on waste package.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question 49	Waste Package: Effects of low temperature oxidation on containers.		Advance the design of the waste package to three options. The metal barriers scientific investigation plan was submitted to the NRC on 1/31/95. Submit a supplemental response to the NRC.

Item ID	Item Description	Status	Action Description
Question 50	Waste Package: Assumption that stress propagation results in corrosion.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question 51	Design second research criteria for accepting waste from Idaho National Engineering Laboratory and Hanford.	Closed 11/8/94	NRC evaluation of DOE responses. NRC considers this question closed.
Question 52	Waste Package: Leaching properties specification will require the producer to control leaching characteristics of the glass waste.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question 53	Waste Package: Specification of cooling rate of the glass waste.	Closed 3/7/95	NRC Evaluation of DOE Response. NRC considers this question closed.
Question 54	Waste Package: Release rates of radionuclides from spent fuels.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question 55	Exploratory Shaft Facility: Interference at the Exploratory Shaft Facility by waste storage tanks, septic field, and waste water lagoon.		Submit a supplemental response to the NRC.
Question 56	Basis for 5 cm of fault displacement in waste package environment.		Supplemental response submitted to the NRC on 5/17/94. Awaiting NRC concurrence.
Question 57	Effects of drilling multipurpose boreholes.		Supplemental response submitted to the NRC on 3/24/93. Awaiting NRC concurrence.
Question 58	Flexibility of the Exploratory Shaft Facility design to accommodate in situ testing of the waste package, if required.		Supplemental response submitted to the NRC on 3/24/93. Awaiting NRC concurrence.

Item ID	Item Description	Status	Action Description
Question 59	Basis for length of in situ thermal tests.		Prepare Study Plan 8.3.1.15.1.6 "In Situ Thermomechanical Properties" and submit to NRC. Submit a supplemental response to the NRC.
Question 60	Exploratory Shaft Facility: Timing of Exploratory Shaft Facility radial borehole test.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question 61	Exploratory Shaft Facility: Accommodation of design changes during Exploratory Shaft Facility construction.	Closed 11/2/92	NRC letter lifting Objection 1. NRC considers this question closed.
Question 62	Repository: Basis for 500 feet of separation from Exploratory Shaft Facility and waste emplacement panel.		Submit a supplemental response to the NRC.
Question 63	Certifying Training Attendance Record reviewers were not principal investigators.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.

APPENDIX F

Change Control Board Actions

Change Control Board Actions

Requirements and Reports Changes

Title	Change Description	Status
Repository Surface Design Report	Changes report delivery from 9/29/94 to 10/31/95	Closed
ESF Design Requirements Document (YMP/CM-0019) Rev. 1, ICN 1	Incorporates design requirements for the integrated data and control system	Closed
Waste Package Conceptual Design Report	Revises report delivery from 12/23/94 to 3/31/95	Closed
Site Design & Test Requirements Document	Revises titles and objectives in five sections	Open
Technical Baseline	Streamlines Project Technical Baseline including deletion of four obsolete requirements documents.	Open
Site Characterization Program Baseline	Restructures Site Characterization Program Baseline including the removal of test objectives duplicated in Site Design & Test Requirements Document and updates of design summary.	Open

Change Control Board Actions

Surface-Based Testing Changes (Page 1 of 2)

Title	Change Description	Status
Geophysical Surveys	Adds Job Package JP94-12 into the Change Control Board Register for drilling deep seismic shot holes.	Closed
Exile Hill Booster Pump	Adds Job Package JP94-24 to Change Control Board Register	Closed
Borehole USW NRG-7/7a	Adds Job Package JP94-03 to Change Control Board Register	Closed
Borehole USW NRG-6	Adds Job Package JP94-19 to Change Control Board Register	Closed
Work Breakdown Structure Element 1.2.5.7	Opens new Work Breakdown Structure element for site activities evaluation and review	Closed
Rock Valley Trenches and Test Pits	Add Job Package JP94-10 to Change Control Board Register	Closed
Studies 8.3.1.5.6 & 8.3.1.15.1.5	Revise testing objectives in studies for future regional climates and environments, and excavation investigations, respectively. Makes editorial changes to Section 8.4 that respond to NRC comments. Incorporate six revised ESF/Repository Interface Drawings as described in Change Request 94/035M2.	Closed
Borehole UE-25 UZ-16	Adds Job Package JP95-13 for initial instrumentation for borehole UE-25 UZ#16	Closed
Crater Flat Tectonics	Adds Job Package JP95-16 to the Change Control Board Register	Open
Borehole USW SD-12	Adds Job Package JP94-04 to the Change Control Board Register	Open

Change Control Board Actions

Surface-Based Testing Changes (Page 2 of 2)

Title	Change Description	Status
Work Breakdown Structure Elements 1.2.3.5.3.1 & 1.3.5.3.5	Funds new USW UZ-7a borehole, reduces work scope of current USW UZ-7 borehole, and funds work on USW UZ-4 and USW UZ-5	Open
Borehole USW UZ-5	Adds Job Package JP95-11 to Change Control Board Register	Open
Borehole USW UZ-7a	Adds Job Package JP95-15 to Change Control Board Register	Open

Change Control Board Actions

Exploratory Studies Facility Changes (Page 1 of 2)

Title	Change Description	Status
ESF North Ramp Station	Adds new Job Package JP94-16 to Change Control Board Register for station 0+60 to 28+15.5	Closed
ESF Electrical Duct Bank Drawings	Revises 10 1B drawings to remove TBVs and incorporated Field Change Requests	Closed
ESF Muck Storage Area	Adds Job Package JP95-3 to the Change Control Board Register	Closed
ESF Package 1A Specifications	Revises Specifications YMP-025-1-SP09 and YMP-025-1-SP10	Open
Medium Voltage Switchgear Specification	Revises specification to incorporate five Field Change Requests and remove one TBV	Closed
ESF Surface Drawing	Revises Drawing Index to remove TBV and include information from another drawing	Closed
Surface Muck Handling System	Adds Job Package JP95-09 to the Change Control Board Register	Closed
ESF Package 1A	Revises four electrical duckbank drawings	Open
ESF Package 1B Electrical Drawings	Revise 33 electrical drawings to remove TBVs and incorporate Field Change Requests	Open
M&O Electrical Specifications	Revises 14 M&O electrical specifications to incorporate Field Change Requests and remove TBVs	Open
ESF Package 1A Electrical System	Deletes 20 electrical drawings regarding obsolete electrical system	Open
ESF Package 1A Water Supply & Distribution System	Revises the Table of Contents to make eight sections of YMP-025-1-SP07 specifications obsolete and incorporates two Field Change Requests	Open

Change Control Board Actions

Exploratory Studies Facility Changes (Page 2 of 2)

Title	Change Description	Status
ESF Division Specification	Revises specifications for temporary surface construction facilities and material/handling equipment, sections -1500 and -1600, respectively.	Open
ESF Package 1A Drawings	Revises 28 drawings to show reference to approved baselined drawings.	Open
ESF Package 1B drawings	Revises nine drawings to remove TBVs and incorporate new scope of work from baselined Package 1D.	Open
ESF Specifications	Revises six civil specifications, including removal of TBVs, incorporation of Field Change Requests, and removal of Q-control in two sections of specification.	Open
ESF Package 1A Topsoil & Rock Storage Area	Revises YMP-025-1-SP04 specifications.	Open
ESF Specifications	Revises 10 subsurface electrical specifications.	Open
ESF Conveyor Foundation	Increases cost estimate for segment of conveyor foundation package by $180K, from $264K to $440K.	Open
ESF Cost Estimate for Surface Preparation Design Package 1D	Reduces ESF Cost Baseline Estimate presented in Chapter 14 of the ESF Technical Baseline by $1.9 million, from $6,245,049 Title I estimate to $4,333,100 Title II estimate. This includes muck storage area, standby power, and tunnel ventilation power.	Open
ESF Packages 1A, 1B and 2A	Transfers ESF design packages from Level 2 Change Control Board control to Level 3 Change Control Board control.	Open

APPENDIX G

Study Plan Status

Study Plan Status (Page 1 of 11)

Study Plan Number	Study Plan Title	Submitted to YMSCO[a]	Approved by YMSCO[b]	Reviewed by NRC[c]	Reviewed by NV[d]
8.3.1.2.1.1	Characterization of the Meteorology for Regional Hydrology	6/26/90	3/13/91	10/21/91	12/10/91
8.3.1.2.1.2	Characterization of Runoff and Streamflow	3/27/89	8/21/90	5/14/91	4/12/91
8.3.1.2.1.3	Characterization of the Regional Ground-Water Flow System	3/1/90	1/18/91	10/4/91	3/19/93
8.3.1.2.1.4	Regional Hydrologic System Synthesis and Modeling	6/6/90	12/18/91	5/6/92	1/29/93
8.3.1.2.2.1	Characterization of Unsaturated-Zone Infiltration	3/9/90	1/18/91	5/31/91	
8.3.1.2.2.2, R0	Water Movement Test	9/23/87	11/9/89	4/8/93	
8.3.1.2.2.2, R1	Water Movement Test	10/17/91	2/10/93	4/8/93	
8.3.1.2.2.3	Characterization of Percolation in the Unsaturated Zone–Surface-Based Study	8/12/88	4/8/91	3/26/92	
8.3.1.2.2.4	Characterization of the Yucca Mountain Unsaturated Zone in the Exploratory Studies Facility (.4, .5, .7, .8, .9)	9/9/87	1/9/89	3/5/93	
8.3.1.2.2.4, R1	Characterization of the Yucca Mountain Unsaturated Zone in the Exploratory Studies Facility (.4, .5, .7, .8)	12/4/92	1/14/93	3/5/93	
8.3.1.2.2.4, R2	Characterization of the Yucca Mountain Unsaturated Zone in the Exploratory Studies Facility (.10)	3/16/93	6/2/94	9/15/94	
8.3.1.2.2.4, R3	Characterization of the Yucca Mountain Unsaturated Zone in the Exploratory Studies Facility (.1, .2)	4/29/94			

Study Plan Number	Study Plan Title	Submitted to YMSCO[a]	Approved by YMSCO[b]	Reviewed by NRC[c]	Reviewed by NV[d]
8.3.1.2.2.5	Diffusion Tests in the Exploratory Studies Facility	11/1/88	4/22/92	1/19/93	11/1/93
8.3.1.2.2.6	Characterization of Gaseous-Phase Movement in the Unsaturated Zone	6/12/89	6/11/91	10/7/91	5/1/92
8.3.1.2.2.6, R1	Characterization of Gaseous-Phase Movement in the Unsaturated Zone	4/6/93	9/30/93		
8.3.1.2.2.7	Hydrochemical Characterization of the Unsaturated Zone	10/24/88	9/18/90	5/1/92	12/28/92
8.3.1.2.2.7, R1	Hydrochemical Characterization of the Unsaturated Zone	12/1/92	9/9/93	1/26/94	
8.3.1.2.2.8	Fluid Flow in Unsaturated, Fractured Rock	9/7/90	8/12/92	1/28/93	
8.3.1.2.2.8, R1	Fluid Flow in Unsaturated, Fractured Rock	12/1/92	12/17/93	8/23/94	
8.3.1.2.2.9	Site Unsaturated-Zone Modeling and Synthesis	1/25/91	7/1/93	11/8/93	
8.3.1.2.3.1.1-6	Characterization of the Site Saturated-Zone Ground-Water Flow System	5/31/89	2/13/91	12/6/91	
8.3.1.2.3.1.7	Characterization of the Site Saturated-Zone Ground-Water Flow System	2/8/88	2/22/90	12/6/91	
8.3.1.2.3.2	Characterization of the Saturated-Zone Hydrochemistry	3/28/90	4/22/92	1/4/93	
8.3.1.2.3.3	Saturated-Zone Hydrologic System Synthesis and Modeling	9/4/90	1/14/93	6/16/93	
8.3.1.3.1.1	Ground-Water Chemistry Model	3/15/91	5/4/94		

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Study Plan Number	Study Plan Title	Submitted to YMSCO[a]	Approved by YMSCO[b]	Reviewed by NRC[c]	Reviewed by NV[d]
8.3.1.3.2.1	Mineralogy, Petrology, and Chemistry of Transport Pathway	1/22/88	6/13/89	8/20/90	12/28/92
8.3.1.3.2.2	History of Mineralogical and Geochemical Alteration of Yucca Mountain	3/28/88	12/18/91	4/27/92	1/24/94
8.3.1.3.3.1	Natural Analog of Hydrothermal Systems in Tuff	No Study Plan to be Developed			
8.3.1.3.3.2	Kinetics and Thermodynamics of Mineral Evolution	3/25/94			
8.3.1.3.3.3	Conceptual Model of Mineral Evolution				
8.3.1.3.4.1	Batch Sorption Studies	10/28/92	8/4/94		
8.3.1.3.4.2	Biological Sorption and Transport	12/12/88	11/25/92	3/25/93	
8.3.1.3.4.3	Development of Sorption Models	10/28/92	8/4/94		
8.3.1.3.5.1/2	Dissolved Species Concentration Limits and Colloid Behavior	9/7/90	9/9/93		
8.3.1.3.6.1	Dynamic Transport Column Experiments	3/10/93			
8.3.1.3.6.2	Diffusion	7/24/89	8/6/93	1/19/94	
8.3.1.3.7.1	Retardation Sensitivity Analysis	12/14/88	8/11/92	1/19/93	
8.3.1.3.7.2	Demonstration of Applicability of Laboratory Data to Repository Transport Calculations	Out Year – Under Development			
8.3.1.3.8.1	Gaseous Radionuclide Transport Calculations and Measurements	No Study Plan to be Developed			

Study Plan Number	Study Plan Title	Submitted to YMSCO[a]	Approved by YMSCO[b]	Reviewed by NRC[c]	Reviewed by NV[d]
8.3.1.4.2.1	Characterization of the Vertical and Lateral Distribution of Stratigraphic Units Within the Site Area	4/12/90	6/9/92	12/14/92	
8.3.1.4.2.2	Characterization of the Structural Features Within the Site Area	9/4/87	2/3/89	2/8/93	
8.3.1.4.2.2, R1	Characterization of the Structural Features Within the Site Area (.3, .5)	2/27/90	4/22/92	2/8/93	
8.3.1.4.2.2, R2	Characterization of the Structural Features Within the Site Area (.3, .5)	11/18/92	12/22/92	2/8/93	2/11/94
8.3.1.4.2.3	Three-Dimensional Geologic Model	2/13/95			
8.3.1.4.3.1	Systematic Acquisition of Site-Specific Subsurface Information	3/27/90	12/8/92	7/19/93	
8.3.1.4.3.2	Three-Dimensional Rock Characteristics Models	5/4/94			
8.3.1.5.1.1	Characterization of Modern Regional Climate	6/24/93	7/25/94		
8.3.1.5.1.2	Paleoclimate Study: Lake, Playa, and Marsh Deposits	10/25/90	10/31/91	4/27/92	1/24/94
8.3.1.5.1.3	Climatic Implications of Terrestrial Paleoecology	2/11/91	1/17/92	8/27/92	1/24/94
8.3.1.5.1.4	Analysis of the Paleoenvironmental History of the Yucca Mountain Region	3/30/90	5/29/91	12/06/91	1/11/93
8.3.1.5.1.5	Paleoclimate-Paleoenvironmental Synthesis	2/2/95			
8.3.1.5.1.6	Characterization of the Future Regional Climate and Environments	12/29/93	6/15/94	10/18/94	

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Study Plan Number	Study Plan Title	Submitted to YMSCO[a]	Approved by YMSCO[b]	Reviewed by NRC[c]	Reviewed by NV[d]
8.3.1.5.2.1	Characterization of the Quaternary Regional Hydrology (.3, .4, .5)	1/26/88	6/8/89	11/24/89	4/9/91
8.3.1.5.2.1, R2	Characterization of the Quaternary Regional Hydrology (.1)	9/25/90	11/10/92	6/24/93	11/1/93
8.3.1.5.2.2	Characterization of Future Regional Hydrology Due to Climate Changes	1/16/91	11/10/92	4/5/93	11/1/93
8.3.1.6.1.1	Distribution and Characteristics of Present and Past Erosion	No Study Plans to be Developed			
8.3.1.6.2.1	Influence of Future Climatic Conditions on Locations and Rates of Erosion				
8.3.1.6.3.1	Evaluation of the Effects of Future Tectonic Activity on Erosion at Yucca Mountain				
8.3.1.6.4.1	Development of a Topical Report on the Effects of Erosion				
8.3.1.8.1.1	Probability of Magmatic Disruption of the Repository	3/29/89	9/19/90	10/5/91	8/8/91
8.3.1.8.1.2	Physical Processes of Magmatism and Effects on the Repository	10/21/92	9/21/93	9/14/94	

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Study Plan Number	Study Plan Title	Submitted to YMSCO[a]	Approved by YMSCO[b]	Reviewed by NRC[c]	Reviewed by NV[d]
8.3.1.8.2.1	Analysis of Waste Package Rupture Due to Tectonic Processes and Events	12/15/89	11/16/92	11/19/93	
8.3.1.8.2.1, R1	Tectonic Effects: Evaluations of Changes in the Natural and Engineered Barrier Systems Resulting from Tectonic Processes and Events	2/18/94			
8.3.1.8.3.1	Analysis of the Effects of Tectonic Processes and Events on Average Percolation Flux Rates Over the Repository	These Studies Have Been Combined Into 8.3.1.8.2.1 R1			
8.3.1.8.3.2	Analysis of the Effects of Tectonic Processes and Events on Changes in Water-Table Elevation				
8.3.1.8.3.3	Analysis of the Effects of Tectonic Processes and Events on Local Fracture Permeability and Effective Porosity				
8.3.1.8.4.1	Analysis of the Effects of Tectonic Processes and Events on Rock Geochemical Properties				
8.3.1.8.5.1	Characterization of Volcanic Features	12/14/88	4/18/90	8/20/90	2/21/91
8.3.1.8.5.2	Characterization of Igneous Intrusive Features	10/13/92	3/7/94	8/22/94	
8.3.1.8.5.3	Investigation of Folds in Miocene and Younger Rocks of the Region	No Study Plans to be Developed			
8.3.1.9.1.1	An Evaluation of Natural Processes that Could Affect the Long-Term Survivability of the Surface Marker System at Yucca Mountain				

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Study Plan Number	Study Plan Title	Submitted to YMSCO[a]	Approved by YMSCO[b]	Reviewed by NRC[c]	Reviewed by NV[d]
8.3.1.9.2.1	Natural Resource Assessment of Yucca Mountain, Nye County, Nevada	7/13/90	11/6/92	3/16/93	2/11/94
8.3.1.9.2.2	Water Resource Assessment of Yucca Mountain, Nevada	10/6/89	8/26/91	5/4/92	12/28/92
8.3.1.9.3.1	Evaluation of Data Needed to Support an Assessment of the Likelihood of Future Inadvertent Human Intrusion at Yucca Mountain as a Result of Exploration and/or Extraction of Natural Resources	No Study Plans to be Developed			
8.3.1.9.3.2	An Evaluation of the Potential Effects of Exploration for, or Extraction of, Natural Resources on the Hydrologic Characteristics at Yucca Mountain				
8.3.1.12.2.1	Meteorological Data Collection at the Yucca Mountain Site	9/28/90	3/20/91	11/12/91	12/2/91
8.3.1.12.2.1, R1	Meteorological Data Collection at the Yucca Mountain Site	3/31/92	8/9/93		
8.3.1.14.2	Studies to Provide Soil/Rock Properties of Potential Locations of Surface/Subsurface Facilities	7/15/91	10/01/91	1/24/92	4/6/92
8.3.1.15.1.1	Laboratory Thermal Properties	3/17/88	10/21/90	8/22/94	
8.3.1.15.1.1, R1	Laboratory Thermal Properties	11/3/92	8/27/93	8/22/94	

Study Plan Number	Study Plan Title	Submitted to YMSCO[a]	Approved by YMSCO[b]	Reviewed by NRC[c]	Reviewed by NV[d]
8.3.1.15.1.2	Laboratory Thermal Expansion Testing	12/1/88	8/21/90	8/22/94	
8.3.1.15.1.2, R1	Laboratory Thermal Expansion Testing	11/3/92	8/27/93	8/22/94	
8.3.1.15.1.3	Laboratory Determination of Mechanical Properties of Intact Rock	2/8/88	5/21/91	Deferred	
8.3.1.15.1.3, R1	Laboratory Determination of Mechanical Properties of Intact Rock	7/19/93			
8.3.1.15.1.4	Laboratory Determination of the Mechanical Properties of Fractures	10/23/91	12/14/94		
8.3.1.15.1.5	Excavation Investigations	3/26/87	1/09/89	8/19/94	
8.3.1.15.1.5, R1	Excavation Investigations	3/18/93	4/22/94	8/19/94	
8.3.1.15.1.6	In Situ Thermomechanical Properties	Out Year – Under Development			
8.3.1.15.1.7	In Situ Mechanical Properties				
8.3.1.15.1.8	In Situ Design Verification	3/20/90	2/3/93	4/15/93	11/1/93
8.3.1.15.2.1	Characterization of the Site Ambient Stress Conditions (.2)	9/22/87	1/11/89	Deferred	
8.3.1.15.2.1, R.1	Characterization of the Site Ambient Stress Conditions (.1)				
8.3.1.15.2.2	Characterization of the Site Ambient Thermal Conditions	10/13/92	6/23/94		
8.3.1.16.1.1	Characterization of Flood Potential of the Yucca Mountain Site	3/30/89	9/17/90	5/8/91	1/22/91

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Study Plan Number	Study Plan Title	Submitted to YMSCO[a]	Approved by YMSCO[b]	Reviewed by NRC[c]	Reviewed by NV[d]
8.3.1.16.2.1	Location of Adequate Water Supply for Construction, Operation, Closure, and Decommissioning of a Mined Geologic Disposal System at Yucca Mountain, Nevada	No Study Plan to be Developed			
8.3.1.16.3.1	Determination of the Preclosure Hydrologic Conditions of the Unsaturated Zone at Yucca Mountain, Nevada	Out Year – Under Development			
8.3.1.17.1.1	Potential for Ash Fall at the Site	No Study Plans to be Developed			
8.3.1.17.2.1	Faulting Potential at the Repository				
8.3.1.17.3.1	Relevant Earthquake Sources	8/1/90	12/18/91	5/18/92	1/13/93
8.3.1.17.3.1, R1	Relevant Earthquake Sources	2/18/94			
8.3.1.17.3.2	Underground Nuclear Explosion Sources	Out Year – Under Development			
8.3.1.17.3.3.1	Ground Motion from Regional Earthquakes	4/21/94			
8.3.1.17.3.3.2	Ground Motion from Underground Nuclear Explosions	2/2/94	9/6/94	12/22/94	
8.3.1.17.3.4	Effects of Local Site Geology on Surface and Subsurface Motions	7/6/90	11/14/91	6/8/92	1/11/93
8.3.1.17.3.5	Ground Motion at the Site from Controlling Seismic Events	10/4/90	7/9/93	11/2/93	
8.3.1.17.3.6	Probabilistic Seismic Hazards Analyses	10/17/94			
8.3.1.17.4.1	Historical and Current Seismicity	10/17/89	9/17/90	5/14/91	11/1/93
8.3.1.17.4.1, R1	Historical and Current Seismicity	11/16/93	11/9/94	2/17/95	

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Study Plan Number	Study Plan Title	Submitted to YMSCO[a]	Approved by YMSCO[b]	Reviewed by NRC[c]	Reviewed by NV[d]
8.3.1.17.4.2	Location and Recency of Faulting Near the Prospective Surface Facilities	12/6/88	5/22/89	11/24/89	5/29/90
8.3.1.17.4.3	Quaternary Faulting Within 100 km of Yucca Mountain, Including the Walker Lane	3/25/92	1/21/93	9/2/93	3/3/94
8.3.1.17.4.4	Quaternary Faulting Proximal to the Site Within Northeast-Trending Fault Zones	8/3/92	3/18/93	9/2/93	
8.3.1.17.4.5	Detachment Faults at or Proximal to Yucca Mountain	5/1/90	7/20/92	2/1/93	1/24/94
8.3.1.17.4.6	Quaternary Faulting Within the Site Area	10/14/88	1/23/91	10/3/91	1/13/93
8.3.1.17.4.7	Subsurface Geometry and Concealed Extensions of Quaternary Faults at Yucca Mountain	No Study Plan to be Developed			
8.3.1.17.4.8	Stress Field Within and Proximal to the Site Area	2/27/95			
8.3.1.17.4.9	Tectonic Geomorphology of the Yucca Mountain Region	No Study Plan to be Developed			
8.3.1.17.4.10	Geodetic Leveling	3/30/90	1/18/91	10/4/91	2/1/93
8.3.1.17.4.11	Characterization of Regional Lateral Crustal Movement	No Study Plan to be Developed			
8.3.1.17.4.12	Tectonic Models and Synthesis	4/30/93	11/18/94	2/6/95	
8.3.1.20.1.1	Characterization of the Altered Zone	1/30/95			
8.3.3.2.2.1	Seal Material Properties Development	Out Year – Under Development			
8.3.3.2.2.3	In Situ Testing of Seal Components	9/16/94			

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Study Plan Number	Study Plan Title	Submitted to YMSCO[a]	Approved by YMSCO[b]	Reviewed by NRC[c]	Reviewed by NV[d]
8.3.4.2.4.1	Characterization of the Chemical and Mineral Changes in the Postemplacement Environment	8/8/94			
8.3.4.2.4.2	Hydrological Properties of Waste Package Environment	12/20/93	2/27/95		
8.3.4.2.4.2, R1	Hydrological Properties of Waste Package Environment	2/28/95			
8.3.4.2.4.3	Characterization of the Geomechanical Attributes for the Waste Package Environment	6/28/89	12/11/92	4/21/93	
8.3.4.2.4.4	Engineered Barrier System Field Tests	7/9/93			
8.3.4.2.4.5	Effects of Man-Made Materials on Water Chemistry	4/28/94			

[a] Submitted to YMSCO and under review.
[b] Completed YMSCO review.
[c] Completed NRC initial review with no objections.
[d] Received comments from State of Nevada.

APPENDIX H

Glossary

GLOSSARY

Accessible environment means the atmosphere, the land surface, surface water, oceans, and the portion of the lithosphere that is outside the controlled area.

Barrier means any material or structure that prevents or substantially delays the movement of water or radionuclides.

Boiling water reactor (BWR) means a nuclear reactor system that uses boiling water in the primary cooling system. Steam from the primary cooling system turns turbines to generate electricity.

Borehole means a hole made with a drill, auger, or other tools for exploring strata in search of minerals, supplying water for blasting, emplacing waste, proving the position of old workings or faults, or releasing accumulations of gas or water. Boreholes include core holes, dry-well-monitoring holes, waste-emplacement boreholes, and test holes for geophysical or ground-water characterization.

Closure means final backfilling of the remaining open operational areas of the underground facility and boreholes after the termination of waste emplacement, culminating in the sealing of shafts.

Confinement as it pertains to radioactivity, means the retention of radioactive material within some specified bounds. Confinement differs from containment in that there is no absolute physical barrier in the former.

Containment means the confinement of radioactive waste within a designated boundary.

Controlled area means a surface location, to be marked by suitable monuments, extending horizontally no more than 10 kilometers in any direction from the outer boundary of the underground facility, and the underlying subsurface, which area has been committed to use as a geologic repository and from which incompatible activities would be prohibited before and after permanent closure.

Degradation means the general lowering of the surface of the land by erosive processes, especially by the removal of material by flowing water.

Disposal means the emplacement in a repository of high-level radioactive waste, spent nuclear fuel, or other highly radioactive material with no foreseeable intent of recovery, whether or not such emplacement permits the recovery of such waste, and the isolation of such waste from the accessible environment.

Drift means a horizontal or nearly horizontal, mined passageway.

Emplacement means the act of placing waste containers in prepared positions. For the proposed repository at Yucca Mountain, two methods are currently being considered: emplacement of a single waste container in a shallow vertical borehole in the floor of the emplacement drift or emplacement of multiple waste containers in long horizontal boreholes in the wall of the drift.

Engineered barrier system means the manmade components of a disposal system designed to prevent the release of radionuclides from the underground facility or into the geohydrologic setting. Such term includes the radioactive-waste form, radioactive-waste canisters, materials placed over and around such canisters, any other components of the waste package, and barriers used to seal penetrations in and into the underground facility.

Environmental impact statement means the document required by Section 102(2)(C) of the National Environmental Policy Act of 1969. Sections 114(a) and 114(f) of the Nuclear Waste Policy Act of 1982 include certain limitations on the National Environmental Policy Act requirements as they apply to the preparation of an environmental impact statement for the development of a repository at a characterized site.

Exploratory studies facility means a facility constructed for the purpose of performing underground studies during site characterization.

Fault means a fracture or a zone of fractures along which there has been displacement of the sides relative to one another parallel to the fracture or zone of fractures.

Flow path means the theoretical line that ground water follows in moving from a recharge area to a discharge area.

Flux means the ratio of the volume of fluid per unit area per unit time. Also known as specific discharge.

Geologic repository means a system, requiring licensing by the NRC, that is intended to be used, or may be used, for the disposal of radioactive waste in excavated geologic media. A geologic repository includes (1) the geologic-repository operations area and (2) the portion of the geologic setting that provides isolation of the radioactive waste and is located within the controlled area.

Ground-water flux means the rate of ground-water flow per unit area of porous or fractured media measured perpendicular to the direction of flow.

Ground-water travel time means the time required for a unit volume of ground water to travel between two locations. The travel time is the length of the flow path divided by the velocity, where velocity is the average ground-water flux passing through the cross-sectional area of the geologic medium through which flow occurs, perpendicular to the flow direction, divided by the effective porosity along the flow path. If discrete segments of the flow path have different hydrologic properties, the total travel time will be the sum of the travel times for each discrete segment.

Guidelines means Part 960 of Title 10 of the Code of Federal Regulations–General Guidelines for the Recommendation of Sites for Nuclear Waste Repositories.

High-level radioactive waste means (1) the highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations; and (2) other highly radioactive material that the Nuclear Regulatory Commission, consistent with existing law, determines by rule requires permanent isolation.

Issue means a question relating to the performance of the mined geologic disposal system that must be resolved to demonstrate compliance with the applicable Federal regulations (including 10 CFR Part 60, 10 CFR Part 960, 40 CFR Part 191, and 10 CFR Part 20). See Section 8.1.1.

Isolation means inhibiting the transport of radioactive material so that the amounts and concentrations of this material entering the accessible environment will be kept within prescribed limits.

License application means an application for a license from the U.S. Nuclear Regulatory Commission to construct a repository.

Mined geologic disposal system (MGDS) means a system, requiring licensing by the U.S. Nuclear Regulatory Commission, that is used for the disposal of high-level radioactive waste in excavated geologic media. It is synonymous with "geologic repository."

Multibarrier system means a system of natural and engineered barriers, operating independently or relatively independently, that acts to contain and isolate the waste.

Multipurpose canister means a sealed, metallic container holding multiple spent nuclear fuel assemblies in a dry, inert environment and overpacked separately and uniquely for the various system elements of storage, transportation, and disposal.

National Environmental Policy Act means the Federal statute that is the national charter for protection of the environment. The Act is implemented by procedures issued by the Council on Environmental Quality. These procedures ensure that environmental information is available to public officials and citizens before Federal decisions are made and before Federal actions are taken. The National Environmental Policy Act of 1969 appears at 42 USC 4321 et seq.

Natural barrier means the physical, mechanical, chemical, and hydrologic characteristics of the geologic environment that individually and collectively act to minimize or preclude radionuclide transport.

Natural system means a host rock suitable for repository construction and waste emplacement and the surrounding rock formations. It includes natural barriers that provide containment and isolation by limiting radionuclide transport through the geohydrologic

environment to the biosphere and provide conditions that will minimize the potential for human interference in the future.

Notice of intent means a notice published in the Federal Register that an environmental impact statement will be prepared and considered by a Federal agency. The notice is required by the National Environmental Policy Act implementing procedures. The notice must describe the proposed action and possible alternatives; describe the agency's proposed scoping process including whether, when, and where any scoping meeting will be held; and state the name of an agency official who can answer questions about the proposed action and the environmental impact statement.

Nuclear Waste Policy Act means the Nuclear Waste Policy Act of 1982, as amended, 42 USC 10101, et seq.

Overpack means a structural component used to hold and protect a multi-purpose canister so that the combination meets the Nuclear Regulatory Commission requirements for its application. There are several types of overpacks: (1) for transportation under 10 CFR Part 71; (2) for transfer under 10 CFR Part 72; (3) for storage under 10 CFR Part 72; and (4) for disposal under 10 CFR Part 60. An overpack is designed for its particular use in conjunction with a multi-purpose canister.

Perched ground water means unconfined ground water separated from an underlying body of ground water by an unsaturated zone. Its water table is a perched water table. Perched ground water is held up by a perching bed whose permeability is so low that water percolating downward through it is not able to bring water in the underlying unsaturated zone above atmospheric pressure.

Performance assessment means any analysis that predicts the behavior of a system or system component under a given set of constant and/or transient conditions. Performance assessments will include estimates of the effects of uncertainties in data and modeling.

Postclosure means the period of time after the closure of the geologic repository.

Preclosure means the period of time before and during the closure of the geologic repository.

Pressurized water reactor (PWR) means a reactor system that uses pressurized water in the primary cooling system. Steam formed in a secondary cooling system is used to turn turbines to generate electricity.

Pre-waste-emplacement means before the authorization of repository construction by the Nuclear Regulatory Commission.

Radioactive waste or "waste" means high-level radioactive waste and other radioactive materials, including spent nuclear fuel, that are received for emplacement in a geologic repository.

Repository construction means all excavation and mining activities associated with the construction of shafts, shaft stations, rooms, and necessary openings in the underground facility, preparatory to radioactive-waste emplacement, as well as the construction of necessary surface facilities, but excluding site-characterization activities.

Saturated zone means that part of the Earth's crust beneath the water table in which all voids, large and small, are ideally filled with water under pressure greater than atmospheric.

Seismic means pertaining to, characteristic of, or produced by earthquakes or earth vibrations.

Site means a potentially acceptable site or a candidate site, as appropriate, until such time as the controlled area has been established, at which time the site and the controlled area are the same.

Site characterization means activities, whether in the laboratory or in the field, undertaken to establish the geologic conditions and the ranges of the parameters of a candidate site relevant to the location of a repository, including borings, surface excavations, excavations of exploratory shafts, limited subsurface lateral excavations and borings, and in situ testing needed to evaluate the suitability of a candidate site for the location of a repository, but not including preliminary borings and geophysical testing needed to assess whether site characterization should be undertaken.

Sorption is a term including both adsorption and absorption, and means the binding, on a microscopic scale, of one substance to another, such as by adsorption or ion exchange. In this document, the word is especially used for the sorption of dissolved radionuclides onto aquifer solids or waste-package materials by means of close-range chemical or physical forces.

Spent nuclear fuel means fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated by reprocessing.

Stakeholders means individuals or organizations who have an important, ongoing interest in the service and service quality of the Office of Civilian Radioactive Waste Management.

Stoichiometry means (1) the application of the laws of definite proportions and of the conservation of matter and energy to chemical activity; (2) the quantitative relationship between constituents in a chemical reaction.

Substantially complete containment means (1) by virtue of the intrinsic properties and design of the waste package components subjected to the range of conditions anticipated in the underground facility, 80 percent or more of the waste packages will retain all their radioactivity for a containment period of 1,000 years after permanent closure of the repository; (2) at any time during the containment period, at least 99 percent of the radioactivity resulting from the original waste emplaced in the underground facility will be retained within the set of waste packages; (3) any releases from the waste packages that occur during the containment period should be gradual such that releases from the engineered

barrier system in any year during this period should not exceed one part in 100,000 of the total inventory of radionuclide activity present in the geologic repository system in that year.

Surface facilities means repository support facilities within the restricted area.

Systems engineering systemically applies science and engineering principles to control a complex total system development effort for the purpose of achieving an optimum balance of all system elements. It is a process that transforms and integrates operational needs and requirements into a description of system requirements to maintain the overall system effectiveness.

Thermal loading means the application of heat to a system, and is usually measured in terms of watt density. The thermal loading for a repository is the watts per acre produced by the radioactive waste in the active disposal area.

Unsaturated zone means the zone between the land surface and the water table. Generally, water in this zone is under less than atmospheric pressure, and some of the voids may contain air or other gases at atmospheric pressure. Beneath flooded areas or in perched water bodies, the water pressure locally may be greater than atmospheric.

Waste package means the waste form and any containers, shielding, packing, and other sorbent materials immediately surrounding an individual waste container.

10 CFR Part 60 means the Nuclear Regulatory Commission regulation, titled "Disposal of High-Level Radioactive Waste in Geologic Repositories," that sets forth technical requirements governing development of a permanent geologic repository for spent nuclear fuel and high-level radioactive waste.

10 CFR Part 960 means the Department of Energy regulation, titled "General Guidelines for the Recommendation of Sites for Nuclear Waste Repositories," that establishes guidelines to compare sites and select a site for recommendation to the President for development of a geologic repository.

APPENDIX I

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Office of Scientific and Technical Information
U.S. Department of Energy
Post Office Box 62
Oak Ridge, TN 37831

National Technical Information Service
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5285 Port Royal Road
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APPENDIX J

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APPENDIX K

Acronyms, Abbreviations, and Symbols

Acronyms, Abbreviations, and Symbols

CRWMS	Civilian Radioactive Waste Management System
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
ESF	Exploratory Studies Facility
FY	fiscal year
LBL	Lawrence Berkeley Laboratory
LLNL	Lawrence Livermore National Laboratory
Los Alamos	Los Alamos National Laboratory
M&O	Civilian Radioactive Waste Management System Management and Operating Contractor
NRC	U.S. Nuclear Regulatory Commission
OCRWM	Office of Civilian Radioactive Waste Management
Project	Yucca Mountain Site Characterization Project
QA	quality assurance
SCP	Site Characterization Plan
SNL	Sandia National Laboratories
USGS	U.S. Geological Survey
YMP	Yucca Mountain Site Characterization Project
YMSCO	Yucca Mountain Site Characterization Office

Scientific/Engineering Terms and Units

BP	before present
darcy	= $10^{-12}m^2$ (permeability)
gpm	gallons per minute
ka	kiloannum (thousand years ago)
Ma	megannum (million years ago)
pH	negative log of hydrogen ion concentration (acidity/alkalinity)
ppb	parts per billion
ppm	parts per million

Acronyms, Abbreviations, and Symbols (Continued)

Borehole Letter Designators

c	Hydrologic test hole
G	Geologic
GA	Geologic angle "exploratory hole"
GU	Geologic unsaturated zone
h	Horizontal drilled hole
H	Hydrologic Research Facility holes
J	Jackass Flats (water wells)
N	Neutron hole
NRG	North Ramp Geologic hole
p	Paleozoic or pre-Tertiary hole
RF	Repository Surface Facility hole
SD	Systematic Drilling hole
SRG	South Ramp Geologic hole
UE	Underground Exploratory
USW	Underground southern (Nevada) waste hole
UZ	Unsaturated zone hole
UZN	Unsaturated zone neutron hole
V	Volcanic hole
VH	Volcanic/hydrologic hole
WT	Water table hole

Thermomechanical Stratigraphic Designators

CHn	Calico Hills nonwelded
PTn	Paintbrush nonwelded
TCw	Tiva Canyon welded
TSw1	Topopah Spring densely welded devitrified lithophysal-rich tuff
TSw2	Topopah Spring densely welded devitrified lithophysal-poor tuff
TSw3	Topopah Spring basal vitrophyre

Trench Designators

BMT	Bare Mountain Trench
CF	Crater Flat
GDF	Ghost Dance fault
MWV	Midway Valley
NRT	North Ramp Trench
SCR	Stagecoach Road
SCF	Solitario Canyon fault

Pavement Designators

ARP-1	Antler Ridge Pavement 1

Acronyms, Abbreviations, and Symbols (Continued)

Metal Designators

ASTM	American Society for Testing and Materials
UNS	Unified Numbering System for Metals and Alloys

Metric Units

°C	degree Celsius
cm^3	cubic centimeters
cm	centimeter (= 10^{-2} m or 2.54 inches)
d	day
g	gram (= 0.3527 ounce)
h	hour
ha	hectare (= 2.48 acres)
Hz	hertz (cycles per second)
J	joule (Newton-meter)
°K	degree Kelvin
kg	kilogram (= 10^3 grams or 2.2046 pounds)
km	kilometer (= 10^3 m or 0.6213 mile)
L	liter (= 0.2641 gallon)
MTU	metric tons of uranium equivalent
MTIHM	metric tons of initial heavy metal
m	meter (= 3.2808 feet)
mg	milligram (= 10^{-3}g)
mgal	milligalileo
mL	milliliter (= 10^{-3} L)
mm	millimeter (= 10^{-3} m)
µm	micrometer (= 10^{-6} m)
nm	nanometer (= 10^{-9} m)
nT	nanotesla
Pa	pascal (also, MPa = megapascal, kPa = kilopascal)
S	siemens
s	second
V	volt
W	watt
kWh	kilowatt-hour
MWh	megawatt-hour
MWd	megawatt-day
GWd	gigawatt-day