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Nuclear Waste Policy Act
(Section 113)

Site Characterization Progress Report: Yucca Mountain, Nevada

October 1, 1996 - March 31, 1997

Number 16

October 1997

U.S. Department of Energy
Office of Civilian Radioactive Waste Management

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Note to Readers

During this reporting period, we continued the implementation of objectives outlined in the 1996 draft Program Plan. The program is currently focused on completing the work required for the 1998 viability assessment. While not a substitute for the site recommendation, the viability assessment will serve as an invaluable management tool by focusing the site investigation and facility design on key tasks and unresolved issues. The viability assessment will also serve as a major informational input to the policy process and provide all parties with a common frame of reference for evaluating our work.

We have completed excavation of the main tunnel of the Exploratory Studies Facility as well as alcoves for thermal testing and investigation of the Ghost Dance Fault. Detailed planning for an additional tunnel across the repository block is ongoing. Excavation of the starter tunnel should begin in early FY 1998, and excavation across the repository block should begin mid FY 1998. Although Congressional FY 1998 budget reductions have unfortunately reduced our original 1998 planned science experiments in the tunnel and alcoves, I do expect valuable information to support the design and performance assessment activities to still be obtained.

Total system performance assessment has continued to play an important role in focusing the site characterization activities on those issues most significant to repository performance. During this reporting period, we adopted several measures to ensure the Total System Performance Assessment for the viability assessment would provide a clear record of the evaluation and would be readily understandable to readers and reviewers. For example, we conducted seven abstraction-testing workshops and two formal expert elicitations to develop and document the input to the evaluation. These activities were observed by representatives of the Nuclear Regulatory Commission, the Nuclear Waste Technical Review Board, and other interested parties. In addition, an independent peer review of the Total System Performance Assessment is underway. Members of this peer review panel observed our abstraction-testing workshops and have delivered the first of three interim reports. This report is being evaluated by the program and the peer review will continue to review the entire performance assessment process. The second interim report is expected in the first quarter of FY 1998; the third interim report, in the third quarter of FY 1998. A final report is expected mid FY 1999.

Design activities continued to focus on resolving key design issues and on designing systems, structures, and components of the repository system that have little or no regulatory precedent and will have a major impact on performance assessment, schedule, construction, and cost. Continued field study and modeling of the Yucca Mountain site resulted in increased understanding of the systems and processes at work.

The viability assessment will assemble the results of these recent activities with the other scientific and technical information collected in over 15 years of site investigations into a workable repository design and an analysis of its cost and performance. The viability assessment will also define a path forward to a site recommendation and license application. Its completion will continue progress towards a national decision on geologic disposal at Yucca Mountain.

Sincerely,

Lake H. Barrett, Acting Director
Office of Civilian Radioactive
Waste Management

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EXECUTIVE SUMMARY

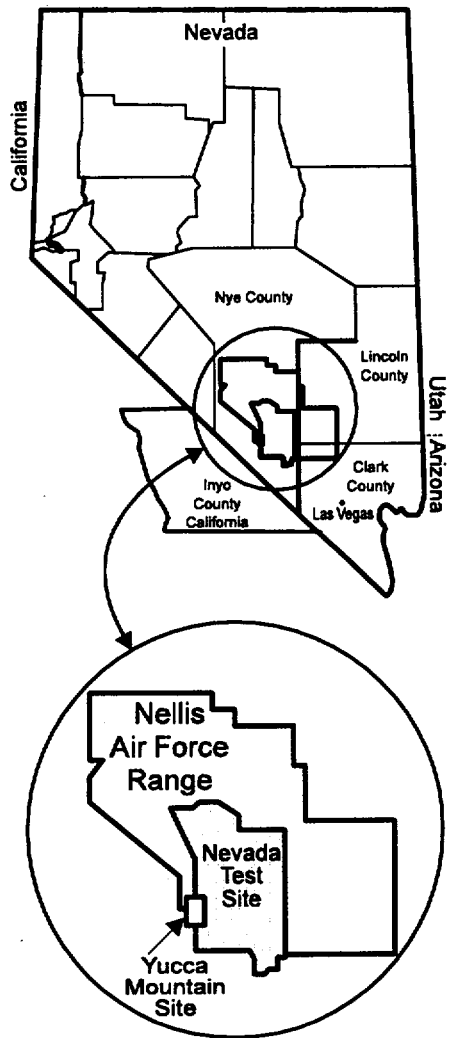
Site characterization activities at Yucca Mountain, Nevada, from October 1, 1996, through March 31, 1997. Sixteenth in a series reported in accordance with the requirements of Section 113(b)(3) of the Nuclear Waste Policy Act of 1982, as amended, and 10 CFR 60.18(g).

During the first half of fiscal year 1997, activities at the Yucca Mountain Site Characterization Project (Project) were focused on implementing the objectives of the 1996 Revision 1 Program Plan (revised Program Plan) issued by the Office of Civilian Radioactive Waste Management of the U.S. Department of Energy (Department).

To help support Project progress toward Plan objectives, the Department began re-evaluating its waste containment and isolation strategy in light of the new information about the percolation flux rates described in the last progress report. A revised summary of the strategy should be available next period. In addition, the Department published a Notice of Proposed Rulemaking to amend the repository siting guidelines and began taking public comments.

The fiscal year 1997 Energy Water and Development Appropriations Act provides that the Department shall complete a viability assessment by September 30, 1998. Scientific and engineering activities this period were directed toward providing information for the 1998 viability assessment. The Project adopted several measures to ensure the total system performance assessment to support the viability assessment would provide a complete and unambiguous record of the evaluation for traceability and be readily understood by the reader and reviewer (transparency). A major effort toward those ends was the conduct of seven abstraction-testing workshops designed to ensure that the performance assessment properly reflects the comprehensive process models for natural and engineered systems developed by principal investigators. In addition, formal expert elicitations began on two of the important foundational process-level models for the potential repository system at Yucca Mountain—the site-scale unsaturated zone flow model and the waste package degradation model.

Design activities continued to focus on resolving key design issues and on designing systems, structures, and components of the repository system that have little or no regulatory precedent and have a major impact on performance assessment, schedule, construction, and cost.



Location of Yucca Mountain site

Two tests in the thermal testing program are under way and a third is being planned and constructed. These tests will provide information on how the heat generated by the emplaced waste will affect the rock and the fluids in the repository system. The single-heater test began in August 1996, and preliminary results are becoming available. The large block test began in February 1997. Test setup is under way for the drift-scale heater test, scheduled to begin in December 1997.

The following sections summarize progress toward achieving Program Plan objectives and report the Project's technical progress.

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT PROGRAM

The Department's revised Program Plan, released last reporting period, outlines a focused, integrated program of site characterization, design, engineering, environmental, and performance assessment activities that will achieve key policy and statutory objectives. The revised plan modified the 1994 Program Plan to reflect the increased understanding of the Yucca Mountain site and the ongoing policy process.

The revised plan identifies three near-term objectives for the Project: (1) updating in 1997 the regulatory framework for repository siting to be consistent with a more focused program driven by the results of performance assessment; (2) supporting a 1998 viability assessment of Yucca Mountain; and (3) if the site is suitable, submitting a Secretarial site recommendation to the President in 2001, and a license application to the U.S. Nuclear Regulatory Commission (Commission) in 2002. Outlined in the following sections are the bases for the near-term objectives, the Department's strategies for achieving those objectives, Project progress in achieving those objectives, and the Department's waste containment and isolation strategy. Details on Project progress are presented following this Program summary.

Regulatory Framework Update

To achieve the first near-term objective, the Department is reviewing and proposing to revise its siting guidelines (10 CFR Part 960). The guidelines were first promulgated when multiple sites were under consideration. Over the past decade, however, legislation has dictated characterizing a single site and developing site-specific standards to protect the public. During this time

period, the technical understanding of the site has increased dramatically, especially after the Exploratory Studies Facility provided underground access. Thus, the Department proposed to update its siting guidelines by adding a subpart that would focus specifically on the overall preclosure and postclosure performance of the potential repository system at Yucca Mountain.

The Department's proposed amendments to the guidelines would refer to the site-specific radiological protection standard being developed by the U.S. Environmental Protection Agency (Agency) pursuant to the Energy Policy Act of 1992. The Agency's site-specific standard will appear in 40 CFR Part 197. The Energy Policy Act also requires the Commission to implement the Agency standard by revising the disposal regulations (10 CFR Part 60) within one year after the Agency Administrator promulgates the site-specific standard to make the regulations consistent with the standard. In the interagency review process, the Department will provide input to both the Agency and the Commission regarding their revisions to help ensure the resulting regulatory framework can be implemented. Since the last progress report, however, neither the status of the standard nor the Department's view on issues relevant to implementing the standard has changed.

In modifying its siting guidelines, the Department is proceeding in accordance with a public rulemaking process that began December 16, 1996, with the publication of a Notice of Proposed Rulemaking. In addition to accepting written comments, in January the Department held public hearings in Las Vegas, Nevada. The public comment period is scheduled to close next reporting period, and the Department expects to issue a final rule in mid-late 1998. If implemented, the regulatory changes would streamline the process for site evaluation and repository development, while protecting public health and safety and the environment.

The Department published its Notice of Proposed Rulemaking on December 16, 1996, beginning a public process to update the siting guidelines (10 CFR Part 960).

Viability Assessment

During this reporting period, Project activities have concentrated on supporting the upcoming viability assessment. The viability assessment is not the same as the site suitability determination and site recommendation. Rather, it is an interim step toward that recommendation. The viability assessment will serve two purposes: first, to guide the completion of the work required for an evaluation of site suitability and preparation of a license application, and second, to provide policy makers with a better estimate of the viability of a geologic repository at the Yucca Mountain site. The viability

assessment is a logical convergence point at which the Department can make an improved appraisal of the prospects for geologic disposal at Yucca Mountain using the results of the program first described in the 1988 Site Characterization Plan and the results from excavation of the Exploratory Studies Facility. These results allow the Department to develop an integrated picture of the repository system at the site that was previously impossible. The information the Department produces for the viability assessment will be an important validation of the practicality of the existing national policy of geologic disposal, and will allow policy makers to make a measurably improved judgment of the prospects of recommending Yucca Mountain for repository development and licensing to authorize construction.

The viability assessment will include the following:

1. The preliminary design concept for the critical elements for the repository and waste package

2. A total system performance assessment, based upon the design concept and the scientific data and analysis available by September 30, 1998, describing the probable behavior of the repository in the Yucca Mountain geological setting relative to the overall system performance standards

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

4. An estimate of the costs to construct and operate the repository in accordance with the design concept.

The Department has developed plans for all four components of the viability assessment, as discussed in the following sections.

Current repository and waste package design activities are focusing on design elements critical to waste isolation and radiological safety that have little or no regulatory precedent.

Repository and Waste Package Design. Currently, repository and waste package design activities are focusing on key design issues and design of critical systems, structures, and components that have little or no regulatory precedent and have a major impact on performance assessment, schedule, construction, and cost. When complete, the viability assessment design effort will have evaluated the technological feasibility of the conceptual designs but will not have developed all the detail needed for licensing.

During this reporting period, the Project continued to modify designs to reflect the de-emphasis on the multi-purpose canister and to

accommodate receipt of mainly uncanistered spent nuclear fuel. Sensitivity studies for the higher percolation fluxes at the repository level that were reported last period were performed on the engineered barrier system. Laboratory tests on waste package materials and waste forms continued to provide input to degradation process models. In addition, both laboratory and field tests are being conducted to assess changes in concrete caused by the hydrothermal cycle. These tests will be used to support a design decision on using concrete for mechanical support in the repository emplacement drifts. The Commission's revision of 10 CFR Part 60 on design basis events became effective this period, and the Project grouped and prioritized analysis events previously identified for consideration as design basis events. This rule change resulted in limits and models for Project design basis events that are more consistent with those of the commercial nuclear industry.

Total System Performance Assessment. Total system performance assessment, the second component of the viability assessment, is a key element in the Department's performance-driven program. This assessment will evaluate the range of probable behavior of the repository in the Yucca Mountain geologic setting.

To provide a valid and defensible evaluation of the site's performance, the Project is developing an integrated total system performance assessment to support the viability assessment. Important concerns are that model development be focused on issues that are most important to performance and that the evaluation ensure traceability (provide a complete and unambiguous record) and transparency (be easily understood by the reader and reviewer).

To ensure traceability, the Project has adopted three processes along with accompanying records: a series of abstraction-testing workshops, a formal expert elicitation process, and peer review.

Measures to Ensure Traceability in Total System Performance Assessment

- *Abstraction-Testing Workshops*
- *Formal Expert Elicitation*
- *Peer Review*

The first process, the abstraction-testing process, is used to ensure that the total system performance assessment properly reflects results from the highly detailed and computationally intensive site and engineered system process models. The models characterize processes and features of both the natural and the engineered systems and represent the work of site characterization, design, environmental programs, and performance assessment. In the probabilistic total system performance assessment calculation, abstracted models are used as surrogates for the comprehensive process models. The abstracted models must, however, maintain the essential elements of the process models, including key interdependencies. This abstraction-testing process is critical to the success of the Project.

This period, Project staff prepared for, conducted, and evaluated the results of several abstraction-testing workshops. During the seven workshops held this period, Project staff developed a list of criteria against which all issues were then ranked for importance to postclosure performance. From this ranking, the highest priority issues were identified. Finally, a short synopsis for the abstraction-testing plans was developed. Following the workshops, work began on completing the details of the plans that will guide the implementation of the analyses identified in the workshops. The results will be the parameters, process models, and alternative concepts used in the total system performance assessment supporting the viability assessment. Two more abstraction-testing workshops are scheduled for next period.

The second process to achieve traceability is a formal expert elicitation, which is used to characterize the state of existing knowledge in an area. The expert elicitations follow the guidance provided in the Commission's Branch Technical Position on the Use of Expert Elicitation in the High-Level Radioactive Waste Program. The expert elicitations are used (a) to quantify and document the uncertainties in the process models to strengthen the assessment and (b) to involve outside experts in the evaluation of all available data. Formal expert elicitation is currently under way on the site-scale unsaturated zone flow model—one of the most important of the foundational process-level models.

For peer review, the third process, an external panel of experts has been established to monitor and review the preparations for the assessment, as well as the final product. The peer review panel will first review the previous total system performance assessments and then make observations on the plans, approach, and assumptions for the performance assessment to support the viability assessment. The reviewers will also review the process modeling and the performance assessment abstraction process. Finally, they will provide a formal peer review of the assessment supporting the viability assessment, and the comments and recommendations will be incorporated into the performance assessment to support the license application. The peer review panel convened this period, and member orientation began in February 1997.

Measures to Ensure Transparency in Total System Performance Assessment

- *Graphic presentation*
- *Electronic hypertext*
- *Computerized data retrieval and selection system*

Besides the three steps to ensure traceability, the Project is also using specific measures to ensure transparency. There is an initiative under way to examine ways of graphically presenting the total system performance assessment results to make them more easily understood by those who are not performance assessment specialists. The Project is also investigating using hypertext to increase the reviewer's electronic

access to data sources and cited materials and developing a computerized data retrieval and selection system to help trace and document decisions made in data selection. The hypertext effort will be coordinated with similar work on the Licensing Support System.

License Application Plan and Cost. The third component of the viability assessment—the License Application Plan—will define the remaining work required to complete a license application and the associated schedules and costs. Submittal and docketing of a license application to the Commission, should the Yucca Mountain site be found suitable, is a major programmatic goal.

During this reporting period, the Department began developing the License Application Plan. In developing the plan, the Project will draw on the available models and data that describe the natural system, the repository and waste package designs, and the total system performance assessment, together with the strategy for evaluating waste containment and isolation. The License Application Plan will also include a high-level discussion of the Project's licensing strategy, a description of the license application content requirements specified by 10 CFR 60.21, and a description of the performance confirmation plan.

Cost to Construct and Operate. The fourth component of the viability assessment includes the estimated costs and schedules to construct and operate the repository system in accordance with the critical elements of the design concept. The estimates will encompass completion of site characterization, performance confirmation, and construction, operation, and closure of a repository. The cost and schedule estimates will be a factor in policy decisions regarding the feasibility of and justification for continuing with the work required for licensing and construction of a geologic repository.

Work began this period on developing the cost estimate to construct and operate a repository. Efforts this period included generating an annotated outline for the cost document, updating the cost account structure, updating cost models, and developing a life-cycle cost schedule.

Work began this period on developing the cost estimate to construct and operate a repository.

The estimates will be based on the repository and waste package designs developed for the viability assessment and on scientific testing and analyses completed by 1998. Because not all the details of the design will be developed fully by the 1998 viability assessment, some design assumptions will be used to complete the estimates.

Site Recommendation and License Application

After the viability assessment, the Project will prepare the additional information required for site recommendation and the license application. If the site is found suitable in accordance with the then-existing siting guidelines, the Secretary of Energy will issue a site recommendation in 2001, following public hearings to be held in the State of Nevada before a possible site recommendation. If the site is approved by the President and permitted to take effect after submission to the U.S. Congress, a license application will be submitted in 2002 requesting authorization to construct a repository. This schedule will allow repository operations to emplace waste beginning in 2010.

During this reporting period, the Project resumed preparation of the Environmental Impact Statement that would accompany any site recommendation. Preparation was deferred earlier after the public scoping period because of budget constraints. Work also began on several documents that will be key to developing the license application: the Project Integrated Safety Assessment, the Technical Guidance Document for License Application Preparation, and the License Application Management Plan. The Project Integrated Safety Assessment will summarize the current knowledge about the site obtained from scientific investigations, design, and performance assessment. The document will become a starting point for the license application by updating and using the information in the safety analysis report that supports the license application. The technical guidance document will provide authors with detailed content guidance, regulatory requirements, and acceptance criteria for the license application. The License Application Management Plan establishes the process for managing the development of the license application.

The objectives of Department and Commission interactions are reaching a common understanding of issues significant to overall repository performance and agreement on methods and approaches to important technical issues.

Interactions between the Department and the Commission are an important part of the prelicensing period before a decision is made whether to recommend the site. The Department believes that interactions with the Commission staff should focus on two objectives: (1) reaching a common understanding regarding the issues that are significant to overall repository performance, and (2) reaching agreement on the adequacy of proposed methodologies and approaches to address important technical issues, such as criticality control and seismic design. The goal of Department and Commission interactions is to reach a mutual understanding of the repository concept as it develops. This understanding will provide a basis for the Commission's preliminary comments (to be included in the Department's site suitability package) on the sufficiency of site

characterization and design for inclusion in a license application. During this reporting period, the Department continued interactions with the Commission staff to help resolve the issues of seismic hazards, igneous activity, and repository criticality. Many of the interactions involved resolving Commission comments on the Department's methodology reports.

Waste Containment and Isolation Strategy

The Department's waste containment and isolation strategy is being used to focus the efforts leading to the viability assessment and to guide the work beyond the viability assessment. The two technical objectives of the strategy are (1) to limit the annual dose to members of the general public following permanent closure of the repository and (2) to provide total containment of the waste within the emplaced waste packages for several thousand years during the period of highest radionuclide inventory and temperature. The strategy outlines the Department's approach to addressing and resolving postclosure performance issues and also focuses the science and design work needed to determine postclosure performance.

After a summary version of the strategy was completed and distributed in July 1996, new information derived from interpretations of several site investigations indicated the potential for average percolation flux values at the repository horizon in the range of 1 to 10 millimeters per year or potentially higher, with part of this flux associated with fast pathways. Percolation flux affects all the system attributes identified in the strategy as most important for predicting the performance of the engineered and natural barriers: rate of water seeping into the repository, waste package lifetime (containment), rate of release of radionuclides from breached waste packages, radionuclide transport through engineered and natural barriers, including dilution in the saturated zone below the repository. Higher percolation flux may result in an increase in flux into the repository and a reduction of the time radioactive particles take to travel between the repository and the accessible environment. Also, higher percolation flux is expected to increase the relative humidity in the waste emplacement drifts, potentially leading to shorter waste package lifetimes. One of the highest priorities of the Project continues to be reducing the uncertainty in the range of percolation flux that can be expected at the repository horizon. A revised summary version of the strategy is scheduled to be issued next reporting period.

Percolation flux values affect all the system attributes identified in the waste containment and isolation strategy as most important for predicting the performance of the engineered and natural barriers.

Specific progress in site investigations, design, and performance assessment supporting the revised Program Plan is discussed in the following section on Project progress.

PROJECT PROGRESS

Project activities this reporting period supported the objectives of the revised Program Plan, particularly the viability assessment. The following sections report progress in site investigations, repository design, waste package, performance assessment, Exploratory Studies Facility design and construction, and Project programmatic activities. Specific details relating to Project activities are presented in the respective chapters of the report and in supporting technical papers and reports referenced throughout the main body of the report.

Site Investigations and Analyses

Site investigations and analyses this period supported the development of the viability assessment through continued surface-based testing, testing in the Exploratory Studies Facility, and laboratory testing. In addition, analyses and process model development continue to provide information and input for design and the total system performance assessment components of the viability assessment. The major technical questions focus on thermal effects, hydrologic properties of major faults, percolation flux, saturated zone characteristics, and implications of climate change for repository performance.

The Project continues to collect data to reduce the uncertainties in the range of percolation flux that can be expected in the repository horizon.

Unsaturated Zone Characterization. The Project continued its modeling, testing, analysis, and data collection activities to reduce the uncertainties in the range of percolation flux that can be expected in the repository horizon. Evidence on percolation flux continues to accumulate from a suite of ongoing testing in the Exploratory Studies Facility and surface boreholes that includes environmental isotope and fracture-coating studies, temperature monitoring, perched water evaluations, moisture monitoring, and pneumatic testing.

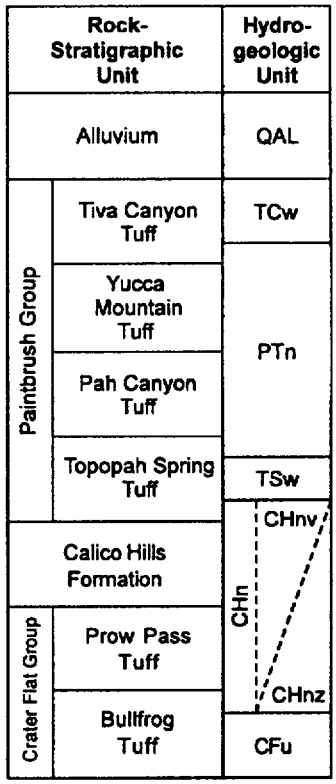
Systematic and feature samples in the ESF continue to show chlorine-36 from weapons testing in a few distinct fractured or faulted zones, indicating that at least a component of the water is less than 50 years old. Locations where multiple samples indicate chlorine-36 from weapons testing appear to be associated with major faults mapped at the surface. Rapid penetration of surface water to repository depth

seems to occur only where faults cut all the way through the Paintbrush nonwelded hydrogeologic unit (PTn in the diagram) overlying the repository host rock. The amount and distribution of chlorine-36 from weapons testing found at the repository horizon seem to depend on the rate of surface water infiltration into and through the Tiva Canyon welded hydrogeologic unit (TCw). Distribution also seems to depend on the presence of small subsidiary faults or interconnected joints in the Topopah Spring Tuff (TSw) that cause the downward percolating water to spread laterally within the Topopah Spring Tuff away from fault zones such as the Sundance fault.

Tritium analysis of water extracted from rock samples in the Bow Ridge Fault Alcove of the Exploratory Studies Facility confirms the indications from chlorine-36 samples that water is transmitted rapidly through the Tiva Canyon welded hydrogeologic unit along the Bow Ridge fault. Likewise, tritium from weapons testing extracted from rock samples from the Upper Paintbrush Tuff Contact Alcove, which is located at the base of the Tiva Canyon welded hydrogeologic unit, suggest the relatively fast transport of water through the Tiva Canyon welded hydrogeologic unit above the potential repository horizon.

Other studies indicate that percolation flux rates may decrease with depth because of lateral flow both above and below the potential repository horizon. Estimates of unsaturated zone percolation flux from differences in temperature data between the saturated zone and the unsaturated zone in three boreholes indicate percolation flux rates of about 5 to 24 millimeters per year. But differences in temperature within the unsaturated zone alone (Topopah Spring Tuff and Calico Hills Formation) in two of the boreholes indicate lower rates of about 2 to 5 millimeters per year. Studies of the ratios of uranium-234 to uranium-238 in calcite and opal veins also point to decreases in percolation flux with depth. The ratios in samples from the Tiva Canyon Tuff, the Paintbrush nonwelded hydrogeologic unit, and the upper part of the Topopah Spring Tuff indicate larger rates of percolating water. The ratios in samples from the repository horizon, however, seem to indicate that relatively smaller rates of percolating water reach the repository horizon.

Moisture monitoring in the Paintbrush nonwelded hydrogeologic unit in the south ramp of the Exploratory Studies Facility offered some clues about water potential and also ventilation effects. The initial measurements taken from instruments indicated that the water potential is considerably higher than indicated by measurements from boreholes. The data suggest a higher percolation flux through the Paintbrush



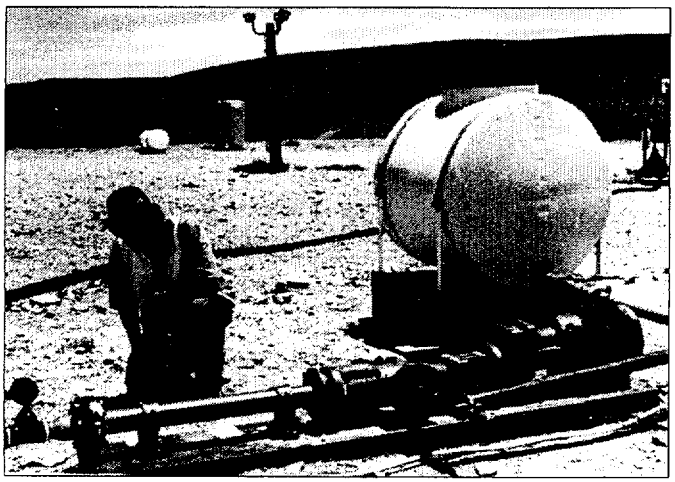
QAL = Quaternary Alluvium
TCw = Tiva Canyon welded unit
PTn = Paintbrush nonwelded unit
TSw = Topopah Spring welded unit
CHn = Calico Hills nonwelded unit
CHnv = Calico Hills nonwelded vitric unit
CHnz = Calico Hills nonwelded zeolitized unit
CFu = Crater Flat unit

Correlation of hydrogeologic units with rock stratigraphic units.

Nationally recognized experts are meeting to evaluate unsaturated zone flow characterization and modeling.

nonwelded hydrogeologic unit than would have been estimated using borehole data. Matrix flux in the Paintbrush nonwelded hydrogeologic unit has not yet been estimated using this new information.

Characterizing percolation flux in the unsaturated zone is critical to the Project's waste containment and isolation strategy, and the unsaturated zone flow model is therefore one of the most critical process-level models to be incorporated into the total system performance assessment supporting the viability assessment. Thus, the first expert elicitation to support the viability assessment has been started on the unsaturated zone model. A series of three workshops was conducted involving data collectors and analysts, modelers, seven nationally recognized experts in the field of unsaturated zone flow characterization, and observers. The purpose of the elicitation is to assess quantitatively the uncertainties associated with the model predictions of the spatial and temporal distribution of percolation flux.



C-hole testing

Saturated Zone Testing. Reactive and conservative tracer testing was completed in the Bullfrog-Upper Tram interval of the C-hole complex, the most productive zone of the volcanic aquifer. Tracer tests are used to estimate flow and transport parameters. These parameters are input to numerical flow and transport models and will be used in transport calculations to support the total system performance assessment for the viability assessment. Ultimately, the results will help predict likely dilution rates for radionuclides released from the repository, as well as the probable ground-water travel time for the radionuclides to move from the repository to the accessible environment.

Results from the C-hole pumping tests indicate that the system is a dual porosity flow and transport system. Tracers travel in the fractures but also diffuse into the rock matrix. This process is expected to increase travel time and enhance sorption. Matrix diffusion and sorption appear to be effective retardation and dilution mechanisms. The Project plans additional testing throughout 1997 on the low-flow zone (Prow Pass interval).

The studies indicate that even if a small fraction of the radionuclides reaches the water table quickly (within 10,000 years), the saturated zone would significantly dilute radionuclide concentrations before they reach the accessible environment. Thus, the saturated zone provides a defense against the most uncertain aspects of unsaturated zone performance; namely, that a fraction of the inventory could be rapidly transported to the water table.

The saturated zone provides a defense against the most uncertain aspects of the unsaturated zone performance; namely, that a fraction of the inventory could be rapidly transported to the water table.

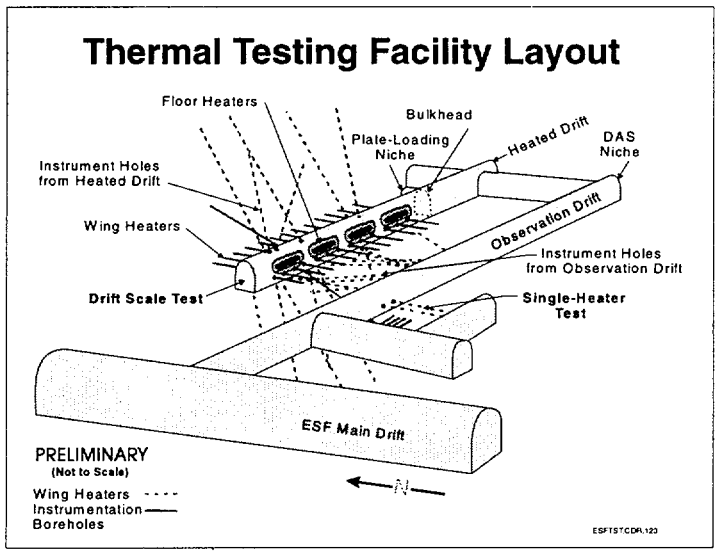
Transport. Transport activities this period continued to provide evidence about the potential radionuclide transport through the natural system. The migration (or transport) of radionuclides is affected by a variety of physical and chemical factors in the natural system, one of the most important being the amount and rate of flowing water.

A workshop was conducted to ensure proper abstraction and testing of the process-level model on unsaturated zone radionuclide transport. This workshop effort is part of the process to ensure that the total system performance assessment for viability assessment is valid and defensible. At the workshop, an abstraction-testing proposal was developed for sensitivity studies to examine the effects of mineral alteration on unsaturated zone radionuclide transport. Results of this workshop suggest that repository-induced alteration of existing minerals and glasses in Yucca Mountain tuffs could change the hydrologic properties (permeability and porosity) and geochemical properties (sorption capacity, composition including water) of the natural media over time. The end result of the reactions is that the unsaturated zone could be different in the future than it is today, and simulations of radionuclide transport in the unsaturated zone should consider possible changes in the rock properties. Abstractions will continue throughout the fiscal year.

Results of a workshop suggest that repository-induced alteration of existing minerals and glasses in Yucca Mountain tuffs could change the hydrologic properties (permeability and porosity) and geochemical properties (sorption capacity, composition including water) of the natural media over time. The end result of the reactions is that the unsaturated zone could be different in the future than it is today

Altered Zone. Modeling this period evaluated potential flow barriers in the altered zone—the region around the repository that may be changed by the heat of the emplaced radioactive waste. Reactive transport simulations in the altered zone indicate that when a flux of 100 millimeters per year is driven into the rock by the heat from the waste, solids could precipitate and seal fractures in less than 100 years. Such blockages would then force fluid to drain through the pillars between emplacement drifts. This water would thus bypass the waste without contacting it.

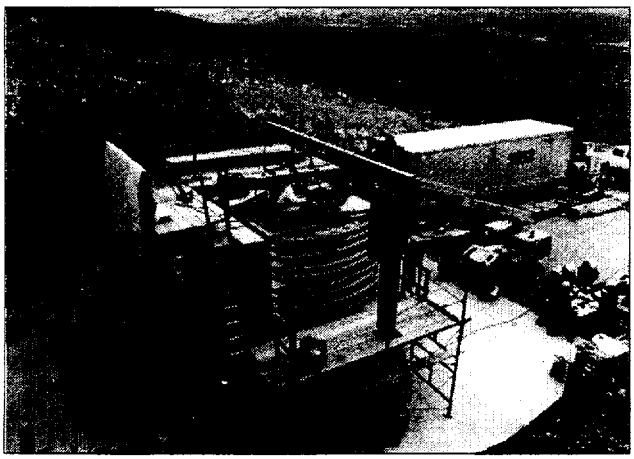
Thermal Testing. Three major in situ tests are being conducted to determine effects of heat from emplaced radioactive waste on surrounding rocks. The single-element heater testing that



Schematic of Thermal Testing Facility showing single-heater test and drift

began last period continued in the Thermal Testing Facility. In this test, the heat comes from electric heaters that simulate the heat from emplaced radioactive waste in a repository. Some preliminary results indicate that convective heating effects are smaller than predicted from the thermohydrologic analyses. This may be because vapor escaping the block or heat loss through fracture systems is not accounted for in the modeling. Indications are that at temperatures above boiling, temperature predictions agree quite well with measured values. The heating phase of the single-heater test will be continued until the end of May 1997, when a decision will be made to continue the heating phase for another three months or to begin a cooling phase. Data will be taken throughout the heating and cool-down phase.

A test configuration has been developed for the drift-scale test scheduled to begin at the end of 1997. This test will be used to predict and measure coupled thermal-mechanical-hydrological-chemical processes. The test consists of a single heated drift 5 meters in diameter with electrical heater canisters placed in the drift to simulate waste packages. The test will provide information on temperature distribution and heat transfer modes; on the propagation of drying and re-wetting regions; on changes in water chemistry and mineralogy; and on thermal expansion and deformation modulus. Two to four years of heating are planned, depending on the processes observed in the first two years.



Large Block Test

The large block test to study coupled thermal-mechanical-hydrological-chemical processes began at Fran Ridge. The large block test is occurring in a medium with controlled thermal and moisture boundaries and with known multiple fractures and inhomogeneities. Instrumentation and waste package materials will be tested in a quasi in situ environment. Instrumentation was installed and the heaters turned on in February 1997. The heating phase of the large block test will continue throughout most of the next reporting period. The interior block temperature will be raised to approximately 140°C, with the temperature at the top of the block kept near 60°C,

and these conditions will be held stable for about a month. After that time, the heaters will be turned off to start a cool-down phase. Data acquisition will be continuous during the heating and cool-down phases.

Geology. Mapping activities and data from alcove boreholes continue to provide a clearer picture of the faults affecting the Yucca Mountain central block. Mapping of the central block of Yucca Mountain has given geologists a better description of intrablock faults, such as Ghost Dance, Abandoned Wash, and Busted Butte. These faults spread out toward the surface into a series of branching faults from convergence at depth. The mapping indicates the pattern is maintained for block-bounding faults. This fundamental understanding of fault geometry will help geologists understand the deformation associated with Solitario Canyon fault, which bounds the western edge of the repository area.

Recent drilling in the Northern and Southern Ghost Dance Fault Alcoves has confirmed that the contact between the repository horizon and the upper lithophysal zone of the Topopah Spring Tuff is within 1 meter of the location predicted by the three-dimensional lithostratigraphic model. Video logs and core from the horizontal borehole in the Northern Ghost Dance Fault Alcove showed that the main trace of the Ghost Dance fault is about 154 meters east of the main drift of the Exploratory Studies Facility. Projection of the surface trace underground of the fault to the location of the main trace indicates that the fault is nearly vertical.

Projection of the surface trace of the Ghost Dance fault to the location of the main trace indicates that the fault is nearly vertical.

A study of potential magma sources in the Yucca Mountain region was completed. The results show that there is no large low-velocity zone under Crater Flat or Yucca Mountain that would suggest a major near-surface source of magma. This in turn corroborates some of the assumptions made in the Probabilistic Volcanic Hazard Analysis.

The process to develop ground motion and fault displacement information for design and performance assessment advanced this period with the resumption of the Probabilistic Seismic Hazards Assessment process. The assessment consists of two parts: (1) seismic source and fault displacement characterization and (2) ground motion characterization. The process uses panels of experts and formal elicitation of experts to examine data and interpretations. Several workshops and elicitation meetings were held this period. The final assessment will provide input to the final calculations of the annual probabilities of varying levels of ground motion and fault displacement. The process will be completed next reporting period.

Several branches of evidence are converging to provide sufficient understanding of past climate cycles to be able to generally forecast timing and magnitude of climate change in the Yucca Mountain area.

Climate. Paleoclimate records have been further refined, allowing a better understanding of past climate cycles in smaller time increments. Also, several branches of evidence are converging to provide sufficient understanding of past climate cycles to be able to generally forecast timing and magnitude of climate change in the Yucca Mountain area. Analysis of diatoms (microscopic fresh water plants with silica shells) and ostracodes (small fresh water crustaceans) indicates extremely rapid changes in the climate at Owens Lake, California. The lake, which is a source of data on regional Quaternary climate, often varied from an overflowing, fresh water system to a closed, saline or even dry system in less than 1,000 years. These kinds of changes are more typical of interglacial and transitional periods than of the glacial periods. Ostracode records from about 55,000 years ago to present show very rapid shifts from dry climates similar to those of today to brief periods of warm, wet climates supported by summer rains.

Scientists have found that several types of records of past climate correspond well with each other. These include the isotope records at Devils Hole, Nevada, and the paleoclimate records from Owens Lake, California. In addition, both these records correspond to the marine oxygen isotope records that document global change in the earth's temperature and ice volume. The records indicate that the timing and rate of past climate change at Yucca Mountain coincided with the large, cyclic changes in global climate throughout the Quaternary. Using this knowledge and the knowledge that global climate shifts are related to changes in total solar heating, researchers think it may be possible in general terms to forecast the timing of climatic change in the Yucca Mountain area. Similarly, using the knowledge about how past magnitudes of climate change are related to particular segments of the solar radiation cycle, they think it may be possible to forecast the magnitude of future climate change in the region. Specifically, because the present-day segment of the solar cycle resembles that of about 400,000 years ago, the characteristics of the climate of that time may be expected to generally recur in southern Nevada.

Key Design Issues

- *Performance confirmation concept*
- *Engineered barrier system performance*
- *Waste handling capability*
- *Emplacement drift ground support concept*
- *Thermal loading*
- *Retrievability concept*
- *Remote control operations*
- *Disposal of site-generated waste*
- *Repository subsurface mapping strategy*
- *Postclosure performance standards*
- *Criticality control*
- *Repository seals*
- *Regional service agents/interim storage facility interface*
- *Additional waste forms*
- *Waste package sizes and weights*
- *Waste package materials*
- *Design basis model*
- *Subsurface development*
- *Surface development*
- *Site development*

Repository Design Activities

The Project continues its philosophy of a phased and evolving design that will support the viability assessment,

environmental impact statement, site recommendation, and license application. Current work is focused on resolving key design issues and on designing systems, structures, and components that have little or no regulatory precedent and have a major impact on performance assessment, schedule, constructability, and cost. Even though the key design issues do not have to be completely resolved to support the viability assessment, sufficient progress is required to limit future redesign.

Regulatory Basis. In keeping with its design philosophy, the Project began developing technical guidance based on regulatory requirements to support its phased approach. The Project began identifying appropriate acceptance criteria for important systems, structures, and components in support of phase one design for the viability assessment. Later, the guidance to support phase two design (design development to support the license application) will be developed. The Engineering Compliance Plan will document the guidance for use by the design organization and the authors of the engineering chapters of the eventual license application. The plan will identify the information necessary to provide reasonable assurance to the Commission that the repository design supports construction of a repository that would not pose an unacceptable risk to the health and safety of the public or the repository workers. The plan will also identify regulatory guidance and industry standards that may apply to the repository design.

Regulatory guidance to support design will be documented in the Engineering Compliance Plan.

The rule change to 10 CFR Part 60 incorporating design basis events became effective this period. In compliance with the requirements, the Project continued to refine its preliminary set of design basis events identified last period and also began analysis of the design basis events. Previously selected external events (caused by factors not directly related to repository design or operation) and internal events were grouped into analysis groups and the groups were prioritized on the basis of their potential impact on repository design, availability of information to support the analysis, and whether the analysis is needed to support the viability assessment.

Two pilot analyses were begun that will serve as templates for other consequence analyses that will be performed in future reporting periods. These pilot analyses are the first to incorporate revised radiological safety criteria from the revised 10 CFR Part 60. Analysis of design basis events will be used to refine the list of repository and waste package systems, structures, and components subject to quality assurance requirements and to help determine the level of design detail required to support the viability assessment and the license application.

Two pilot analyses were performed that are the first to incorporate revised radiological safety criteria from the revised 10 CFR Part 60.

Supporting Activities. Supporting activities included improving the efficiency of the subsurface layout and analyzing activities that will impact repository operations.

The repository design and emplacement concepts continued to be refined to minimize the amount of excavation necessary to emplace waste.

The repository design and emplacement concepts continued to be refined to limit the amount of excavation necessary to emplace waste. Three potential space-saving concepts were identified. First, analysis of areal mass loading indicated that raising the loading to about 85 metric tons of uranium per acre would mean the repository area could be reduced slightly (2 percent) from that given in the advanced conceptual design while still meeting thermal goals. Second, minimizing drift space surrounding defense high-level waste could reduce the emplacement area required by about 10 percent. Finally, for a given areal mass loading, using a wider drift spacing coupled with closer waste package spacing in the drifts could also reduce the amount of excavation needed. The concepts have not yet been approved for implementation in the design, and further work to determine whether to implement them is in progress.

The Project analyzed the effect on Waste Handling Building operations of changing to receipt of predominantly uncanistered fuel.

The Project analyzed the effect on Waste Handling Building operations of changing to receipt of predominantly uncanistered fuel. The analysis compared wet and dry handling concepts and preliminarily recommended a preferred waste handling approach that would include a staging area with five operation lines (three wet lines for uncanistered assemblies and two dry lines for canistered wastes). Handling operations for shipping casks and canisters, bare and canistered fuel, and disposal container operations were modeled. Also analyzed were staffing and shielding requirements. Analyses continue and the results will eventually be reflected in future revisions of the concept of operations and system design documents.

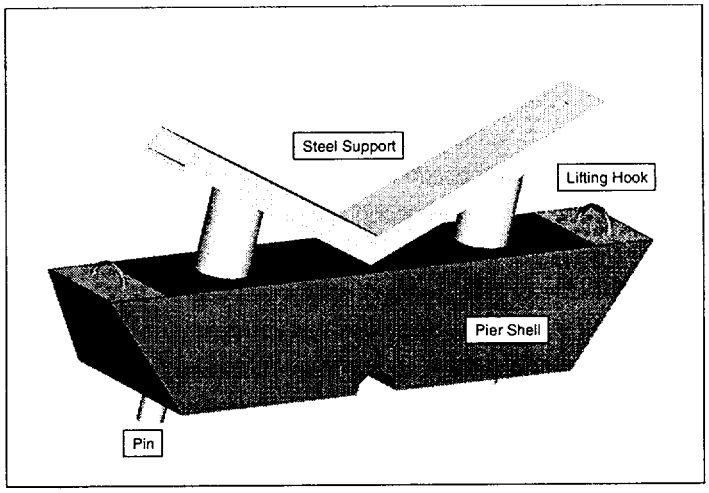
Waste Package Design Activities

Waste package design continued to emphasize the receipt and handling of uncanistered fuel because of the de-emphasis on the multi-purpose canister effort. Work this period focused on thermal, structural, and criticality analyses; and on the selecting of materials for waste packages support and inverts.

Design Analyses. Design analyses included thermal, structural, and criticality work. Thermal design efforts have advanced in three main areas: (1) evaluating the repository and emplacement drift thermal behavior and its impact upon waste packages, (2) evaluating waste package thermal conditions with regard to meeting the licensing

equirements, and (3) evaluating and designing the waste package support and invert based on its thermal and structural performance under nominal repository conditions.

Two major structural design analyses are in process: (1) preliminary design of the waste package support and pier, and (2) waste package structural analyses. The objective of the first analysis is to determine appropriate dimensions and materials for the waste package support and pier on the basis of structural requirements. The purpose of the second is to determine component dimensions. Component dimensions are required to show the adequacy of the uncanistered fuel waste package design with stainless steel-boron neutron absorber plates under loading encountered during waste package drop events.



Waste Package Support and Pier Preliminary Design

The criticality activities consisted of developing inputs in support of Revision 1 of the Disposal Criticality Analysis Methodology Technical Report, developing the technical basis for integral principal isotope burnup credit, evaluating waste package designs for criticality control, and meeting with Commission staff to discuss Revision 0 of the methodology report. Revision 1 of the technical report is scheduled to be released late in fiscal year 1997. These activities are supporting the development of the Disposal Criticality Analysis Methodology Topical Report, scheduled to be completed and submitted to the Commission in 1998.

Near-Field Studies. Sensitivity studies related to potential percolation flux continued. One sensitivity study investigated the relationship between drift seepage and percolation flux for both homogeneous and heterogeneous rock conditions. The modeling showed that when heterogeneity in fracture properties increased, the threshold percolation flux at which water is able to seep into the drift decreased. In homogeneous conditions, narrowing the fracture aperture distribution also reduced the predicted threshold percolation flux.

A second sensitivity study investigated the influence of percolation flux on temperatures in the drift-scale test. The modeling indicated that for a 5 millimeter per year flux (a value chosen as representative of current predictions of percolation flux), the maximum

drift-wall temperature at the center between the two ends of the heated drift would be more than 100°C lower than for a flux of 0.05 millimeters per year.

A third sensitivity study examined the sensitivity of fracture flow to percolation flux. Greater water pressure (as would be expected for higher percolation flux) was found to strongly increase fracture flow.

Both laboratory and in situ tests are being conducted to evaluate the hydrothermal alteration of concrete.

The Project is conducting both laboratory and in situ tests to evaluate the hydrothermal alteration of concrete. Experimental results will support a design decision about the use of concrete in the repository and a specific decision on the use of precast concrete liners for mechanical support in repository emplacement drifts. Laboratory tests are being used to determine microstructural, mineralogical, and mechanical changes in concrete and changes in water chemistry because of the hydrothermal cycle. For in situ testing, concrete samples have been placed in the large block test at Fran Ridge and the single-heater test in the Exploratory Studies Facility. Samples will also be placed in the drift-scale test. Observations will be made while the heaters are operating; after the tests, samples will be collected and follow-up studies conducted.

The drift-scale test was analyzed using a three-dimensional model. The model was used to predict (a) the maximum expected temperature rise at selected locations in the thermal test area, (b) the ventilation requirements for the neighboring drifts, and (c) the insulation requirements for the thermal bulkhead that separates the heated and unheated parts of the heated drift. The results of the modeling will be used in the design and construction of the test.

Performance Assessment Program

Current efforts are focused on preparing for the next total system performance assessment, planned for the 1998 time frame, in support of the viability assessment. Much effort was concentrated on model abstraction and testing of process-level models. In addition, experiments and modeling continued on waste package and engineered barrier materials and waste forms. A waste retrievability requirements study began; this study is a precursor to the design activity expected next period. In addition, a performance confirmation plan is being prepared.

Model Abstraction. The Project has adopted an abstraction-testing process as one measure to ensure that the total system performance assessment supporting the viability assessment is valid and defensible. The performance assessment supporting the viability assessment will be constructed of models developed to represent processes and features of both the natural and the engineered systems. The abstraction-testing process is being used to ensure the results from the highly detailed and computationally intensive site and engineered system models are properly reflected in the abstracted models used for performance assessment.

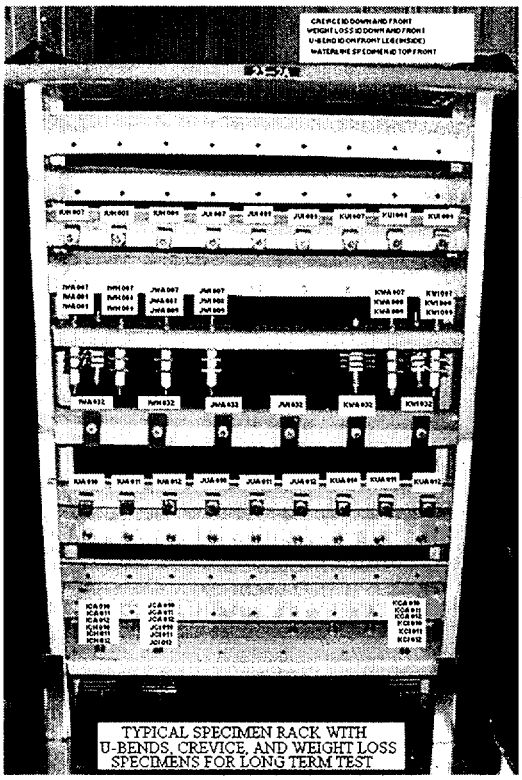
Although the processes and features are strongly interdependent, the performance assessment analysts have broken the processes into components to facilitate analysis and the abstraction-testing process. These processes and their key outputs in abstraction are shown in the box on this page.

The abstraction process includes three major elements: planning, workshops, and implementing abstraction-testing plans developed during the workshops. The workshop participants include data collectors, process modelers, subsystem performance assessment modelers, and total system performance assessment modelers.

Process	Key Output in Abstraction
Unsaturated zone flow	Percolation and seepage flux
Thermohydrologic flow	Humidity, temperature
Near-field environment	Sorption, dispersion
Waste package degradation	Containment time
Waste form alteration and mobilization	Solubility, diffusive/advective flux
Unsaturated zone transport	Advective velocity distribution
Criticality	Probability, effects
Saturated zone flow and transport	Dilution
Biosphere	Dose conversion factors

Abstraction-testing workshops were held on seven topics this reporting period.

This reporting period, workshops were held on the following topics: (1) unsaturated zone flow, (2) thermohydrologic flow, (3) near-field environment, (4) waste package degradation, (5) waste form alteration and mobilization, (6) unsaturated zone transport, and (7) criticality. The results of these seven workshops include a listing of the performance measures or prioritization criteria against which all issues were ranked for importance to postclosure performance. Also, a list of the highest priority issues was defined and a short synopsis of the various testing and analysis plans was developed. After the workshops, work began on the detailed testing and analysis plans. Two more workshops are scheduled for next period: (1) saturated zone flow and transport and (2) biosphere.



Testing in the long-term corrosion facility

Materials Testing. Many different types of material studies are being conducted to investigate the potential corrosion of waste package container materials placed in the potential repository horizon. Studies in the long-term corrosion testing facility, which began shortly before the end of last period continued. Three classes of materials are being studied: corrosion resistant, corrosion allowance, and intermediate corrosion resistant. This comprehensive test is planned to last at least five years, with test specimens periodically removed and inspected. The first set of specimens was withdrawn at the end of March 1997. The information from these tests will be used to refine process models that will be provided to the performance assessment and the waste package design groups.

Investigations into conditions that increase the susceptibility of metals to aqueous film corrosion began to provide clues about the mechanics of corrosion on materials contaminated with salts typical of the repository environment. Investigators are particularly concerned about corrosion once conditions become damp and humid. This period, studies showed that salt-covered specimens of carbon steel corrode very fast at first, but with time, the salt is "consumed" by the oxidation process and the corrosion eventually stops. Later, the oxide transforms into a stable oxide and spalls off the surfaces.

In electrochemical tests, various alloys were tested to determine the potential for localized corrosion, such as pitting. The alloys were tested in brines of various salt content. Alloy C-22 (a nickel-chromium-molybdenum alloy) and Ti Grade-12 (a titanium-base alloy) were immune to localized attack under all experimental conditions tested, thus suggesting their suitability for use as inner container materials.

In other testing, galvanic corrosion tests began in January 1997 to investigate the electrochemical interaction between the dissimilar metals proposed for the multibarrier waste package designs. Tests to determine if corrosion is enhanced by microorganisms present in the potential repository were extended from room temperature to 50°C. Stress-corrosion crack growth tests are being performed in a very severe environment used to distinguish between candidate materials. Results indicate that Alloy 825 (an iron-nickel-chromium-molybdenum alloy), which is a potential candidate for the inner barrier, became susceptible to stress-corrosion cracking after being in an acidified salt solution at 90°C for 30 to 90 days.

In the abstraction-testing workshop on waste package container degradation, some of the individual models for the different corrosion modes were consolidated. This was particularly true for those affecting the inner barrier material and its interaction with the corrosion products and remaining structure of the outer barrier.

Waste Form. Waste form activities included evaluations of commercial spent nuclear fuel and defense high-level waste glass dissolution and leaching, spent nuclear fuel oxidation, and thermodynamic data development for geochemical modeling. Tests on spent nuclear fuel included flow-through tests, and testing of commercial spent nuclear fuel in three types of unsaturated zone conditions: high drip rate, low drip rate, and vapor tests. Dry-bath weight gain tests are in progress to determine the oxidation response of spent nuclear fuel. Long-term unsaturated tests (drip tests) continued on two glass compositions (Savannah River Defense Waste Processing Facility and West Valley ATM-10). A glass alteration model has been developed for use in waste package performance modeling and is reported in the Waste Form Characterization Report.

A glass alteration model has been developed for use in waste package performance modeling.

In the abstraction-testing workshop related to waste form (waste form degradation and radionuclide mobilization), the highest ranked issues for spent nuclear fuel were dissolution/alteration rate, release rate, solubility limits, colloidal kinetics, and cladding degradation. High burnup spent nuclear fuel test samples were also identified as an issue. For high-level waste glass, the highest ranked issues were dissolution/ alteration rate, release rate, solubility limits, and colloidal kinetics.

Waste Retrievability. A waste retrievability study is being conducted to develop the technical rationale for the mined geologic disposal system design approach to be used for complying with the 10 CFR Part 60 requirements related to retrievability. This study will also identify potential scenarios concerning the final disposition of the retrieved waste. The Retrievability Strategy Report was completed in April 1997, and the related mined geologic disposal system retrieval design activity is scheduled to be completed at the end of fiscal year 1997.

Both the retrievability system study report and the related mined geologic disposal system retrieval design activity are scheduled to be completed next reporting period.

Performance Confirmation. A performance confirmation plan is being prepared. The plan will provide details of planned performance confirmation activities, including surface-based parameter evaluations, evaluations of model predictions, and corrective actions if necessary. As in the previously developed concept study report, the plan will (a) identify the processes to be simulated for postclosure performance

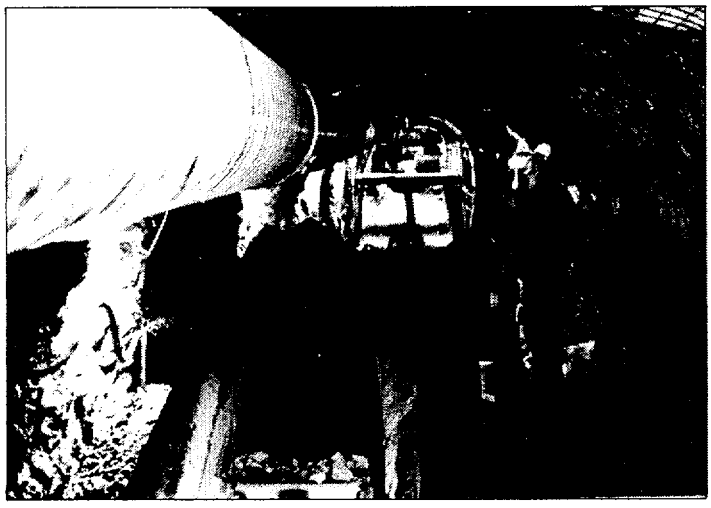
assessment in support of a license application, (b) list the site and mined geologic disposal system design parameters needed for these analyses, (c) from this list, recommend the parameters that need to be measured, monitored, observed, tested, and analyzed following the submittal of a license application to construct a repository, and (d) describe specific performance confirmation activities and facilities for performance confirmation data acquisition and related evaluations.

Exploratory Studies Facility Design and Construction

Activities associated with the Exploratory Studies Facility concentrated on completing the south ramp excavation and testing alcoves. Only surface support facilities necessary to support subsurface construction are being built. Construction of underground support and utility facilities continued at a rate needed to support the progress of the tunnel boring machine.

Very blocky ground reduced tunnel boring machine progress in December and January to 2.5 meters per excavation day

Exploratory Studies Facility. The tunnel boring machine is now tunneling up the south ramp and at the close of the reporting period was 132 meters from reaching the south portal and daylight. During the first two months of this reporting period, the tunnel boring machine advanced at an average rate of 21.6 meters per excavation day. Very blocky ground, however, was encountered in late November that significantly reduced progress, and during December and January the average advance rate fell to 2.5 meters per excavation day. The poor ground conditions required extensive material be removed by hand from around the tunnel boring machine before invert segments were installed. Almost continuous installation of steel sets for ground support was also required.



Northern Ghost Dance Fault Alcove construction

In early February, ground conditions improved significantly so that the tunnel boring machine advance rate averaged 20 meters per excavation day for the month. Under the present schedule, the tunnel boring machine is expected to reach daylight in April.

Alcove Construction. Three test alcoves were under construction this period. Excavation of the Thermal Testing Facility was completed in early February 1997 fulfilling a Project milestone. Construction is continuing in the Thermal

Testing Facility to support the planned drift-scale test scheduled to start in the first quarter of fiscal year 1998. Excavation of the access drift of the Northern Ghost Dance Fault Alcove was extended to its planned length of 134 meters, and the exploratory borehole was reentered and extended to locate the fault and testing on the fault began. The excavation of the drill-test room for the Northern Ghost Dance Fault Alcove began. In addition, the initial phase (about 143 meters) of the drift access for the Southern Ghost Dance Fault Alcove was completed.

Design work continued to support the Thermal Testing Facility and Northern Ghost Dance Fault Alcove. Designs for the excavation for the drift-scale heater test and associated test support features and the drill-test room for the Northern Ghost Dance Fault Alcove were issued for construction.

Programmatic Activities

Project planning and licensing activities were focused on activities to support the viability assessment of Yucca Mountain as a permanent geologic repository.

The Project baselined a revision to its long-range plan in December 1996.

Planning. The Project baselined a revision to its long-range plan in December 1996. The revision reflected the detailed fiscal year 1997 work scope and funding plan that was baselined on September 30, 1996. The long-range plan revision reaffirms the essential schedules, milestones, and key Yucca Mountain Site Characterization activities described in the revised Program Plan. The activities directly supporting the fiscal year 1998 viability assessment were planned in detail, consistent with the baselined long-range plan.

Regulatory Activities. Interactions with Commission staff and other organizations continued. Issue resolution activities were the main focus of several interactions with Commission staff. These interactions centered on defining the methodologies used to address the issues of seismic hazards, igneous activity, and criticality.

In response to Commission staff comments, the Department revised the first seismic topical report and resolved Commission staff comments on the second seismic topical report. Both reports are expected to be reissued next period. The Department plans to prepare the third and final seismic topical report in fiscal year 1998.

Two major interactions on igneous activity occurred this period. First, Commission staff provided three comments on the Department's process to complete the expert elicitation for the report of the Probabilistic Volcanic Hazard Analysis for Yucca Mountain. The report documented the results of the expert elicitation to assess the probability of disruption of the potential repository by an igneous eruption or intrusion, and also quantified the uncertainties associated with this assessment. The staff concluded that the elicitation process generally appeared consistent with the Commission's Branch Technical Position. The Commission staff also indicated that a path to resolve their comments on the use of expert judgment to supply licensing information has been addressed.

The Department and Commission staffs agreed on a path forward to resolving the igneous activity issue.

In the second interaction, Department and Commission staffs agreed on a path forward to resolving the igneous activity issue. At the completion of the exchange, they developed a list of agreements that will help resolve the issue.

Regarding the criticality issue, the Commission staff provided comments on the Disposal Criticality Analysis Methodology Technical Report. This report provides a preliminary description of the proposed risk-based disposal criticality analysis methodology. The staffs met to discuss and begin to resolve some of the comments. Revision 1 of this technical report is expected to be completed by the end of fiscal year 1997 and will provide the basis for a topical report that will seek Commission acceptance of the proposed methodology that will include the technical basis for burnup credit.

The Department completed the first part of the second phase of the transition of quality assurance functions from the affected organizations to the Department.

Quality Assurance. In quality assurance activities, the Department completed the first part of the second phase of the ongoing reengineering of the quality assurance function within the Program. This effort began in response to initiatives to improve the effectiveness of work in Departmental offices and also to cut costs. The implementation of this part of the reengineering plan was controlled by a transition plan that transferred the surveillance function performed by the individual affected organizations to the Department, effective in February 1997. The Department intends to implement the final phase to transition the remaining quality assurance functions to the Department during the next reporting period. In addition, in March the Department issued Revision 6 of the Quality Assurance Requirements and Description document, the principal Program quality assurance requirements document. This revision addressed and incorporated Commission comments concerning scientific investigation and design control.

Program Outreach. In Program outreach activities, Project staff completed a video that highlights Project activities completed during the last fiscal year. Also updated was the Project stakeholder plan that describes plans for fostering public involvement in Project activities.

Numerous educational activities continued, including operation of the Yucca Mountain Science Centers, scouting workshops, Science Bowl competition, Scout Expo '96, and a Futures Expo on career opportunities. Project personnel participated in ceremonies opening the Net Day '96 initiative in Nevada. This initiative was to connect schools to the Internet and had been supported by Project personnel through contributions and volunteer effort. For the Beatty Science Center, the Project compiled an album of historic photos of early native Americans for use in new cultural resource activities.

Activities at a science center

EPILOGUE

On April 25, 1997, the Project completed the excavation of the approximately five-mile tunnel of the Exploratory Studies Facility, which had begun in September 1994. This is a major Project milestone, and the completed tunnel serves as an underground laboratory providing scientists and engineers the opportunity to gather information not readily available from any other source. Scientific experiments in the tunnel and alcoves continue to provide valuable information to support the viability assessment and future activities such as the site recommendation and license application. Testing in the Thermal Testing Facility alcove of the tunnel also continued as the single-heater test moved into the cooling phase of the experiment. The nine-month heating phase was completed on May 28, 1997. The cooling phase will continue for approximately nine months. Data collected during the heating and cooling phases will be analyzed and compared with model results.

The Department extended for a third time the public comment period for its rulemaking activity for the proposed revision of its siting guidelines (10 CFR Part 960). The public comment period closed May 16, 1997. The Department expects to issue a final rule in mid-late 1998.

In June 1997, the Department approved a modification to the current fiscal year and long-range plan to include the construction of an

east-west cross drift. The effort will include design and construction of the drift, construction of three test alcoves, and drilling and testing supporting these excavations. Data from this construction will enhance scientific understanding of the behavior of the site, including engineering, construction, health, safety, regulatory, and performance aspects of the potential repository.

The Department is considering a revised format for the Progress Report that would provide a more succinct, high-level summary of the most important activities, or focal points of the Program. The revised format would include brief discussions of major activities, focus on items of greatest interest during the reporting period, and result in a significantly streamlined document. In generating this document, increased reliance would be placed on references for technical details and Appendix A would be the first reference to the Progress Report. Appendix A would be maintained as a separate referenced document and be revised once every six months. Provision of a streamlined Progress Report would provide readers with a more user-friendly document and meet the reporting requirements of the Nuclear Waste Policy Act and the Nuclear Regulatory Commission's 10 CFR Part 60.

CHAPTER 1 - INTRODUCTION

This Site Characterization Progress Report summarizes progress on site characterization activities at Yucca Mountain, Nevada, for the period October 1, 1996, through March 31, 1997. The report is the sixteenth in a series issued approximately every six months to report progress and results of site characterization activities being conducted to evaluate Yucca Mountain as a possible geologic repository for the disposal 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, as amended (NWPAA, 1987), and 10 CFR 60.18(g).

This 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 (Program) resulting from the ongoing collection and evaluation of site information, systems analyses, development of repository and waste package designs, and results of performance assessment activities. Details on the activities summarized can be found in the numerous technical reports cited throughout the progress report.

Yucca Mountain Site Characterization Project (Project) activities this period focused on implementing the near-term objectives of the revised Program Plan issued last period. Near-term objectives of the revised Program Plan include updating the U.S. Department of Energy's (DOE) repository siting guidelines to be consistent with a more focused performance-driven program; supporting an assessment in 1998 of the viability of continuing with actions leading to the licensing of a repository; and if the site is suitable, submittal of a Secretarial site recommendation to the President in 2001 and license application the U.S. Nuclear Regulatory Commission (NRC) in 2002. During this reporting period, the Project developed and baselined its long-range plan in December 1996. That revision reflected the detailed fiscal year (FY) 1997 work scope and funding plan previously baselined at the end of FY 1996. Site characterization activities have been focused to answer the major open technical issues and to support the viability assessment.

The following sections of Chapter 1 present Project history, outline the bases for the near-term objectives, discuss the DOE's strategies for achieving these objectives, and note progress in achieving these objectives. The chapters after this introduction describe Project activities that occurred during this reporting period that support the Program.

1.1 HISTORICAL PERSPECTIVE

The Project started in 1977 when the DOE began evaluating the possibility of disposing of high-level radioactive waste in a geologic repository at the Nevada Test Site. Over the next two years, the 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, the DOE conducted a formal screening of Nevada Test Site Area 25 (within which a part of Yucca Mountain lies). 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 (NWPA, 1993). As a result of this formal evaluation, the 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 high-level radioactive waste and spent nuclear fuel. The Act also created the OCRWM within the DOE and assigned that office the responsibility for developing a waste management system.

In response to requirements in Section 112(a) of the Act, the 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. In response to the issuance of the Environmental Assessment, surface-based studies at Yucca Mountain accelerated. Initially, these studies consisted of nonsurface-disturbing testing in existing exploratory boreholes and wells controlled by the government; analyses of, and experiments with, rock and water samples; geophysical surveys; meteorological, hydrologic, and seismic monitoring; geologic mapping; and sampling of surficial materials. From the mid-1980s to 1994, the DOE planned for and then conducted a comprehensive site characterization program based on the Site Characterization Plan (SCP) (DOE, 1988).

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, the OCRWM issued an SCP in accordance with the Act and continued conducting a program of detailed site-specific investigations and evaluations to assess the suitability of Yucca Mountain. The NRC issued its review of the SCP, the Site Characterization Analysis (NRC, 1989), in July 1989. This document identified points requiring clarification and NRC concerns in the form of comments, questions, and objections.

During the first half of FY 1994, the DOE conducted preliminary evaluations of various options for restructuring the repository program to meet changing needs and expectations. The 1988 SCP had presented a comprehensive testing, design, and performance assessment program. The scientific information obtained as the Project activities progressed was expected to be used to focus the Program on activities needed for site characterization and safety analysis. However, external and internal pressures since 1988 tended to broaden, rather than to focus the Program, and resulted in rising expectations about the level of certainty in understanding the natural geologic systems and the performance of engineered barriers in the geologic setting. By the late 1980s, Congress had begun to express concern about 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, the DOE developed and refined a new approach designed to show early observable progress within the financial resources likely to be available. The 1994 Program Plan, issued December 19, 1994 (DOE, 1994a), summarized the new approach, and the DOE began implementing this new approach during the first half of FY 1995.

By the end of FY 1995, however, Program redirection requested by Congress and consequent reductions in funding for FY 1996 again significantly altered the direction of the repository program described in the 1994 Program Plan. The DOE recognized that, because of the significant reduction in funding, a much reduced repository program would be required that, consistent with Congressional guidance, focused on the core scientific activities at Yucca Mountain and that deferred the preparation and submittal of a license application to the NRC. As a result, the target dates in the 1994 Program Plan for constructing a geologic repository and for emplacing waste underground also were deferred. The funding reductions resulted in curtailed site investigations and postponement of both the environmental impact statement and revisions to the annotated outline for the license application.

During the second half of FY 1996, the DOE released Revision 1 of the Civilian Radioactive Waste Management Program Plan in draft form (DOE, 1996a). This draft plan reflected a revised Program approach to be compatible with congressional guidance and expected funding levels and to answer the most critical technical issues remaining about the design of the repository and its expected performance in the geologic setting. This modified approach reflected the increased technical understanding of the Yucca Mountain site. This draft plan, as implemented by the Project's long-range plan (CRWMS M&O, 1996a) and annual fiscal year plans, incorporates a focused, integrated program of site characterization, design, and performance assessment that will result in a license application for a repository at Yucca Mountain, if the site is suitable. The Energy and Water Development Appropriations Act for FY 1997 in effect approved the DOE's new strategy and directed that a viability assessment of the Yucca Mountain site be submitted to the President and Congress by September 30, 1998.

1.2 OBJECTIVES OF THE REVISED PROGRAM PLAN

In its revised Program Plan, the DOE identified three near-term objectives: (1) updating in 1997 the DOE repository siting guidelines to be consistent with a more focused program driven by the results of performance analysis; (2) supporting an assessment by 1998 of the viability of continuing with actions leading to the licensing of a repository; and (3) if the site is suitable, submitting a Secretarial site recommendation to the President in 2001, and a license application to the NRC in 2002.

The following sections discuss the near-term objectives of the revised Program Plan.

1.2.1 1997 Update of Repository Siting Guidelines

A key element in the revised Program strategy is reviewing and proposing revisions to the DOE repository siting guidelines. Over the past decade, legislation has moved to characterization a single site instead of multiple sites and toward developing site-specific standards to protect the public. First, in 1987 Congress directed that the DOE characterize the Yucca Mountain site and terminate activities at the other sites. In 1992 Congress directed the U.S. Environmental Protection Agency to promulgate a site-specific standard for Yucca

Mountain for protection of the public. The NRC must then modify the technical requirements and criteria for licensing a repository (10 CFR Part 60) to be consistent with that site specific standard. Thus, the DOE proposes to amend its siting guidelines (10 CFR Part 960), which were promulgated in 1984, in response to these national policy changes and to increasing technical understanding of the Yucca Mountain site.

The proposed revisions to the siting guidelines are intended to eliminate the comparative siting criteria for evaluating the suitability of the Yucca Mountain site for development as a repository. Instead, the DOE is proposing to add a site-specific subpart focused on the overall performance of the repository system during operations and after closure, rather than separately evaluating individual aspects of the site. An overall system performance approach is the appropriate method to consider all relevant site features because it identifies in an integrated manner those attributes of the site and engineered components that are most important to the protection of public health and safety.

The DOE is using a public rulemaking process to modify 10 CFR Part 960, which began with a Notice of Proposed Rulemaking (61 FR 66157) issued for public comment. The Notice of Proposed Rulemaking published on December 16, 1996, began a public comment period that is scheduled to close next reporting period. The DOE expects to issue a final rule in mid-late 1998. When implemented, the regulatory changes should streamline the process for site evaluation and repository development, while protecting public health and safety and the environment.

1.2.2 1998 Viability Assessment

The second principal objective of the revised plan is to address by 1998 the major open technical issues, including those related to the waste containment and isolation strategy, so that an informed assessment can be made of the viability of licensing and constructing a geologic repository at the Yucca Mountain site.

The viability assessment is not the same as the site suitability determination and site recommendation. Rather, it is a step along the way that is essential for the rational completion of the site recommendation. The viability assessment has two purposes: first, to guide the completion of the work required for an evaluation of site suitability and preparation of a license application, and second, to provide the legislators with a better estimate of the viability of a geologic repository at the Yucca Mountain site.

The viability assessment is a logical convergence point at which the DOE can make an improved appraisal of the prospects for geologic disposal at Yucca Mountain using the results of the program first described in the 1988 SCP and the results from the excavation of the Exploratory Studies Facility. These results allow the DOE to develop an integrated picture of the repository system at the site that was previously impossible.

The evaluation of the site will not be finished in 1998, but the assessment will bring many individual data elements together into a comprehensive perspective for the first time. The information produced for this viability assessment will be an important validation of the practicality of the existing national policy of geologic disposal and will allow policy makers to make a measurably improved judgment of the prospects for recommending Yucca Mountain for repository development and licensing to authorize construction. When the data and information are delivered, policy makers may determine that the current program should be changed or amended or that DOE should continue to implement the revised Program Plan. Currently, the Project is concentrating most of its effort on supporting the viability assessment.

1.2.3 Site Recommendation and License Application

If the site is determined to be suitable, the DOE would proceed with issuing the statutorily prescribed environmental impact statement and Secretarial recommendation to the President. If the site were approved by the President, the DOE would submit a license application to the NRC in 2002.

Environmental Impact Statement

The Nuclear Waste Policy Act of 1982, as amended, requires that a final environmental impact statement accompany any Secretarial site recommendation to the President. Any such environmental impact statement would be adopted to the extent practicable by the NRC in connection with the issuance of a construction authorization and license. The environmental impact statement process began with the Notice of Intent published in the *Federal Register* on August 7, 1995. The public comment period closed December 5, 1995, following 15 public meetings across the nation. Because of decreased Project funding for FY 1996 and direction provided by Congress in that fiscal year appropriation, preparation of the environmental impact statement was deferred until this reporting period. Work has now begun on reviewing and summarizing public scoping comments, gathering data, and identifying data needs. The draft environmental impact statement is scheduled to be issued in FY 1999 and the final environmental impact statement issued in FY 2000.

Site Recommendation

If the site is determined to be suitable with respect to the then-existing siting guidelines, a decision to recommend to the President that the site be approved for development as the nation's first high-level waste repository is expected in FY 2001. In FY 2000, the DOE would inform the public that it is considering a site recommendation and would announce a schedule for public hearings on the possible site recommendation. After the hearings and before recommending the site to the President, the DOE would notify the State of Nevada about the decision to recommend the site.

As required by Section 114 of the Nuclear Waste Policy Act of 1982, the basis for the decision on the site recommendation would include (a) a description of the proposed repository, including preliminary engineering specifications; (b) a description of the waste form or packaging and an explanation of the relationship between the geologic environment and the waste packages and waste forms; (c) a discussion of data obtained during site characterization relating to the safety of the site; (d) the final environmental impact statement; and (e) preliminary comments by the NRC concerning the sufficiency of site characterization. The site recommendation also would include the views and comments of the Governor of the State of Nevada, the State legislature, and any affected Indian tribe, as well as other information the Secretary of Energy considers appropriate and any impact report submitted by the State.

A Project Integrated Safety Assessment, scheduled to be completed in 1998, will present integrated information about the technical elements of the Program. This document will describe and integrate information on site conditions, repository and waste package design, and performance assessment. After completion, the document will be provided to the NRC for review as one basis for its preliminary comments on the sufficiency of information on the site and design for inclusion in a license application. The Project Integrated Safety Assessment will be used as the starting point for developing the license application.

License Application and Revised Approach to Licensing

The goal of submitting a successful license application remains central to the Program's mission. The technical reports and supporting data associated with the components of the viability assessment will help improve the understanding of the repository concept, and provide a comprehensive appraisal of the prospects for licensing and constructing a geologic repository at Yucca Mountain. Although the information will not be sufficient for licensing, this work is a logical step toward developing a first-of-a-kind repository. In completing the license application, the Project will define a repository concept that includes a facility and waste package design consistent with the characteristics of the Yucca Mountain site and will assess the performance of this repository. Appropriately, the DOE will develop a repository concept and ensure that it adequately protects public health and safety before seeking approval from outside parties. In so doing, the Project will examine alternatives and will propose a repository system that can be achieved within rational cost and schedule restraints.

During this reporting period, the DOE began developing three products that will support development of the license application: the License Application Plan, the License Application Management Plan, and the Technical Guidance Document for License Application Preparation. As described in Section 1.2.2, the License Application Plan is one of the products of the viability assessment and will describe the work to be performed between the viability assessment and the license application.

The License Application Management Plan will provide the management framework within which the license application will be developed. Information included will be the layout of the license application, the document control process for the license application, and a step-by-

step description of the process by which the license application will be developed. The management plan is expected to be completed by the end of FY 1997.

The Technical Guidance Document for License Application Preparation will provide guidance to authors on the technical and licensing content of their license application chapters. The technical guidance document will list the regulatory requirements applicable to each chapter and will provide acceptance criteria for the authors to use to verify they have provided an adequate licensing case in their chapters. The document will also describe how industry standards and other available guidance should be used in the licensing case to be presented in the license application. The initial guidance document is scheduled to be completed by the end of FY 1997. At that time, some of the regulatory requirements and acceptance criteria will still be under development, so this initial document will still have gaps and will provide interim guidance.

The DOE believes that interactions with the NRC staff before the license application should focus on two objectives: reaching a common understanding regarding the issues that are significant to overall repository performance, and reaching agreement on the adequacy of proposed methodologies and approaches to address important technical issues such as criticality control and seismic design. The goal is to reach a mutual understanding of the repository concept as it develops. This understanding will provide a basis for NRC preliminary comments (to be included in the DOE site suitability package) on the sufficiency of site characterization and design for inclusion in a license application.

This approach is a departure from previous efforts that focused on resolving individual issues related to specific site characteristics in isolation from one another or from a specific design concept. The DOE believes the sufficiency of site characterization data and analyses can only be determined within the context of a coherent repository concept that includes both design and system performance. Thus, the DOE will first develop the overall repository concept before addressing specific issues related to licensing. The DOE will seek insights from the NRC staff throughout this process regarding issues affecting licensing and approaches and methodologies for addressing specific technical issues. This reporting period, interactions continued with the NRC staff on the issues of seismic hazards, igneous activity, and repository criticality.

Since the NRC's 1989 revision of 10 CFR Part 2, including a new Subpart J that required the DOE to design and develop an electronic information management and distribution system (designated the Licensing Support System) was issued, discussions with the NRC have led to an understanding that most of the requirements for a Licensing Support System may be met by using available Web technology. The NRC and DOE are actively pursuing alternative solutions to a Licensing Support System. While the NRC is proposing reasonable alternatives to a Licensing Support System in a rewrite of Subpart J, Project staff is reprocessing records into a format that will allow access via the Internet or transfer to a Licensing Support System if that requirement remains and prototyping an electronic format for licensing documents. The prototype effort is expected to conclude in June 1997 and will allow the DOE to determine whether electronic licensing documents are feasible and the manner in which such documents should be generated.

Linkages from a licensing document to its supporting documentation would provide easy traceability for reviewers.

The current strategy recognizes that additional information would be obtained through continued surveillance, measurement, testing, analysis, and performance assessment during the construction and operation of the repository. This information would be reflected in subsequent license application updates and amendments.

Beyond license application submittal, the Project would place high priority on those tests designed to enhance 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 provide key information. The Project also would give high priority to confirming the behavior of engineered barriers within the range of expected repository conditions.

If the NRC issues a license to receive and possess spent nuclear fuel and high-level radioactive waste, the scientific work will focus on verifying the terms and conditions of the license with regard to site and repository characteristics and performance and on obtaining data on changes to the site caused by repository construction and waste emplacement. The object 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 application for a license amendment to close the repository will not be submitted until sufficient confirmatory test information is available to provide adequate confidence to support a decision to close the repository. The repository will be designed and operated to preserve the option to retrieve the emplaced waste for up to 100 years after the beginning of waste emplacement, or until the NRC decides to permit permanent closure. A decision to exercise the retrieval option may be made on the basis of the results from performance confirmation, or it may be prompted by a policy decision related to geologic disposal of spent nuclear fuel, or recycling of fissile material in nuclear reactors.

1.3 WASTE CONTAINMENT AND ISOLATION STRATEGY

The waste containment and isolation strategy is being used to focus the remaining effort to the viability assessment and to guide the work beyond the viability assessment. The strategy focuses on two technical objectives: first, to limit the annual dose to members of the general public following permanent closure of the repository; and second, to provide total containment of the waste within the emplaced waste packages for thousands of years during the period of highest radionuclide inventory and temperature. The strategy outlines the approach to addressing and resolving postclosure performance issues for licensing and also focuses the science and design work needed to determine postclosure performance in the period leading to the viability

assessment and beyond. The strategy also incorporates new site information and designs, realistic performance predictions, and potential regulatory changes.

A summary version of the strategy was completed and distributed to the Nuclear Waste Technical Review Board and to the NRC in July 1996. After the summary was completed, new information derived from interpretations of several site investigations indicated the potential for average flux values at the repository horizon in the range of 1 to 10 millimeters per year or even higher, with a part of this flux associated with fast pathways. Percolation flux affects all the system attributes identified in the strategy as most important for predicting the performance of the engineered and natural barriers: rate of water seeping into the repository, waste package lifetime (containment), rate of release of radionuclides from breached waste packages, radionuclide transport through engineered and natural barriers, including dilution in the saturated zone below the repository. Higher percolation flux could mean shorter travel times to the accessible environment, an increase in the number of waste packages being dripped on, higher relative humidity, and a reduction in the ability of the heat from the waste to drive water in the host rock away and to produce and maintain a dry repository. Determining percolation flux is particularly challenging because no method is available to measure these low flux values. Also, empirical data are scarce and there is a need for further study. Thus, the DOE began re-evaluating the strategy. A revised summary is scheduled to be issued next reporting period.

The percolation flux information has far-reaching effects, impacting design, performance assessment, and cost—the components of the viability assessment. Thus, the evolving flux information and unsaturated zone models will be factored into the ongoing work toward viability assessment, site recommendation, and license application.

The viability assessment will include:

1. The preliminary design concept for the critical elements for the repository and waste package;

2. A total system performance assessment, based upon the design concept and the scientific data and analysis available by September 30, 1998, describing the probable behavior of the repository in the Yucca Mountain geological setting relative to the overall system performance standards;

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

4. An estimate of the costs to construct and operate the repository in accordance with the design concept.

The following sections describe these deliverables and report current status.

Repository and Waste Package Design

The first component of the viability assessment— repository and waste package design—addresses those design elements critical to determining the feasibility and performance of the repository and engineered barrier system. The effort will evaluate the technological feasibility of the designs but will not develop all the detail needed for licensing.

The repository and waste package designs build on previous work, including the Mined Geologic Disposal System Advanced Conceptual Design Report (CRWMS M&O, 1996b) that was published in March 1996. The Project continues its philosophy of a phased and evolving design that will support the viability assessment, environmental impact statement, site recommendation, and license application. Current design is focusing on designing systems, structures, and components that have little or no regulatory precedent and have a major impact on performance assessment, schedule, constructability, and cost. These issues, based on the waste containment and isolation strategy, arise from thermal management of the waste-generated heat, the role of supplemental engineered barriers, corrosion of waste packages, and dissolution of radioactive wastes.

Scientific and engineering information obtained during testing and analysis of data from the Exploratory Studies Facility will be incorporated into the designs. Site programs and performance assessment activities will provide data and criteria for designs. The designs will serve as a basis for estimating repository costs and schedules and for identifying additional design work needed for licensing. The design information will also be used as an input to the total system performance assessment that will support the viability assessment.

This period in keeping with its design philosophy, the Project began developing guidance to support its phased design approach toward licensing. Design activities this reporting period include modifying waste handling operations to reflect the de-emphasis of the multi-purpose canister and performing design analyses (including structural, thermal, shielding, and criticality) to accommodate uncanistered spent nuclear fuel. In addition, laboratory tests are being performed on waste package materials and waste forms to provide input for waste form degradation process models.

Total System Performance Assessment

The second component of the viability assessment—total system performance assessment—will describe the probable behavior of the repository system consisting of the natural and engineering systems and calculate the variation and uncertainty in this performance.

The performance assessment, scheduled for the 1997-1998 time frame, will reflect an integrated site and engineered system using design concepts and data available at that time. Uncertainties will continue to exist in the characterization of both the engineered component and natural system processes. These uncertainties will be reflected in the alternative conceptual models and parameter distributions considered in the analyses. Thus, the performance

assessment also will evaluate the possible range of performance caused by uncertainty in key factors, such as ground-water flow, thermal effects, and corrosion.

To ensure that the bases for the assessment are valid and defensible, the Project has developed a process to perform an integrated total system performance assessment to support the viability assessment. Model development must be focused on issues that are most important to performance. To ensure traceability (a complete and unambiguous record) and transparency (ease of understanding by the reader and reviewer), the bases for assumptions and results must be clear, readable, complete, and documented. Traceability and transparency are continuing concerns of both the Project and the NRC, and these concerns were also raised by the Performance Assessment Advisory Group of the Nuclear Energy Agency. This group compared and evaluated the specific technical approaches of ten recent system assessments, including two that address Yucca Mountain (one by DOE and one by NRC). In their review, the group noted problems in traceability and transparency.

As a critical step to ensure traceability, a process was established to ensure that performance assessments properly reflect results from the highly detailed and computationally intensive site and engineered system models and from the scientific data that constitute the basis of these models. The activities are designed to integrate the work of site characterization, design, environmental programs, and performance assessment. It is not feasible nor efficient to incorporate all the complexity inherent in all the specific process models into a probabilistic total system performance assessment calculation. Instead, abstracted models are used as surrogates for the comprehensive process models. The abstracted models must, however, maintain the essential elements of the process model, including key interdependencies. Several processes have been identified as key: unsaturated zone flow, thermohydrologic flow, waste package degradation, near-field environment, waste form alteration and mobilization, unsaturated zone transport, saturated zone flow and transport criticality, and biosphere. This abstraction process is critical to the success of the Project.

For the total system performance assessment supporting the viability assessment, Project staff have undertaken an extensive program of defining, developing, and testing abstracted models in the nine technical disciplines most important to repository performance. The abstraction and testing activities occur in three steps. The first step is the planning needed to identify a preliminary list of issues and the activities to be accomplished. The next step is to hold a workshop to develop a consensus on the relative importance of issues related to the process model and to develop plans to analyze the highest ranked issues. The workshops include data collectors, process modelers, subsystem performance assessment modelers, and total system performance assessment modelers. Following the workshops, the third step occurs when the details of the abstraction-testing plans are completed and the analyses and testing performed.

This reporting period, seven workshops were held, and two more workshops are scheduled for next period. The abstraction workshops are only one of several measures the Project is taking to ensure the traceability and transparency of the total system performance assessment supporting the viability assessment. Two other measures, plus their accompanying records, are being used to ensure traceability.

First, a formal expert elicitation process has been instituted. In support of the assessment for the viability assessment, this process will follow the nine-step process outlined in the NRC's Branch Technical Position on the use of expert elicitation (NRC, 1996a). The purpose of this process is (a) to quantify and document the uncertainties in the process models to strengthen the assessment and (b) to focus on process models that are very significant to total system performance. This process is currently under way on the site-scale unsaturated zone flow model—one of the most important of the foundational process-level models. A series of three workshops involving data collectors and analysts, modelers, and nationally recognized experts in the field of unsaturated zone flow characterization was conducted.

Second, a peer review panel of external experts has been established to monitor and review the preparations for the assessment, as well as the final product itself. The peer review panel will first review the previous total system performance assessments from 1991, 1993, and 1995 and make observations on the plans, approach, and assumptions for the assessment to support the viability assessment. The reviewers will also review the process modeling and the abstraction process. Finally, they will provide a formal peer review of the assessment supporting the viability assessment and the comments and recommendations will be incorporated into the assessment that will support the license application. During this reporting period, the peer review panel was convened and its orientation began.

Besides the steps to ensure traceability, the Project is also using specific measures to ensure transparency. An initiative is starting to examine ways of presenting the total system performance assessment results graphically so that they would be more easily understood by those who are not performance assessment specialists. The Project is also investigating using hypertext to increase the reviewer's electronic access to data sources and cited materials and developing a computerized data retrieval and selection system to help trace and document decisions made in data selection.

License Application Plan

The third component of the viability assessment—license application plan—will define the work required to complete a license application. Submittal and docketing of a license application to the NRC, should the Yucca Mountain site be found suitable, is the DOE's central goal.

During this reporting period, Project staff began developing the License Application Plan, which will guide the development of the license application. The plan will describe Project work to be performed between the viability assessment and the license application, and give a schedule and a cost estimate for this work. The plan will also outline the Project's licensing strategy, describe the license application content requirements specified by 10 CFR 60.21, and describe the performance confirmation plan. The information developed for the License Application Plan will also be used to support the development of the license application, if the site is determined to be suitable. The draft plan is scheduled to be completed late in FY 1997.

Cost and Schedule Estimates

A set of estimated costs and schedules for the repository system is the fourth component of the viability assessment. The estimates will encompass completion of site characterization, performance confirmation, and construction, operation, and closure of a repository. The cost and schedule estimates will be a factor in policy decisions regarding the feasibility of and justification for continuing with the licensing and construction of a geologic repository.

The estimates will be based on the repository and waste package designs developed for the viability assessment and on scientific testing and analyses completed by 1998. Because not all the details of the design will be developed fully by the 1998 viability assessment, some design assumptions will be used to complete the estimates.

Work began this period on developing the cost to construct and operate a repository. The cost estimating process includes the development of a cost analysis document that will summarize the assumptions to support the cost estimate, the development of a life cycle cost schedule, and the identification of models to be used in the estimate. The cost analysis document will also define data bases and data sources used and will contain a draft cost estimate for review. This reporting period, the Project generated an annotated outline for the cost analysis document, updated the cost account structure, updated cost models, and developed a life cycle cost schedule. Work is continuing on assembling model descriptions for each cost module, assembling assumptions, collecting and integrating data, and generating a draft of the cost analysis document summarizing the FY 1997 work.

Progress Report

1.4 PROGRESS REPORT CONTENT

As shown in the box on Page 1-13, the main chapters of the progress report deal with programmatic, site, design and construction, and performance assessment activities. Various appendixes support the main text. This report reflects the information available and the status of the Project as of March 31, 1997. An Epilogue has been added at the end of the Executive Summary to identify important events occurring after the close of the reporting period and before the report is printed.

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 summary of major decisions, accomplishments, and issues of interest during the reporting period.

CHAPTER 2 - PROGRAMMATIC ACTIVITIES

This chapter reports the results of the Yucca Mountain Site Characterization Project (Project) planning and regulatory activities, including baseline control, environmental compliance, and licensing. Other programmatic activities reported include those in quality assurance (QA) and public outreach. Programmatic activities focus, evaluate, plan, control, and ensure the quality of site characterization, design, and performance assessment activities.

Programmatic activities this period focused on supporting two of the three near-term objectives of the U.S. Department of Energy's (DOE) revised Program Plan: updating in 1997 the regulatory framework for determining the suitability of the site for the proposed repository concept and providing information for a 1998 viability assessment of continuing toward the licensing of a repository (DOE, 1996a). The key features of the revised Program Plan, as well as DOE's philosophies for achieving its near-term objectives, are discussed in Chapter 1. The following summarizes the notable programmatic accomplishments during this reporting period.

In line with the goals of the Plan, the DOE published a Notice of Proposed Rulemaking on December 16, 1996 (61 FR 66157), to amend its siting guidelines in 10 CFR Part 960 by adding a new site-specific subpart for Yucca Mountain. Public comments are currently being taken, and the public comment period is scheduled to close next period. In other planning and control activities, the Project baselined a revision to its long-range plan. The revision reflected the work scope and funding plan for fiscal year (FY) 1997.

In regulatory activities, the U.S. Nuclear Regulatory Commission (NRC) staff and DOE identified several points of agreement that define a path for resolving the issue of igneous activity. Work began on three documents that will support the development of the license application: the License Application Plan, the License Application Management Plan, and the Technical Guidance Document for Preparation of the License Application.

Additional progress was made in reengineering the QA function within the Office of Civilian Radioactive Waste Management (OCRWM) Site Characterization Program (Program). This is a phased transition of QA functions from the individual affected organizations to the OCRWM Office of Quality Assurance; the transition is expected to be complete in the next reporting period. Once complete, the Office of Quality Assurance would have complete responsibility for all QA functions within the OCRWM Program.

Details of these and other programmatic activities are presented in the rest of the chapter.

2.1 PROJECT PLANNING AND BASELINE CONTROL

The Project baselined a revision to its long-range plan and also began implementing the recommendations for streamlining the document hierarchy. The Mined Geologic Disposal System (MGDS) Requirements Document is currently being revised, and when approved, that revision will affect several of the Project regulatory and management control documents.

2.1.1 Project Planning and Scheduling

The Project baselined a revision to its long-range plan in December 1996. That revision reflected the detailed FY 1997 work scope and funding plan that was baselined on September 30, 1996. The long-range plan revision reaffirms the essential schedules, milestones, and key Yucca Mountain site characterization activities described in the revised Program Plan.

Detailed annual planning for FY 1998 work scope is being carried out in stages. The activities directly supporting the FY 1998 viability assessment were planned in detail during this reporting period using an integrated schedule and detailed basis-of-estimates (a correlation of the scope of work and the resources required to complete the work). The detailed planning is consistent with the baselined long-range plan, although some schedule adjustments have been made. No major Project milestones have been negatively impacted.

Forecast: The remainder of the FY 1998 activities will be planned, but not to the level of detail as those activities directly supporting the viability assessment. Instead, a compilation of all activities will be costed, analyzed, and prioritized. Some adjustments may be made to the detailed scope or schedule to accommodate required work interfaces and to remain within the administration's budget submittal. This work will support a further update to the Project long-range plan that will also address results of Project work accomplished to date. During the last quarter of FY 1997, the detailed Project annual plan for FY 1998 will be prepared and baselined.

2.1.2 Document Hierarchy and Program Baseline

The Civilian Radioactive Waste Management System (CRWMS) Document Hierarchy for OCRWM identifies both Program- and Project-level documents, including both regulatory and management documents. During this reporting period, streamlining of the document hierarchy, as recommended by the Technical Baseline Hierarchy Task Group, was approved, and implementation began. The recommendations of the task group were incorporated into baseline change proposals. The changes incorporated included (a) moving the MGDS Requirements Document from Program-level control to Project-level control; (b) replacing the existing repository and engineered barrier requirements documents with the MGDS Requirements Document; and (c) moving the repository and engineered barrier requirements documents to the CRWMS Management and Operating Contractor (M&O) control until the system design documents are approved and controlled by the Change Control Board. Implementing this streamlining of the document hierarchy will directly affect the requirements documents listed in Appendix B.

2.1.2.1 Regulatory and Management Controls

Changes in Project-level documents that control both regulatory and management activities were made during this reporting period. The MGDS Requirements Document (DOE, 1996b) was revised to coincide with Revision 3 of CRWMS Requirements Document and the

Technical Baseline Streamlining Initiative. Revision 3 of the MGDS Requirements Document is in review. The Controlled Design Assumptions Document (CRWMS M&O, 1996c) is being revised to incorporate key design assumptions supporting the viability assessment. Changes to several documents, however, are on hold pending the completion of the current revision of the MGDS Requirements Document.

Forecast: When Revision 3 of the MGDS Requirements Document is approved, the repository and engineered barrier requirements documents will be removed from Level 2 Change Control Board control. The changes in Project-level documents that control both regulatory and management activities as identified in the current CRWMS Document Hierarchy are summarized in Appendix B.

2.1.2.2 Change Control Board Actions

The mission of the Project Change Control Board is to ensure that changes to the Project baseline or documents controlled by the Change Control Board are made with adequate consideration of the technical, regulatory, QA, programmatic, and cost and schedule impacts that such a change would have on each element of the Project. Change control, as exercised by the Change Control Board, prevents unnecessary, untimely, or marginal changes and expedites the approval and implementation of changes that are needed to significantly benefit the Project.

Appendix C provides a table summarizing significant changes presented to the Project Change Control Board since October 1, 1996. The changes exhibit cost, schedule, and work scope activities that impacted the cost and schedule baseline.

Forecast: Changes to regulatory and management control documents will proceed following the completion of the current revision of the MGDS Requirements Document.

2.2 REGULATORY ACTIVITIES

Regulatory activities associated with suitability, environmental compliance, and licensing (including interactions with the NRC) continued this reporting period to support the near-term objectives of the revised Program Plan.

2.2.1 Suitability Activities

The DOE published a Notice of Proposed Rulemaking in the *Federal Register* on December 16, 1996, (61 FR 66157) to amend its siting guidelines in 10 CFR Part 960 by adding a new site-specific subpart for Yucca Mountain. A public hearing was held in Las Vegas, Nevada, on January 23, 1997, as part of the public comment process. In response to comments received from the public, the original 60-day public comment period that began on December 16, 1996, was extended to 91 days. This extension was announced in a second *Federal Register*

notice on February 3, 1997, (62 FR 4941). A second 30-day extension was announced in a third *Federal Register* notice on March 20, 1997 (62 FR 13355). This notice extended the public comment period to April 16, 1997.

Forecast: A draft final Notice of Proposed Rulemaking will be prepared after the DOE has considered the public comments. The draft final version will then be submitted to the NRC for their concurrence review.

2.2.2 Environmental Compliance Activities

During the reporting period, several environmental surveys and permitting actions were completed for new and planned site characterization activities at Yucca Mountain. Progress in these areas is reported in this section.

2.2.2.1 Permits

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

Water Quality

Quarterly bacteriological sampling of the Exploratory Studies Facility (ESF) potable water system, required by the Nevada Department of Health, continued this reporting period. The state-certified laboratory that analyzed the samples reported the absence of coliform bacteria in the system. In addition, as required by the septic tank general discharge permit, the annual discharge monitoring report, filed in January 1997 for the ESF septic/leachfield system, documented compliance with permit conditions.

Two waiver time extensions for permits 58827 and 58829 were submitted to the State Engineer for continued testing at the boreholes at the C-hole complex.

Forecast: Submittal of water quality permits will continue in FY 1997, as needed.

Air Quality

On November 25, 1996, a revised Air Quality Operating Permit No. AP9611-0573 was received. The revised permit included numerous clerical corrections and the following three changes requested by the Project: (1) the deletion of the grout batch plant, the CME 85 drill rig, and two Top Head Drive Core drill rigs; (2) the reduction of annual operation hours for the LM300 drill rig; and (3) the reduction of annual operation hours for the Atlas Copco air compressors. The reduction in hours will help maintain the threshold for the Class II Air Quality Operating Permit.

Forecast: Because of changing Project needs, a change in operational hours for certain permitted air emission sources is projected in the second half of FY 1997. The submission of new air quality operating permit applications will continue in FY 1997, as needed.

Underground Injection - Drilling and Tracers

Two tracer tests were requested for the C-hole complex. The tests were conducted to evaluate hydrogeologic properties of the Bullfrog Formation. Tracers currently approved under the Underground Injection Control Permit UNEV89031 were used. Approval was granted by the State of Nevada for the following tests:

1. Injection of lithium bromide, pentafluorobenzoic acid, and fluorescent microspheres in borehole UE-25 c#2 at C-hole complex. Approval was granted on October 8, 1996.

2. Concurrent injection of pyridone into borehole UE-25 c#1 and difluorobenzoic acid into borehole UE-25 c#2 and at C-hole complex. Approval was granted on December 16, 1996.

Approval from the State of Nevada was granted on October 11, 1996, for a request to install an inflatable borehole liner at borehole USW UZ-14. The liner is a temporary instrument capable of providing ambient pneumatic data. The liner was installed in November 1996.

On November 26, 1996, the second ventilation tracer test for the ESF ventilation system was requested. The second test was to evaluate leaks at both the tunnel boring machine cutter head and the trombone air inlet area. The use of 3.75 cubic feet of sulfur hexafluoride tracer was requested, and approval was granted on December 16, 1996. The test was conducted on February 26, 1997.

A letter proposing the use of oil skimmer-treated water for dust control was submitted to the State of Nevada on January 29, 1997. Approval is expected in early April.

Forecast: Tracer requests for drilling new boreholes into the water table and conducting pump tests are expected in the second half of FY 1997. Submittal of additional tracer test requests for the C-hole complex and the ESF ventilation system will continue in the second half of FY 1997, as needed. A request to modify the underground injection control permit to include new reactive tracers proposed for C-hole testing is also projected in the second half of FY 1997.

2.2.2.2 Environmental, Safety, and Health Assessments

Comprehensive and focused, special-issue environmental, safety, and health assessments are performed under a Project proactive assessment program to evaluate organizational and programmatic compliance with Federal and State statutory requirements, DOE Orders, and Project plans and procedures. Comprehensive assessments evaluate a broad range of environmental, safety, and health topics in a specific organization or Project-wide program.

Focused special-issue assessments examine a particular program element, a potential noncompliance condition, or a specific area of concern that is time-sensitive or requires immediate attention.

Comprehensive assessments during this period evaluated the Radiation Protection Program and the Permit Compliance Program. Both programs were found to be in compliance with external regulatory and Project-directed requirements. Recommendations were provided to improve those program elements and practices relating primarily to administrative and training requirements. Focused assessments performed during this period evaluated the management of hazardous waste satellite accumulation areas, used oil, and heavy equipment relative to applicable environmental, safety, and health requirements. As an overall result of these assessments, specific program elements were revised and implemented to improve management practices in these areas. Another assessment examined trends from all past assessments and identified general areas where opportunities exist to enhance specific environmental, safety, and health program elements.

Forecast: Two comprehensive Environmental, Safety, and Health Assessments and four focused, special-issue assessments are planned for the period April 1, 1997, through September 1997.

2.2.2.3 Environmental Surveillance

Approximately 140 environmental surveillances were conducted at the Yucca Mountain site to ensure compliance with environmental, programmatic, and permit requirements. Corrective action and follow-up work were required on 17 (12 percent) of the surveillances, and 3 (about 20 percent) of those follow-up activities were completed during this reporting period.

Forecast: Approximately 170 surveillances are projected for the second half of FY 1997. Remaining corrective action and follow-up work from the first half of FY 1997 will be completed during the second half of FY 1997.

2.2.2.4 Preactivity Surveys

During this reporting period, three land access and environmental compliance activity reviews were completed, and one partially completed preactivity survey for the south portal was canceled because of a requirements change. The preactivity process involves acquiring land access approvals and right-of-way reservations and completing environmental preactivity surveys (which include archaeological, biological and, in certain instances, radiological surveys) before any Project site activity can be initiated. During the first half of FY 1997, one request to initiate preactivity surveys was received.

Forecast: Approximately three to six land access and environmental compliance activity reviews are expected to be completed during the second half of FY 1997.

2.2.2.5 Land Acquisition and Site Access

One new participant request to initiate a site characterization activity was received during this reporting period. The request (Installation of Seismic Stations by Los Alamos National Laboratory) was completed and access authorization granted.

Three requests from the last reporting period have not yet been completed. These include two requests (Installation of University of Nevada, Reno, Seismological Laboratory Seismic Instrumentation in Y-Tunnel and Post Activity Survey for Four Seismic Stations) that are awaiting Nevada Test Site Operations Permits. The third request (Amargosa Desert Digital Seismic Station for Southern Great Basin Seismic Network) is awaiting a right-of-way reservation from the Bureau of Land Management.

Forecast: Three to six land access and environmental compliance activity reviews are expected to be completed during the last half of FY 1997.

2.2.3 Licensing Activities

The DOE's eventual goal is to obtain the necessary licenses and permits for the repository, if the site is found suitable. In pursuit of this goal, licensing activities included the management of and participation in interactions with the NRC and other oversight organizations. These interactions help to clarify regulatory and technical issues and to reach a common understanding of regulatory requirements.

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 interactions between DOE and NRC, meetings of the Advisory Committee on Nuclear Waste, and meetings of the Nuclear Waste Technical Review Board. Appendix D tabulates the interactions with each of the following agencies.

U.S. Nuclear Regulatory Commission

From October 1996 through March 1997, the DOE participated in several interactions with the NRC, including one technical exchange on the igneous activity program. In addition, there were two technical meetings (on ESF construction, scientific studies and testing, and design status) and two management meetings. Numerous informal interactions also occurred between DOE personnel and NRC onsite representatives, including regularly scheduled meetings with the Yucca Mountain Site Characterization Office (YMSCO) Project Manager and Assistant Managers. Also, three Appendix 7 meetings, one on Disposal Criticality Analysis Methodology, one on Level of Design Detail, and one on Seismic Topical Report II (DOE, 1996c) tectonics models were held during this period. Appendix 7 meetings are informal meetings conducted

under the procedures outlined in Appendix 7 of a procedural agreement between NRC and DOE on the principles for interface during geologic site investigation and site characterization (DOE, 1993a). Appendix 7 deals specifically with NRC onsite representatives.

The DOE and the NRC hold periodic management meetings to provide a forum for management-level discussions of issues and concerns associated with the Yucca Mountain Site Characterization Project and other aspects of the CRWMS program. Two such meetings were held on October 23, 1996, and January 15, 1997, by video conference among multiple sites. The locations involved were YMSCO, DOE Headquarters, NRC Headquarters, and the Center for Nuclear Waste Regulatory Analyses in San Antonio, Texas. These meetings covered a number of topics, including an update of the Program Plan and budget, the legislative process, an update of Office of Waste Acceptance and Storage and Transportation activities, and regulatory and licensing issues and topics. The regulatory and licensing topics discussed included the status of 10 CFR Part 960, an update on DOE documentation of decisions, the development of the third seismic topical report, an update of the licensing support system, and NRC QA concerns. Also, an overview was presented of the NRC High-Level Radioactive Waste Program Annual Progress Report Fiscal Year 1996 (NRC, 1997a) before its distribution.

On February 25-26, 1997, at the NRC offices in Rockville, Maryland, the DOE and the NRC conducted a technical exchange on igneous activity. The purposes of the exchange were (a) to define the approach for considering the igneous activity issue in the total system performance assessment supporting the viability assessment and (b) to identify areas of agreement and disagreement on the relevant geologic data, the probability of volcanism, models for calculating consequences, and performance assessment models of igneous activity. Topics discussed at the exchange included the geologic setting and relevant data from the NRC, field studies of the Center for Nuclear Waste Regulatory Analyses, ground magnetic surveys in the Yucca Mountain region, definition of the Yucca Mountain regional system, results from DOE's probabilistic volcanic hazard assessment, DOE plans for the total system performance assessment supporting the viability assessment, NRC staff probability models and their concerns with source zone definitions for the probabilistic volcanic hazard analysis, the structural setting of the Yucca Mountain region relevant to the repository, and integrated volcanism structural models. In addition, the NRC staff presented consequence models for tephra dispersion, subsurface area of dispersion and critical models used in performance assessment, and sensitivity studies performed by the Center for Nuclear Waste Regulatory Analyses.

The technical exchange was significant in that both the NRC staff and the DOE agreed that the issue of igneous activity can be resolved by defining a path for resolution and by identifying the areas where additional work may be required. In closing, both parties further discussed the points of agreement between the NRC and DOE and the proposed path to resolve the subissue of probability of igneous activity. The following agreements reached by the NRC and the DOE are believed to provide a path forward for the resolution of the igneous activity issue:

1. DOE and NRC agree that (a) the rate of volcanism is relatively constant for the last 5 million years and can be assumed to remain relatively constant for the period of

performance; (b) current information indicates silicic volcanism need not be further evaluated; (c) volcanism is of regulatory interest and its probability and consequences will be considered; (d) if determined to be significant with respect to repository performance, the effects of volcanism will be included in the total system performance assessment; (e) the treatment of consequences outlined by DOE that includes extrusive magmatic events (cone and dike formation) and intrusive magmatic events (sill and dike formation) with both direct and indirect effects is generally appropriate at the level of detail provided; and (f) there is uncertainty in consequence analysis for magmatic waste package interactions and that DOE will evaluate this uncertainty.

2. DOE agrees to consider evaluating, through hazard sensitivity studies, new data such as the following:

   - The size and volume of Little Cone

   - The number of events at Anomaly A (a possible buried cinder cone, or intrusion, south of Lathrop Wells cone).

3. NRC believes that a probability of 1×10^{-7} per year is a reasonably conservative upper bound for extrusive events. There are differing views on the lower bound. DOE considers that the probabilistic volcanic hazards assessment provides a defensible basis for characterizing the probability of disruption (includes both intrusive and extrusive magmatic events). The probability distribution function has an upper bound frequency of 1×10^{-7}, a lower bound of 1×10^{-10}, and a mean of 1.5×10^{-8} per year. DOE agrees to explain how the probability distribution function for the probability of disruption will be used in performance assessment, including sensitivity studies, recognizing NRC's comments.

4. DOE agrees to provide the NRC with a letter describing the DOE basis for subissue resolution, as specified in 2 and 3, for consideration in the development of NRC's Issue Resolution Report.

The DOE and the NRC staff conducted technical meetings on December 16, 1996, and March 13, 1997, to discuss the status of ESF construction, design, and ESF-related site characterization activities, and to resolve identified issues. Participants in the multisite video conference were from the NRC offices in Rockville, Maryland, the DOE headquarters, YMSCO, and the Center for Nuclear Waste Regulatory Analyses in San Antonio, Texas. Major topics addressed during the meetings were related to the status of the ESF tunnel and alcove construction, scientific studies and testing update, and description of the engineering design program. Also discussed during the December 16, 1997, technical meeting were NRC staff concerns related to alcove excavation methods, drill-and-blast and mechanical excavation, and thermal tests identified during a July 24, 1996, Appendix 7 meeting on thermal tests. During the March 13, 1997, DOE presented its plans for retrievability. Also discussed were the potential of including in future quarterly meetings a broad range of technical topics related to the ESF and the proposed repository construction, testing, design, and performance assessment.

In addition to the formal interactions with the NRC staff, regularly scheduled informal interactions with the NRC onsite representatives and Appendix 7 meetings were conducted to discuss and maintain communication with the NRC staff on technical and programmatic matters of interest to both agencies. On February 5, 1997, an Appendix 7 meeting on disposal criticality analysis methodology was held in Washington, D.C. Participants were from OCRWM, YMSCO, and the NRC Division of Waste Management. The DOE's objectives for the meeting were (a) to discuss the DOE's proposed postclosure disposal criticality analysis methodology, (b) to understand and address NRC staff concerns and questions on the methodology and on the Disposal Criticality Analysis Methodology Technical Report (CRWMS M&O, 1996d), (c) to better understand the NRC staff's views regarding identified disposal criticality rule issues, and (d) to seek NRC staff feedback on the likelihood of acceptance of the planned criticality analysis methodology. The NRC's objective was to provide DOE early feedback on the acceptability of its proposed disposal criticality analysis methodology. At the conclusion of the meeting the DOE recognized the NRC's concerns and comments, and noted that additional work will be needed to justify the approach in support of a potential license application.

An Appendix 7 meeting on design detail for the license application was held on February 6, 1997, at the NRC Headquarters, in Rockville, Maryland. Participants included OCRWM, YMSCO, and the NRC Division of Waste Management. The DOE's objectives for the meeting were to update the NRC participants on the repository design, to provide an overview of DOE's approach to determining and developing the appropriate level of design detail for the license application, to provide examples of application of that approach, and to seek NRC feedback on the approach.

An Appendix 7 meeting between the NRC and DOE staffs was held on February 27, 1997, to discuss resolution of NRC staff comments on the second in the series of DOE seismic topical reports entitled Preclosure Seismic Design Methodology for a Geologic Repository at Yucca Mountain, (DOE, 1996c). The meeting discussions indicated that all NRC staff comments could be resolved with relatively minor changes and clarifications to the topical report. The DOE expects to receive an NRC staff letter to this effect and plans to revise and reissue the topical report, accordingly.

Advisory Committee on Nuclear Waste

The DOE's participation in the NRC's Advisory Committee on Nuclear Waste meetings was limited during this period. Some of the meetings attended by the DOE staff included discussions of topics related to the OCRWM and the Yucca Mountain Site Characterization Project. The following paragraphs provide the highlights of the 87th, 88th, 89th, and 90th Committee meetings.

The 87th meeting of the Advisory Committee on Nuclear Waste meeting was held October 22-23, 1996 in Rockville, Maryland. This meeting mostly dealt with the administrative topics, future Committee activities and plans, and the preparation of the Committee reports. One topic of interest to the Project discussed was the Branch Technical Position on Requirements for

Radioactive Waste Land Burial Sites Authorized Under Former 10 CFR 20.302, 20.304 and current 20.2002. This meeting was not attended by Project personnel.

The 88th meeting of the Advisory Committee on Nuclear Waste was held November 12-13, 1996, in Rockville, Maryland. The meeting was attended by the DOE-HQ staff. The meeting was originally planned as a retreat and thus, was primarily concerned with planning and issues internal to the Committee. Discussed were the conduct of Committee activities, internal operations and methods for formulating advice, and priority issues for Committee consideration. The Committee also discussed the preparation of proposed Committee reports and future Committee activities and agendas.

The 89th meeting of the Advisory Committee on Nuclear Waste held January 28-30, 1997, in Rockville, Maryland. Reports discussed that were relevant to Yucca Mountain included the Radionuclide Transport at Yucca Mountain, Critical Group and Reference Biosphere for a Waste Disposal Facility Performance Assessment, and Time of Compliance in Low-Level-Waste Disposal. Also discussed were the status of site characterization at the proposed Yucca Mountain repository, the status of the NRC staff's efforts to revise 10 CFR Part 60, the status of an NRC staff paper giving options for NRC response to the DOE-proposed revision of 10 CFR Part 960, and the status of U.S. Environmental Protection Agency rulemaking activities on a new public health and safety standard for Yucca Mountain. This meeting was attended by Project personnel, however, they did not make any presentations.

The 90th Advisory Committee on Nuclear Waste meeting, conducted March 20-21, 1997, in Rockville, Maryland, was attended by Project staff. Presentations were given on the status of the NRC staff review of DOE's siting guidelines (10 CFR Part 960) and on Phase II of the Biosphere Model Validation Study (BIOMOVS II). A representative from the Electric Power Research Institute discussed the biosphere modeling and dose assessment for Yucca Mountain; this modeling is associated with the BIOMASS theme sponsored by the International Atomic Energy Agency. A representative of the Division of Waste Management discussed the major activities the Division will focus on in FY 1997 and proposed a number of interactions with the Committee to discuss those activities. Also discussed were the historical perspective of defense in-depth philosophy and the Committee letter to the Commission on the biosphere and critical group considerations for Yucca Mountain.

Nuclear Waste Technical Review Board

During the last six months, the Nuclear Waste Technical Review Board held two meetings to discuss issues related to the OCRWM Program. The full Board meetings provided a forum for discussion of issues related to the management and disposal of high-level radioactive waste between the Board, program participants, representatives of State and Federal agencies, and the public. At the October 9-10, 1996, meeting in Arlington, Virginia, Dr. Daniel Dreyfus, OCRWM Director, presented an overview of the viability assessment, highlighting its significance to the Program and its relevance to the nation's radioactive waste management policy. In a series of presentations, Project staff discussed aspects of the Program related to repository design, status of exploration and testing, and detailed plans for the components of the viability assessment.

During the meeting, several Board members commented favorably on the substantial progress the Program had made in 1996 and the evidence of better integration of Project activities. In addition, several Board members commented on the need for the Program to retain flexibility in the repository design to accommodate new information resulting from the viability assessment.

During its January 28-29, 1997, meeting in Pahrump, Nevada, the Board met to discuss such topics as transportation, total system performance assessment, Program and Project activities and investigations, and reduction of hydrologic uncertainties. Following Project staff presentations, a round-table discussion addressed transportation-related topics. Participants included the DOE, the State, and local and public interest groups. OCRWM updated the status of activities related to the upcoming viability assessment, the privatization initiative for transportation services, and the generic planning and analysis for possible interim storage of spent nuclear fuel. Hydrogeologic modeling efforts in both the saturated and unsaturated zones at Yucca Mountain, thermal and underground testing, and the scientific work being conducted by Nye County, Nevada, were also discussed on the second day.

On October 3, 1996, the Department responded to recommendations made by the Board in its 13th report entitled "Report to the U.S. Congress and the Secretary of Energy—1995 Findings and Recommendations" (NWTRB, 1996). In its report, the Board stated that OCRWM had made significant progress in characterizing the Yucca Mountain site, despite the budgetary, programmatic, and regulatory uncertainties facing the Program, but it made numerous technical recommendations for strengthening the site characterization program. The Board specifically highlighted the need for adequate and stable funding for the Program to achieve its objectives.

On March 31, 1997, the Board issued its 14th report entitled "Report to the U.S. Congress and the Secretary of Energy—1996 Findings and Recommendations" (NWTRB, 1997). In this report, the Board summarized the major findings, conclusions, and recommendations that have resulted from Board activities during calendar year 1996. While recognizing that much scientific progress has occurred at Yucca Mountain, the Board identified three major areas of concern. These concerns involved the distinction between the viability assessment and site suitability, the need for excavation of an east-west tunnel to determine site suitability, and the evaluation of alternative repository designs. In addition, the Board identified several additional enhancements to the Program and recommended that (1) the advantages of the multi-purpose canister program, such as standardization, be incorporated in the development of the market-driven approach for waste acceptance and transportation services, and (2) the total system performance assessment be "transparent" (easily understood), "valid" (reasonably accurate and representative of actual conditions), properly treat uncertainty, and objectively peer reviewed. The Board also recommended that public understanding and acceptance of total system performance assessment be increased through broader public involvement in the process. The report noted that developing the waste isolation strategy slowed in 1996 because of difficulty in reaching consensus on the issues. The Board, however, was "satisfied that the goal of articulating a clear waste isolation strategy seems to be serving its purpose."

U.S. Environmental Protection Agency

Since the last progress report, the status of a new public health and safety standard for Yucca Mountain, as well as the DOE's view on the issues that are important to the ability to implement the standard, have not changed.

Forecast: The next key step in this process is the interagency review of the draft rule that is coordinated by the Office of Management and Budget. Regular technical interactions and exchanges with the NRC will continue, as will meetings with the Advisory Committee on Nuclear Waste and Nuclear Waste Technical Review Board.

2.2.3.2 Issue Resolution

The DOE's approach to licensing and issue resolution has evolved from the process outlined in Section 8.1 of the Site Characterization Plan (SCP) (DOE, 1988), which focused on resolving individual issues related to specific site characteristics. Issues were dealt with in relative isolation from one another and from an overall concept for the repository system. Experience gained in applying this process, however, indicates that the sufficiency of site characterization data and analyses can generally only be determined within the context of a coherent repository concept that includes both a design and an assessment of its performance in the geologic setting. The DOE believes that licensing success will depend in part on establishing such a conceptual framework and on focusing its near-term interactions with the NRC within the context of this framework.

The DOE is currently in the process of developing an overall repository concept to support the viability assessment and will communicate its progress to the NRC. The concept is expected to evolve over time as the design, site data, and performance analyses mature. As this conceptual framework develops, the DOE will seek to reach a common understanding with the NRC regarding the issues that are significant to the overall performance of a repository at Yucca Mountain. The DOE also will seek to reach agreement on the methodologies and approaches used to address important technical issues such as criticality control and seismic design. A limited number of topical reports will be developed with the goal of receiving NRC safety evaluation reports that can be referenced in a license application as an appropriate means for resolving selected issues.

The goal of this new approach is to reach a mutual understanding of the developing repository concept that will provide a basis for the NRC's preliminary comments on the sufficiency of the DOE's site characterization analysis and design for inclusion in a license application. The revised approach is consistent with the intent of the issues-based approach that was described in the SCP. This approach also reflects the substantial change in the policy framework for repository development and the increased understanding of the Yucca Mountain site and repository design that have occurred since the SCP was written.

Activities conducted during the reporting period that relate to the evaluation of seismic hazards, igneous activity, and repository criticality are summarized in the following sections. The status of actions related to open items from the NRC's Site Characterization Analysis (NRC, 1989) is also discussed.

Seismic Hazards

The DOE revised the topical report, Methodology to Assess Fault Displacement and Vibratory Ground Motion Hazards at Yucca Mountain (DOE, 1994b) to reflect the resolution of NRC staff comments and to incorporate the results of recent work. The resolution of staff comments is documented in an NRC staff letter dated July 25, 1996 (NRC, 1996b). The revised topical report is undergoing QA review, and the DOE plans to issue Revision 1 of the report during the next reporting period.

An Appendix 7 meeting between NRC and DOE staffs was held on February 27, 1997, to discuss resolution of NRC staff comments on the second in the series of DOE seismic topical reports, Preclosure Seismic Design Methodology for a Geologic Repository at Yucca Mountain, Rev. 1 (DOE, 1996c). The meeting discussions indicated that all NRC staff comments could be resolved with relatively minor changes and clarifications to the topical report. The DOE expects to receive an NRC staff letter to this effect and plans to revise and reissue the topical report, accordingly.

The DOE plans to prepare the third and final seismic topical report during FY 1998. This report will present the preclosure seismic design inputs for repository facilities that are important to safety, based on the results of the application of the methodologies in the first two topical reports. After the third seismic topical report has been issued, the DOE expects that the NRC staff will prepare a Prelicensing Evaluation Report for the DOE's seismic hazards evaluation and preclosure seismic design methodologies and the preclosure seismic design inputs. A Prelicensing Evaluation Report would be similar to a Safety Evaluation Report; however, no licensing precedent exists for a Prelicensing Evaluation Report.

Igneous Activity

Extensive volcanism studies and data collection for the DOE Yucca Mountain Site Characterization Project have been conducted since 1979 to provide a scientific basis for volcanic hazard assessment and to assist in applying the data to the regulatory requirements for siting a potential repository at Yucca Mountain. Igneous activity has been identified by the NRC staff as a key technical issue for the Yucca Mountain site as part of the issue resolution activities on the subject of volcanic hazards.

The DOE igneous activity program is directed toward evaluating the significance of igneous activity by reviewing and independently confirming the data, and evaluating and developing alternative conceptual models for the probability and consequences of igneous activity at Yucca Mountain. Reasonable bounding ranges of probability and consequences of igneous activity will be used to assess the impact on repository performance. During the

previous reporting period, the Probabilistic Volcanic Hazard Analysis for Yucca Mountain, Nevada, was submitted to the NRC on June 25, 1996 (CRWMS M&O, 1996e). The report documents the results of an expert elicitation to assess the probability of disruption of the potential high-level waste repository at Yucca Mountain, Nevada, by igneous events and quantifies the uncertainties associated with this assessment.

Since the last submittal of this report, there have been two interactions with the NRC staff to discuss paths for resolution of the igneous activity issue. During an Appendix 7 meeting on September 10, 1996, the NRC staff provided feedback and comments on DOE's Probabilistic Volcanic Hazard Analysis report. The NRC staff's comments mostly dealt with the elicitation process, documentation of the results, and utilization of new data, as compared to the guidance provided in the NRC Branch Technical Position on expert judgment (NRC, 1996a). During this meeting the NRC concluded that the Probabilistic Volcanic Hazard Analysis generally appeared to be consistent with the Branch Technical Position and provided some specific recommendations to consider for subsequent expert elicitation projects. The NRC also indicated that, as a result of the Probabilistic Volcanic Hazard Analysis, the NRC's Site Characterization Open Item 3 has been addressed and several other comments related to the Study Plan 8.3.1.8.1.1 will be closed by a separate NRC staff letter to DOE. The NRC staff provided guidance for closure of Comment 3 regarding reliance on expert judgment for licensing and Comment 7 regarding use of expert judgment versus peer review in a letter to DOE on December 26, 1996 (NRC, 1996c).

On February 25-26, 1997, a technical exchange was conducted in the NRC offices in Rockville, Maryland. The purpose of the exchange was to define the approach to considering igneous activity in total system performance assessment for the viability assessment and to identify areas of agreement and disagreement on the relevant geologic data, the probability of volcanism, models for calculating consequences, and performance assessment models of igneous activity. Both NRC and DOE staffs made presentations.

At the conclusion of this meeting, both agencies developed a list of agreements and defined additional work needed to resolve the igneous activity issue. A summary of this interaction and a complete list of DOE and NRC agreements in defining a path for resolution of the igneous activity issue are provided in Section 2.2.3.1 of this progress report.

Repository Criticality

The disposal criticality issue involves demonstrating that criticality control will be maintained in the repository such that 10 CFR Part 60 criticality requirements and repository performance objectives will be met. Fissile material remains in spent nuclear fuel after discharge from a reactor, and much of that material is very long-lived. Though this material gradually decays to nonfissile materials, additional fissile materials resulting from the decay of some nonfissile materials are created after the spent fuel is emplaced in the repository. Therefore, disposal criticality analysis is required for the period from the time of emplacement to thousands of years in the future.

The Project's approach to dealing with the issue of disposal criticality involves a risk-based criticality analysis methodology that will be used to demonstrate that potential criticality events during the postclosure period will not pose an unacceptable risk to the health and safety of the public. This approach is consistent with the 1995 recommendations of the National Academy of Sciences for Yucca Mountain standards (NAS, 1995).

The Project will also seek NRC approval of accounting for the reduced reactivity associated with spent nuclear fuel as compared with unirradiated fuel of the same initial enrichment. This approach is known as burnup credit. Additional possible criticality control methods are being considered, including the addition of supplemental neutron-absorbing materials and/or moderator-displacing materials to the waste package.

Resolution of disposal criticality issues will be based primarily on the Disposal Criticality Analysis Methodology Topical Report, which is planned for submittal to the NRC in 1998. This topical report will seek NRC acceptance of the DOE's proposed criticality analysis methodology and its method for obtaining burnup credit.

During the previous reporting period, the DOE sent the Disposal Criticality Analysis Methodology Technical Report (CRWMS M&O, 1996d) to the NRC staff for comment and feedback. This report provided a preliminary description of the DOE's proposed risk-based disposal criticality analysis methodology. It will be used as the basis for developing the Disposal Criticality Analysis Methodology Topical Report. During this reporting period, DOE received NRC staff comments on the technical report. On February 5, 1997, the DOE and the NRC held an Appendix 7 meeting in Washington, D.C., to discuss comments from NRC staff and to begin work toward resolving issues identified by the comments.

Forecast: Additional DOE-NRC meetings may occur in upcoming reporting periods to help resolve open issues. During the next reporting period, the DOE will continue to develop the disposal criticality analysis methodology and its supporting models. This effort is planned to lead to a revision to the Disposal Criticality Analysis Methodology Technical Report, scheduled for completion in late FY 1997. DOE plans to reissue the second seismic topical report and to proceed on work in accordance with the agreements on igneous activity established in the Appendix 7 meeting held in February 1997.

Resolution of Site Characterization Analysis Open Items

The NRC has provided guidance for closure of Site Characterization Analysis Comments 3 and 7 relating to Use of Expert Judgment (NRC, 1996c).

At the end of this reporting period, 98 Site Characterization Analysis open items have been closed by the NRC (including 2 objections), and 100 items remain open. Most of the remaining open items await data to be acquired through site characterization activities for resolution. Of the remaining 100 Site Characterization Analysis open items, 32 are currently being reviewed by the NRC staff.

Supplemental responses to Site Characterization Analysis Comment 24 (DOE, 1996d) and Comment 31 (DOE, 1996e) were forwarded to the NRC for consideration.

Appendix E provides the status of Site Characterization Analysis comment resolution, identifying actions that need to be performed to close the item.

Forecast: The Project will continue discussions with NRC to address questions and concerns that may result from the staff's continued review of Seismic Topical Reports I and II.

Activities related to disposal criticality during the next reporting period will be focused on further development of the Disposal Criticality Analysis Methodology Topical Report and on continuing discussions with the NRC regarding the criticality rule in 10 CFR 60.131(b)(7).

Site Characterization Analysis open items will continue to be resolved as the site characterization and other programmatic activities provide pertinent data.

2.2.3.3 License Application

As discussed in Progress Report #15, this section (2.2.3.3) will be titled "License Application" from this progress report forward and will report progress in planning for and development of the license application. The license application is planned to be submitted to the NRC in 2002 to request authorization to begin repository construction. Submittal of the license application would follow successful accomplishment of activities that, by law, precede it. These activities include the following:

- Completion of the repository environmental impact statement
- DOE recommendation of the site to the President
- Presidential recommendation of the site to the Congress
- The site recommendation becoming effective as provided for in the Nuclear Waste Policy Act of 1982.

During this reporting period, the DOE began developing three products that will support development of the license application. These products are the License Application Plan, the License Application Management Plan, and the Technical Guidance Document for Preparation of the License Application.

The License Application Plan will describe the Project work needed to produce a docketable license application between the viability assessment and the license application submittal, give a schedule for this work, and provide a cost estimate for this work. The License Application Plan will also outline the Project's licensing strategy and give the content requirements for the license application. This plan is one of the four products that will be

prepared to support the viability assessment. The information developed for the License Application Plan will also be used to support the development of the license application, if the site is determined to be suitable.

The License Application Management Plan will provide the management framework within which the license application will be developed. Information included will be the layout of the license application, the document control process for the license application, and a step-by-step description of the process by which the license application will be developed.

The Technical Guidance Document for Preparation of the License Application will eventually provide guidance to authors on the technical and licensing content of their license application chapters. The technical guidance document will list the regulatory requirements applicable to each chapter and will provide acceptance criteria for the authors to use to verify they have provided an adequate licensing case in their chapters. The document will also describe how industry standards and other available guidance should be used in the licensing case to be presented in the license application.

In addition, the Management Plan was developed for the Project Integrated Safety Assessment (DOE, 1997a). Project staff then began drafting various sections of the Project Integrated Safety Assessment, which will be used as a starting point for developing the license application. The document will integrate current knowledge of the site obtained from site programs, design, and performance assessment and contain information in a format suitable for updating into a Safety Analysis Report. The document may also be used to initiate the NRC's preliminary sufficiency comments as required by the Nuclear Waste Policy Act. The Project Integrated Safety Assessment is scheduled to be completed in August 1998.

Forecast: The Draft License Application Plan and the Draft Technical Guidance Document, both based on information available in FY 1997, will be completed by the end of September 1997. Revisions to both documents are planned for FY 1998 to incorporate additional information expected to be available at that time. The License Application Management Plan is expected to be completed by the end of FY 1997.

2.3 QUALITY ASSURANCE

The DOE is continuing to monitor the status and adequacy of the OCRWM QA Program. In addition, the DOE continues with the reengineering of the OCRWM QA Program started during the Progress Report #12 reporting period. The reengineering effort began with DOE initiatives to improve effectiveness and to cut costs.

2.3.1 Program Activity

Revision 6 of the Quality Assurance Requirements and Description document was issued during this period (DOE, 1997b). This document is the principal QA requirements document for

the Civilian Radioactive Waste Management Program and contains regulatory requirements and commitments necessary to develop an effective QA program. Revision 6 was developed to address and incorporate NRC comments concerning scientific investigation and design control.

Ten internal audits were conducted during this reporting period. Audits are verification activities that are planned and documented to evaluate compliance with requirements and to determine effectiveness of implementation through a review of objective evidence. The following organizations were audited: U.S. Geological Survey, Kiewit/PB, DOE Office of Environmental Management and the CRWMS M&O, including its activities at national laboratories.

Forty-five surveillances were also conducted during this 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.

Results of audits and surveillances conducted this reporting period indicated that the OCRWM QA Program was in compliance with requirements, effectively implemented, and satisfactory overall. None of the verification activities conducted this reporting period identified conditions that warranted initiation of immediate corrective action or issuance of a stop work order.

In addition to the internal audits and surveillances, a total of 17 supplier audits and 1 supplier qualification survey were performed. Deficiencies identified during these activities are being monitored by the DOE to ensure satisfactory disposition.

During the first half of FY 1995, the DOE initiated a plan to reengineer the QA function on the OCRWM Program. The first phase of this plan, titled "Reengineering of the Quality Assurance Function on the Civilian Radioactive Waste Management Program Transition Plan" (DOE, 1994c) was completed during the Progress Report #13 reporting period. This phase transferred certain verification functions (that is, internal audits, supplier audits and supplier qualification surveys) performed by the individual affected organizations to the OCRWM Office of Quality Assurance. In addition, the DOE assumed complete responsibility for tracking and trending Corrective Action and Nonconformance Reports.

During this reporting period, DOE completed the initial part of Phase II of the ongoing reengineering of the QA function on the OCRWM Program. The implementation of this portion of the reengineering plan was controlled by the plan "Reengineering the Quality Assurance Function on the Office of Civilian Radioactive Waste Management Program Consolidation of OCRWM QA Functions, Phase II Transition Plan, Phase A" (DOE, 1997c). This phase transferred the surveillance function performed by the individual affected organizations to the OCRWM Office of Quality Assurance. The effective date for Phase A implementation was February 1, 1997.

Forecast: The plan to control the implementation of the final phase of the reengineering of the QA function within the OCRWM Program is currently in the approval process. Once approved and implemented, this plan will transition the remaining QA functions performed by the individual affected organizations to the OCRWM Office of Quality Assurance. The Office of Quality Assurance will then have complete responsibility for the management and performance of the QA function within the OCRWM Program. Implementation of the final phase of the transition is scheduled to occur in the next reporting period.

2.3.2 Determination of Importance Evaluations

The DOE is responsible for performing determination of importance evaluations, which remain the mechanism established by the Project to evaluate proposed field activities with respect to their potential for adverse impact to Q-List items or site characterization testing. Because the natural barriers are included in the Q-List, each determination of importance evaluation essentially comprises both a waste isolation evaluation and a test interference evaluation for the proposed activity. Where a reasonable potential for adverse impact is identified, the evaluation establishes appropriate QA controls for the activity to prevent or limit the adverse impact. These controls are then transcribed into the applicable documents for implementing the activity (for example, field work packages, design packages, specifications, and drawings).

The implementing line procedure NLP-2-0, *Determination of Importance Evaluations* that controls this process requires that every determination of importance evaluation be reviewed annually to determine whether critical inputs or assumptions have changed enough that the conclusions of the earlier determination of importance evaluations may no longer be valid.

During the reporting period, a number of determination of importance evaluations received their annual review as required by procedure. No significant changes were identified in either critical inputs or assumptions for the reviewed determination of importance evaluations. Various minor changes were recommended to improve consistency and to update references.

In addition, a number of tracers, fluids, and materials reports from various responsible organizations were reviewed before inclusion in the tracers, fluids, and materials data base. A list of determination of importance evaluations performed during this reporting period is provided in Appendix F.

Forecast: Continuing determination of importance evaluation development work is scheduled for the next reporting period, predominantly in support of surface-based testing and testing in the subsurface ESF.

2.3.3 Q-List and Management Control List/Design Basis Event Analysis

The Q-List (DOE, 1997d) and Management Control List (DOE, 1994d) delineate permanent items (that is, items that may become part of a licensed pre- or postclosure repository). The Q-List includes 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 document (DOE, 1997b). The Management Control List includes those permanent items determined not to be subject to those requirements; they are instead subject to conventional quality management and design controls.

Both documents reflect the conclusions of classification analyses. The Q-List also contains items originally placed on it by "direct inclusion," a conservative approach initiated when the document was first issued. Such items can only be removed through documented analysis.

Classification analyses support the Implementation Line Procedure that identifies whether a permanent item has a function that falls within one of the following seven categories (order does not imply relative importance):

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 (applicable to QA-1 or -2 items)

QA-5 Important to Potential Interaction (this does not include permanent item function, but, rather, failure impact to QA-1 or -2 items)

QA-6 Important to Physical Protection of Facility and Materials

QA-7 Important to Occupational Radiological Exposure.

The classification analysis for ground support systems was revised during the reporting period. The revision clarified ESF permanent function ground support maintenance requirements. Conclusions in this evaluation revision are consistent with the previous ground support evaluations. A classification analysis was also performed for the offsite transportation configuration item. (Offsite transportation had conservatively been included on the Q-List by direction.) The analysis concluded that offsite transportation did not meet any of the QA classification categories and could therefore be removed from the Q-List.

The DOE approved and issued a revision to the Q-List to include classification analysis revisions and to incorporate the Management Control List as an appendix to the Q-List. As a result of this revision, a document action request has been issued to delete the Management

Control List as a separate document. Another major revision to the Q-List is also in progress that will align the Q-List with the current System Description Document organization of structures, systems, and components, which is based on a functional classification analysis of the proposed repository structures, systems, and components. This analysis is expected to be approved next reporting period.

Forecast: Design basis event analyses will continue to be defined and coordinated to evaluate the response of repository structures, systems, and components to potential design basis events to support the designs for the MGDS and Waste Package and to support the establishment of QA classifications for repository items important to radiological safety or waste isolation. A full scope revision of the Q-List will be issued to reflect the current repository design, as defined in the MGDS Advanced Conceptual Design Report (CRWMS M&O, 1996b) as modified through the Controlled Design Assumptions Document (CRWMS M&O, 1996c). In addition, formal QAP-2-3 Classification of Permanent Items classification analyses are expected to be performed for Bin 3 system description documents. The results of the analyses from the Design Basis Event Integrated Task Team effort (see Section 4.2.1 of this progress report) will form the basis for QA classifications of repository structures, systems, and components. These results will be included in future Q-List revisions.

2.4 PROGRAM OUTREACH

The objective of Program Outreach is to ensure open and informative interactions with the public and Project stakeholders in accordance with the Nuclear Waste Policy Act and the Secretary of Energy's Public Participation Policy. To comply with these requirements, the Project conducts interactions with the State of Nevada, the public and public interest groups, the Nevada business community, affected counties, local government agencies, the legislature, and the media. The approach to these interactions can be broken into three areas of emphasis: stakeholder involvement, public outreach, and product development. The following are means by which the Project interacted with, and provided information to, the public and Project stakeholders.

Project staff completed a milestone deliverable, the "1996 Year in Review" video, which highlights activities accomplished on the Project during the last fiscal year. The staff also completed and submitted the FY 1997 Yucca Mountain Project Stakeholder Plan Update. The Plan describes the opportunities planned for involving the public in Project activities through use of meetings, workshops, and other forums associated with the Project.

During this reporting period, 89 tours of Yucca Mountain, including two public open house tours, were conducted for approximately 1249 members of the public and other interested parties. Tours of special interest included the Public Broadcasting System, British Broadcasting, the Associated Press, Waste Management '97, the Nuclear Energy Institute, members of Congress, and Congressional staff members.

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 staff held individual meetings with officials of the affected units of government to discuss Project issues and provide updates of Project activities. The staff also held a teleconference meeting with the affected units of government and other interested members of the public on February 20, 1997, to discuss the proposed FY 1998 budget for OCRWM. A total audience of approximately 8300 people attended 110 speaking presentations during this period, which included 13 technical presentations, 30 general Project overviews, and 67 educational presentations.

Approximately 5800 individuals visited the Yucca Mountain Science Centers, located in Las Vegas, Beatty, and Pahrump, Nevada, during this period. At these centers, Project staff presented two Yucca Mountain Speaker Series lectures; 13 teacher workshops; 3 YMCA workshops; and 7 environmental, energy, and geology workshops for fifth-graders. Other events under the Educational Program included two geology walk-n-talks, two Cadette Girl Scouts workshops, one Brownie Troop workshop, one Cub Scout workshop, one Girl Scout Geology Merit Badge Workshop, and one Science Bowl competition. Project staff also participated in Net Day '96, and set up and staffed exhibits for Scout Expo '96 and the Futures Expo on career opportunities. Project personnel participated in ceremonies opening the Net Day '96 initiative in Nevada. The initiative was to connect schools to the Internet and had been supported by Project personnel through contributions and volunteer labor. The Project also revised the Geology Overview. For the Beatty Science Center, staff composed an album of historic photos of early native Americans for use in new cultural resource activities.

The Yucca Mountain Site Characterization Project Home Page on the Internet was accessed over 300,000 times this period by various national and international business, educational and government entities, and members of the public.

The Project researched, created, revised, modified, and distributed a variety of public information products, responded to external information requests, and operated the Civilian Radioactive Waste Management Information Center toll-free number.

Forecast: Project interactions with public and Project stakeholders will continue as needed.

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CHAPTER 3 - SITE PROGRAMS

INTRODUCTION

The Site Characterization Program (Program) consists of 13 scientific investigation programs comprising more than 100 studies. Through the studies, information about the natural features and processes of the Yucca Mountain site is collected, analyzed, and synthesized. This information is needed to determine whether the Yucca Mountain site is suitable for a repository and, if so, to support repository design and application for the license that would authorize construction of a repository. The information collected will be used to determine (a) whether a repository can be constructed and operated at the site while ensuring the health and safety of the public, and (b) whether the waste emplaced in the repository will remain isolated from the biosphere for thousands of years.

Background

The original testing and analysis approach, as envisioned in the 1988 Site Characterization Plan (SCP) (DOE, 1988), was intended to identify and evaluate significant risks and uncertainties in scientific hypotheses before the license application was prepared and submitted. That testing and analysis program was based on the information requirements in the disposal regulations (10 CFR Part 60) and in the siting guidelines (10 CFR Part 960). The purpose of the SCP was to ensure that sufficient information would be collected to determine the suitability of the site, design a repository, assess the performance of the repository system, and develop an adequate license application for construction authorization. The SCP approach included the flexibility to modify the program as new data confirmed or refuted the importance of specific items of information (see, for example, p. 8-0-1 of DOE, 1988).

Progress in surface and subsurface investigations, especially over the last four and a half years, has allowed the scope of site characterization to be reduced. Observations of the natural system and site data collected since 1978 have allowed many site conditions to be characterized, conceptual models to be advanced, and uncertainties to be bounded. Along with assessments of expected repository performance and continued development of a strategy to contain and isolate the waste, the U.S. Department of Energy (DOE), has used the results from site characterization activities to develop a long-range plan (CRWMS M&O, 1996a) that narrows the scope of the testing and analysis program to focus on the relatively few remaining scientific and technical uncertainties that are important to the design and long-term performance of the potential repository. Recognizing the changes and the need for traceability in the site characterization program, the DOE initiated an effort to document the changes to the program since the SCP was issued. Summary information at the investigation and study level (i.e., 8.3.1.x.x) is included in Appendix A of this progress report.

Data from observation, testing, design and modeling activities, plus published information from non-Yucca Mountain Site Characterization Project (Project) sources will provide the technical basis for the viability assessment, the suitability determination, the Secretarial recommendation, and the license application. By the end of fiscal year (FY) 1998, Project staff expects to provide sufficient information regarding the technical questions about the

characteristics of the site and the expected performance of the repository system to support the viability assessment.

Interrelationships with Other Program Elements

The site investigations program is designed to provide information on the geologic, hydrologic, geomechanical, geochemical, climatological, and meteorological characteristics of the site. Information is gathered using a variety of field and laboratory studies. The information collected under the site investigations program will provide the basis for the site viability assessment and also will be used by other Program elements to support the Site Recommendation Report and license application.

Systems engineering determines various requirements to ensure that (a) site characterization activities do not compromise the design and construction of the Mined Geologic Disposal System and (b) that construction activities do not compromise site characterization activities. Information on the three-dimensional structural and stratigraphic characteristics of the potential repository block is needed for repository design. In particular, faults will affect repository layout, and tectonics studies are needed to establish seismic design parameters. Likewise, site characterization provides information needed to construct the Exploratory Studies Facility (ESF) and establish controls needed to prevent potential interference between tests. Design organizations identify information needs related to ESF and repository design, and establish controls to prevent potential interference between construction and tests. Particularly important items of information for design and construction are geotechnical properties of the rock and seismic hazard assessments.

Site characterization activities provide information vital to waste package design and material selection, including information on climatology; infiltration; and the unsaturated zone, including bounds on infiltration and percolation flux rates and water chemistry. The site investigations program also provides data on the effects of heat on the physical behavior of rock, on the chemical composition of the water, on matrix and fracture flow in the potential host rock for consideration in waste package design, and on relatively humidity. Design issues pertaining to percolation flux and relative humidity are discussed in Chapter 5 of this progress report. Performance assessment issues pertaining to percolation flux and relative humidity are discussed in Chapter 6 of this progress report.

Significant Results During this Reporting Period

The following numbered items describe significant results from various studies during the reporting period. Generally, the results are listed in three subject areas: hydrologic and pneumatic and transport properties, geology and rock properties, and climate.

Hydrologic, Pneumatic and Transport Properties

1. In the ESF, chlorine-36 from weapons testing occurs in a few distinct fractured and/or faulted zones, indicating that at least a detectable amount of the water at depth is less than 50 years old. Initial analysis suggested that chlorine-36 from weapons testing

appeared to be associated with major faults mapped at the surface. No samples containing chlorine-36 that is unambiguously from weapons testing have been detected in samples collected more than 4500 m from the north portal.

During this reporting period analysis (Levy et al., in prep.) of the distribution in the ESF of chlorine-36 from weapons testing appears to depend on (a) the presence of faults that cut the Paintbrush nonwelded (PTn) hydrogeologic unit; (b) the magnitude of surface infiltration; and (c) the structural features that produce downward lateral spreading away from fault zones (Section 3.1.5, Activity 8.3.1.2.2.2.1).

In the Northern Ghost Dance Fault Alcove, higher porosities occur on the western side (hanging wall) of the Ghost Dance fault, and lower porosities occur on the eastern side (foot wall) of the fault. Sample results indicate that in situ saturation and saturated conductivity may be influenced by the zeolite content of the rock (Section 3.1.7, Activity 8.3.1.2.2.3.1).

2. Recent temperature data collected from two boreholes in Pagany Wash may indicate the passage of an infiltration front through the Tiva Canyon Tuff and upper half of the PTn at UE-25 UZ#5.

   Instabilities and unusual oscillations in temperature and water potential data in USW NRG-7a may be the result of air circulation within the Tiva Canyon Tuff that could be driven by density differences related to topography.

   Changes in temperatures and pneumatic pressures from all Topopah Spring Tuff instrument stations in boreholes USW SD-12, USW NRG-7a, and USW SD-7 are apparently responses to ESF construction operations. In USW SD-12, data from the deepest instrument station (situated below the perched-water zone) indicate an atmospheric loading or strain-induced response associated with the synoptic signal component present in the pressure record. This finding indicates that the perched-water zone is of limited extent. Temperature changes attributable to ESF construction have not been observed in other monitored boreholes at Yucca Mountain (Section 3.17, Activity 8.3.1.2.2.3.2).

3. Rock temperatures near the tunnel boring machine were observed to change spatially and temporally, and the changes have been related to evaporation from the rock surfaces. Recent estimates indicate that ESF ventilation operations effectively remove the equivalent of approximately 200 mm/yr (±100 mm/yr) of moisture. Ventilation effects preclude measurements or observations of natural seepage along the ESF, because modern day percolation flux that would be observed as seepage is estimated to be significantly less than the ESF dryout rate.

   Initial values of water potential measured in the south ramp of the ESF were considerably greater than in situ measurements in surface-based boreholes in similar zones of the PTn. The greater water potential values suggest a higher percolation flux through the PTn than would have been estimated using the surface-based borehole

data. However, sensors installed near the ESF wall are drying out at a rate equivalent to 0.5 to 1 mm/day (180 to 365 mm/yr). This rate is supported by the dryout estimated from changes in vapor density calculated using temperature, relative humidity, and wind-speed data. Matrix flux in the PTn using this new data has not yet been estimated (Section 3.1.9, Activity 8.3.1.2.2.4.2).

4. Pneumatic monitoring of boreholes in the Upper Tiva Canyon Alcove showed no differential pressure among three boreholes, and between the boreholes and atmospheric pressure. These observations confirm the large fracture permeability of the Tiva Canyon Tuff. In addition, gaseous-phase carbon-14 data indicate a large degree of mixing between atmospheric and rock gases. Comparisons of matrix air permeability values for the Tiva Canyon Tuff indicate that the tuff is isotropic at shallow depths. However, comparison of pneumatic permeability values in the Tiva Canyon Tuff lower lithophysal zone in the ESF with surface values indicates that the zone in the ESF is anisotropic and has a horizontal-to-vertical permeability ratio of approximately 10:1. Tracer tests in the Tiva Canyon Tuff indicated adsorption of the gaseous tracer in the fault breccia and tortuosity in the tuff (Section 3.1.8, Activity 8.3.1.2.2.4.4).

5. Data from tritium analyses of pore water extracted from rock samples collected from various locations in the ESF have been used to determine the spatial distribution of percolation flux. Tritium detected in the vicinity of the Upper Tiva Canyon Alcove is consistent with the concept that water percolates readily from the land surface to the top of the PTn. Alternative interpretations of the data do not preclude the possibility that young water may have percolated below the PTn into the Topopah Spring Tuff middle nonlithophysal zone at three additional locations in the ESF (Section 3.1.8, Activity 8.3.1.2.2.4.8).

6. Pneumatic monitoring in the Bow Ridge Fault Alcove indicated high permeability in the Tiva Canyon Tuff, Bow Ridge fault breccia, and pre-Rainier Mesa Tuff bedded tuff. Tritium values in matrix water indicate that water less than 50 years old has percolated downward along the Bow Ridge fault and mixed with older water in the rock matrix.

   Air-injection testing in a borehole drilled from the Northern Ghost Dance Fault Alcove showed that the permeability of the Ghost Dance fault zone is more than ten times greater than that of the surrounding tuff. Also, because water was redistributed during the single-hole and cross-hole air-injection tests, the capillary pressure of water held in fractures must be less than one atmosphere (Section 3.1.8, Activity 8.3.1.2.2.4.10).

7. Pore water from the unsaturated zone in the PTn has significantly greater concentrations of major ions and dissolved solids than does perched water or saturated zone water. Recharge of perched or saturated-zone waters, therefore, apparently requires rapid flow through fractures or more permeable regions in the unit to avoid mixing with the chemically concentrated water contained within the PTn. These

interpretations are consistent with tritium and chlorine-36 contents of samples from the deep unsaturated zone at Yucca Mountain.

Deuterium and carbon-14 data from pore water in the Topopah Spring Tuff have been interpreted as indicating a post-glacial age (2,000 to 10,000 years old) for the pore water. Corrected carbon-14 data indicate perched water in boreholes USW NRG-7a, USW UZ-14, and USW SD-9 is from 2,150 to 6,260 years old (Section 3.1.11, Activity 8.3.1.2.2.7.2).

8. Using temperature differences between the saturated and unsaturated zone, estimates of unsaturated zone percolation in three boreholes were, respectively, 9.1 mm/yr at USW H-3, 23.5 mm/yr at USW G-1, and 4.9 mm/yr at USW G-3. However, using temperature data from the unsaturated zone alone (Topopah Spring Tuff and the Calico Hills Formation), estimates of percolation flux were 1.8 mm/yr at USW G-1 and 4.6 mm/yr at USW G-4. The difference in the two percolation flux estimates for USW G-1 may be reflecting nonvertical flow in the lower part of the unsaturated zone. Alternatively, the difference could indicate that, even without obvious evidence in the temperature profile, nonconductive transport of heat in the saturated zone is introducing bias into estimates of the unsaturated-zone percolation flux. If the latter is true, more reliable estimates of the percolation flux might be obtained if heat flows are determined using only data from the unsaturated zone.

   A Project initiative titled "Unsaturated-Zone Model Expert Elicitation" began during the reporting period. In general, experts estimate an average percolation flux of 5 to10 mm/yr within the potential repository area based on results of infiltration studies, borehole temperature data, and geochemical isotopic data (Section 3.1.13, Activity 8.3.1.2.2.9.1).

9. Borehole monitoring of water levels in the saturated zone has indicated no seasonal water-level trends in any of the monitored intervals. Regional ground-water withdrawals did not appear to cause water-level changes. Most annual water-level fluctuations were attributed to responses to barometric-pressure changes and earth tides (Section 3.1.14, Activity 8.3.1.2.3.1.2).

10. A long-term pumping test at the C-hole complex has established large-scale structural control on flow in the saturated zone southeast of the potential repository site. The test also confirmed hydraulic connection between the C-holes and holes UE-25 ONC#1 and USW H-4. The overall cone of depression for the test is elongated along the axis aligned in a west-north-west direction where recent geologic mapping indicates discontinuous faults with associated fractures. The faults and fractures probably are the reason for the hydraulic connections between the C-holes and both UE-25 ONC#1 and USW H-4.

11. Recently completed research about chelated transport of iron has shown that chelation significantly affects the transport of iron in crushed tuff. Therefore, there is strong potential for enhanced transport of radioactive wastes by chelation.

12. Calcite and opal veins from the Tiva Canyon Tuff, the Paintbrush nonwelded hydrogeologic unit, and the upper part of the Topopah Spring Tuff have low uranium-234/uranium-238 ratios similar to surficial calcite. The data are interpreted as evidence that large volumes of percolating water would strip available uranium-234 resulting in low ratios. However, samples from the repository horizon have much higher ratios. The higher ratios are interpreted to indicate that relatively small volumes of percolating water reach the repository horizon.

    Reactive transport simulations were conducted for flow regimes that may be expected near the boiling front under conditions in which saturation has been achieved. Preliminary results indicate that the primary concern for hydrologic properties is the formation of cristobalite and/or calcite plugs in fractures in which flux exceeds about 100 mm/yr. The results indicate that under these conditions, precipitation of solids at the boiling front could seal fractures in less than 100 years. Where the movement of the front is slow, fracture sealing could restrict fluid movement at the boiling front. The results also suggest that drainage of fluid through pillars between emplacement drifts may constrain flow because of precipitation from cooling water as the flow enters regions of lower temperatures (Section 3.2.2, Activity 8.3.1.3.2.1.3; Section 3.14, Activity 8.3.1.20.1.1.4).

Geology and Rock Properties

1. Recent drilling in the crowns of the Northern Ghost Dance Fault Alcove and the Southern Ghost Dance Fault Alcove has confirmed that the contact between the Topopah Spring Tuff upper lithophysal zone (Tptpul) and the middle nonlithophysal zone (Tptpmn—repository horizon - see Buesch et al., 1996a) is within 1 m of the location predicted by the three-dimensional lithostratigraphic model. Video logs and core from a horizontal hole, drilled from the Northern Ghost Dance Fault Alcove access drift showed that the main trace of the Ghost Dance fault is located about 154 m east of the ESF main drift. The geometry of distributed fractures in the hanging wall (west side) and the foot wall (east side) is consistent with observations on the surface. Projection of the surface trace of the fault to the location of the main trace at the ESF level indicates that the fault is nearly vertical (Section 3.3.3, Activity 8.3.1.4.2.1.1).

2. Mapping of the central block of Yucca Mountain (Day et al., in press) has shown that numerous intrablock faults that are a narrow zone at depth, such as the Ghost Dance, Abandoned Wash, and Busted Butte faults, "horsetail" toward the surface into a series of bifurcating faults. Mapping during the reporting period has shown that this pattern is maintained for block-bounding faults. The results of this work can be applied directly to understand the foot wall deformation associated with the Solitario Canyon fault, which bounds the western margin of the repository area. Bulk permeability is generally proportional to deformation; so if a reliable method to project changes in deformation can be developed, it may be possible to identify areas of potentially increased permeability that would increase the amount of percolation flux (Section 3.3.4, Activity 8.3.1.4.2.2.1).

3. Geotechnical characterization of the main drift focused primarily on rock-mass quality and mechanical properties. For the main drift, the averages of all rating systems yield rock quality ratings of poor to fair. Between ESF Stations 28 + 00 (2800 m) and 37 + 00 (3700 m) rock quality was fair and decreases to the south (Section 3.3.4, Activity 8.3.1.4.2.2.4).

4. Preliminary results from the single heater test indicate that (a) convective heating effects are smaller than predicted from the thermohydrologic-hydrologic analyses, possibly because of vapor escaping the block or from heat loss through fracture systems not accounted for in the modeling; (b) at temperatures above boiling, temperature predictions agree quite well with measured values; (c) the rock mass thermal expansion coefficient is 10 to 20 percent less than the thermal expansion coefficient of the intact rock; (d) the rock mass modulus does not yet show any significant effect from temperature; and (e) the rock bolts installed in the heated zone of the test show greater reduction in tension load than bolts installed in rock remaining at ambient conditions. The tension load is reduced because the expansion of steel in the rock bolts is greater than the expansion of the rock in the temperature range of the test (Section 3.11.5, Activity 8.3.1.15.1.6.2).

5. Data from geotechnical instruments monitoring ground-support conditions and drift convergence have identified no significant concerns regarding the integrity of the ground support or the stability of the opening.

6. A report describing the results of foam-rubber modeling of normal-fault earthquakes provides evidence that near-field ground motions from normal faulting earthquakes may be less than from similar size thrust and strike-slip earthquakes (Section 3.13.9, Activity 8.3.1.17.4.1.2).

7. Observations from the distribution of precariously balanced rocks in the Yucca Mountain region indicate that earthquakes similar in size to the Little Skull Mountain earthquake ($M_L = 5.6$) have not occurred during the last few thousand years.

8. Results from teleseismic tomography studies indicate that no large low-velocity zone exists under Crater Flat or Yucca Mountain. Therefore, no major source of magma is indicated beneath Crater Flat or Yucca Mountain.

Climate

Various paleoclimate and paleohydrologic data were interpreted and synthesized in efforts to establish the nature, duration, amplitude, and magnitude of past climatic changes in the Yucca Mountain region. These interpretations are being used to constrain and bound future climate scenarios for Yucca Mountain, and to guide simulations of possible future conditions with the nested global-regional climate model.

1. The results from diatom and ostracode high-resolution records indicate that limno-climate changes at Owens Lake were extremely rapid; the lake often varied from an

overflowing, freshwater system to a closed, saline or even dry system, in less than a millennium. These types of changes are more typical of interglacial and transitional periods than they are of glacial periods.

Ostracod records for the period from about 55 ka through the Holocene (10 ka to present) show very rapid (decadal) shifts from dry climates, like those of today, to brief periods of warm, wet climates, probably supported by summer rains. The appearance of the full glacial climate (25 ka) was also rapid, but the condition persisted for several millennia.

Radiocarbon-age control has shown that deposition in paleowetlands in the Las Vegas and Indian Springs Valleys was more episodic that originally thought. Packrat (*Neotoma sp.*) midden data imply that the local water table elevation rose above the surface of the valley bottoms only during century- to millennium-long wet periods.

Data from the Owens Lake and from the paleowetlands records indicate that the penultimate glacial period (170 to 130 ka) was substantially wetter than the last glacial period (40 to 10 ka) (Section 3.4.2, Activity 8.3.1.5.1.2).

2. A significant amount of correspondence has been observed between the isotope record at Devils Hole, Nevada, and the paleoclimate records from Owens Lake, California. In addition, both of these records correspond to the marine oxygen isotope records that document global changes in the earth's temperature and ice volume. The correspondence demonstrates that the timing and rate of past climate change at Yucca Mountain coincided with the large, cyclic changes in global climate throughout the Quaternary. Global climates are closely linked to astronomically derived changes in solar insolation and future changes in solar insolation can be determined accurately. Because some understanding has been gained of the magnitude of regional climate change within particular segments of the solar insolation cycle, it may be possible, in general terms, to forecast the magnitude of future climate change in the Yucca Mountain region. In particular, the present-day segment of the insolation cycle resembles the climate that occurred about 400,000 years ago. Therefore, the characteristics of climate that happened about 400,000 years ago may be expected to generally recur in southern Nevada (Section 3.4.5, Activity 8.3.1.5.1.5).

Overview

Table 3-1 lists the 13 scientific programs, and one study that was added after the SCP was issued, that now make up the site characterization effort at Yucca Mountain, Nevada. This table also lists the progress report section number for each program, briefly describes the scope of each program, and references the corresponding section of the SCP.

These programs are discussed in detail in the progress report sections listed in Table 3-1. The discussions in these sections reflect the impact of consolidating study plan work scopes on the individual studies and activities of the SCP. The discussions contain many references to study plans, identify SCP sections for which study plans have not been written, and explain why

Table 3-1. Descriptions and Site Characterization Plan Sections (in parentheses) for Site Programs Described in Chapter 3

3.1	Geohydrology	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)
3.2	Geochemistry	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)
3.3	Rock Characteristics	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)
3.4	Climate	Analyzes paleoclimate, paleohydrology, and paleoenvironment, and characterizes modern climate, future climate, and future hydrology (SCP Section 8.3.1.5)
3.5	Erosion	Characterizes modern and past erosion and evaluates the potential effects of future climate and tectonics on erosion (SCP Section 8.3.1.6)
3.6	Postclosure Tectonics	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)
3.7	Human Interference	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)
3.8	Meteorology	Characterizes the site and regional meteorological conditions of the Yucca Mountain vicinity (SCP Section 8.3.1.12)
3.9	Offsite Installations and Operations	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)
3.10	Surface Characteristics	Characterizes the topographic characteristics and properties of soil and rock in the site area (SCP Section 8.3.1.14)
3.11	Thermal and Mechanical Rock Characteristics	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)

Table 3-1. Descriptions and Site Characterization Plan Sections (in parentheses) for Site Programs Described in Chapter 3 (continued)

3.12 Preclosure Hydrology	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)
3.13 Preclosure Tectonics	Characterizes faults, seismicity and tectonic stress field, and evaluates the potential for faulting, ground motion, and volcanic activity in the site vicinity during the preclosure period (SCP Section 8.3.1.17)
3.14 Altered Zone Characterization	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 [new study added after SCP issued])

specific study plans may not be developed. Explanations may include work scope that has been transferred or aggregated into other study plans; work that has been completed and reported; or work for which no study is necessary because data are available from other sources. The status of the study plans is summarized in Appendix G.

Four figures and one additional table have been included to help the reader understand the information presented in this chapter. These figures and the table are referenced in many of the study descriptions.

- Figure 3-1 shows surface features in the Yucca Mountain region.
- Figure 3-2 shows the locations of the proposed repository block and of boreholes in the potential repository area.
- Figure 3-3 shows locations of selected geologic and potential repository features related to significant results reported this period.
- Figure 3-4 shows the ESF and test alcoves and presents a summary of the remaining test activities for each alcove.
- Table 3-2 shows the stratigraphy of Yucca Mountain as determined for various usage classifications.

See the references section (Appendix L) for information about compilation of figures required by Federal Executive Order 12906 (59 FR 71, p. 17671-17674).

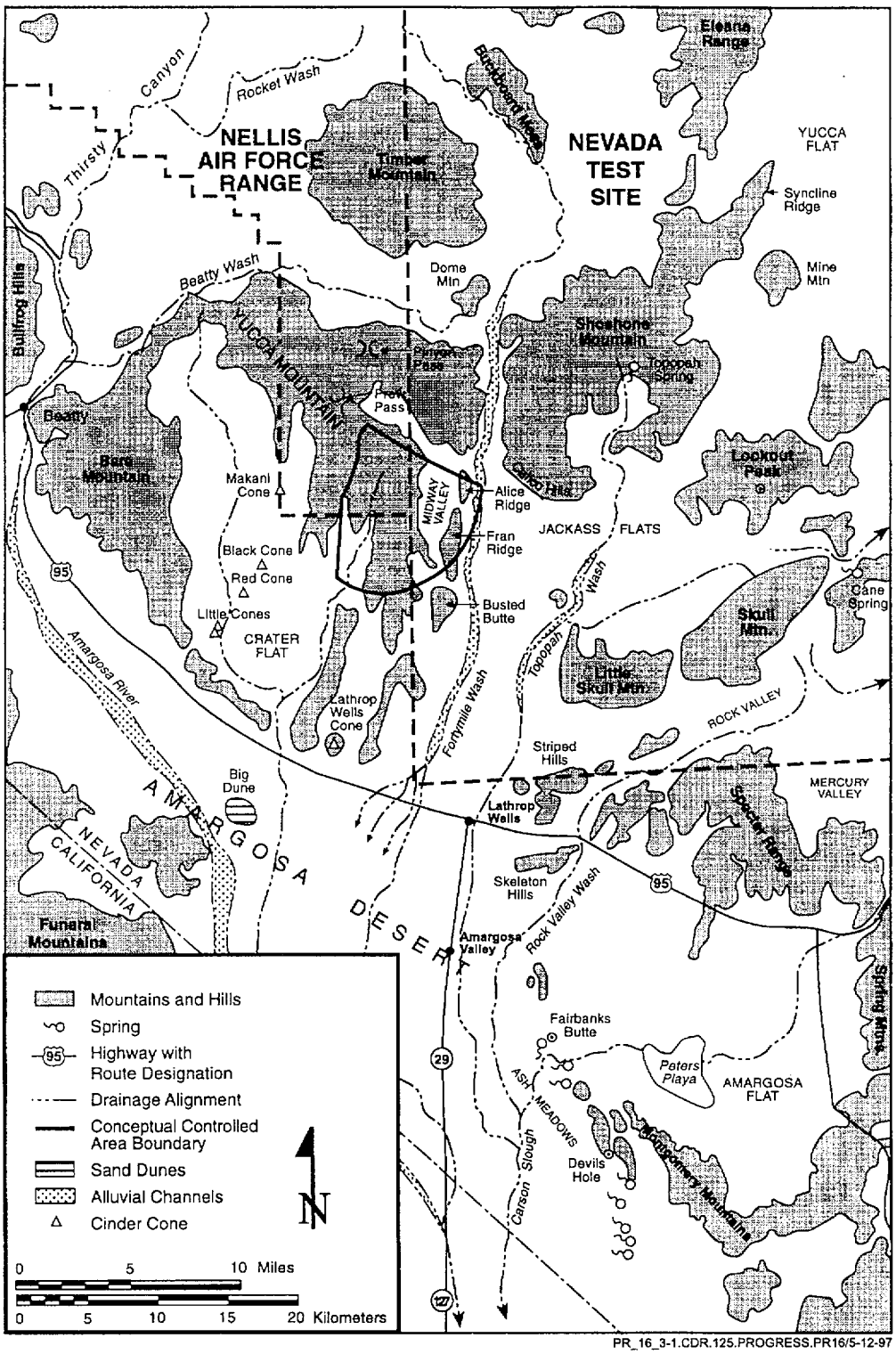
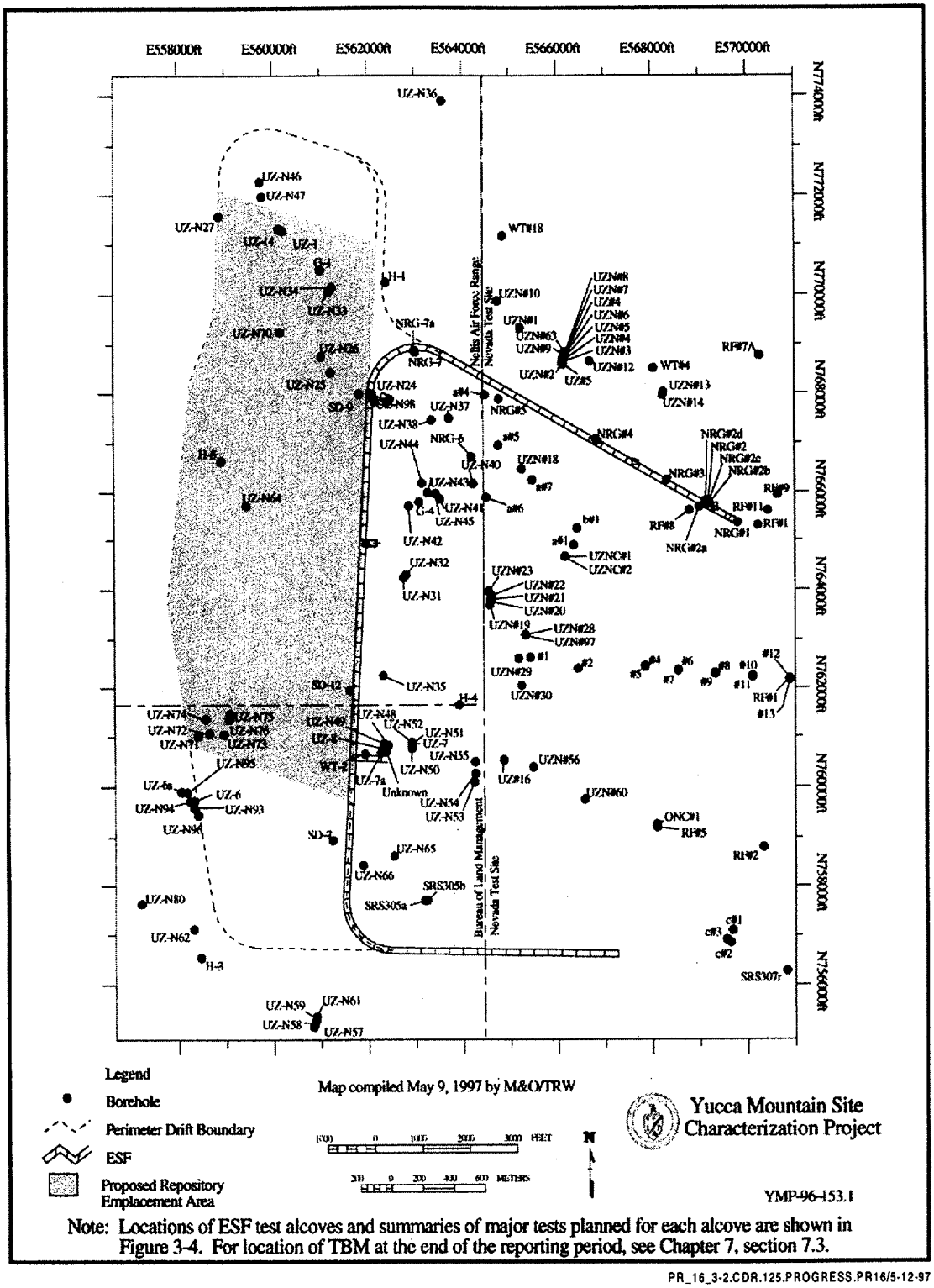


Figure 3-1. Regional Location and Surface Features Map



Note: Locations of ESF test alcoves and summaries of major tests planned for each alcove are shown in Figure 3-4. For location of TBM at the end of the reporting period, see Chapter 7, section 7.3.

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Figure 3-2. Map Showing the Exploratory Studies Facility, Potential Repository Block, and Repository Area Boreholes

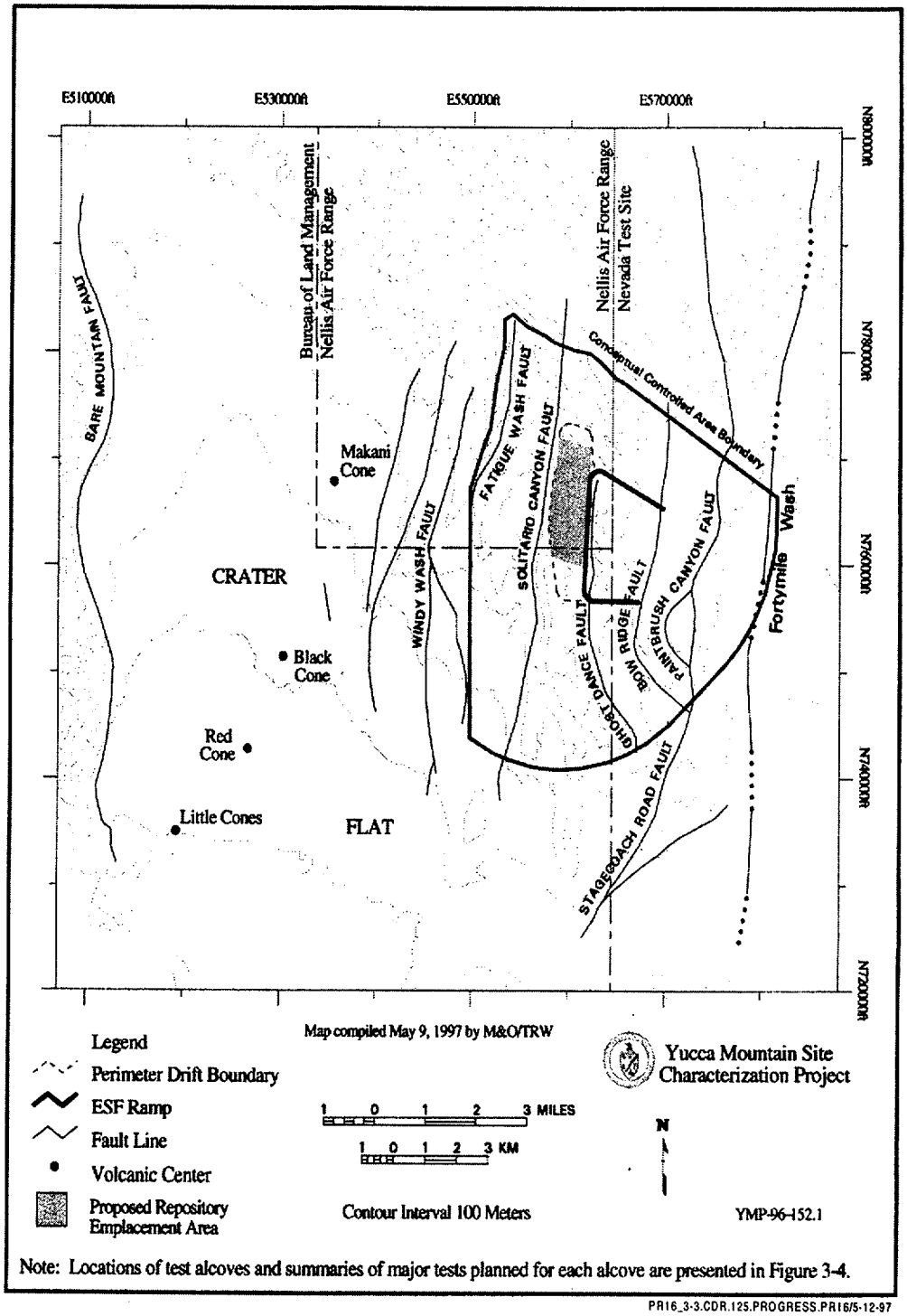

Figure 3-3. Map Showing Locations of Selected Site Features

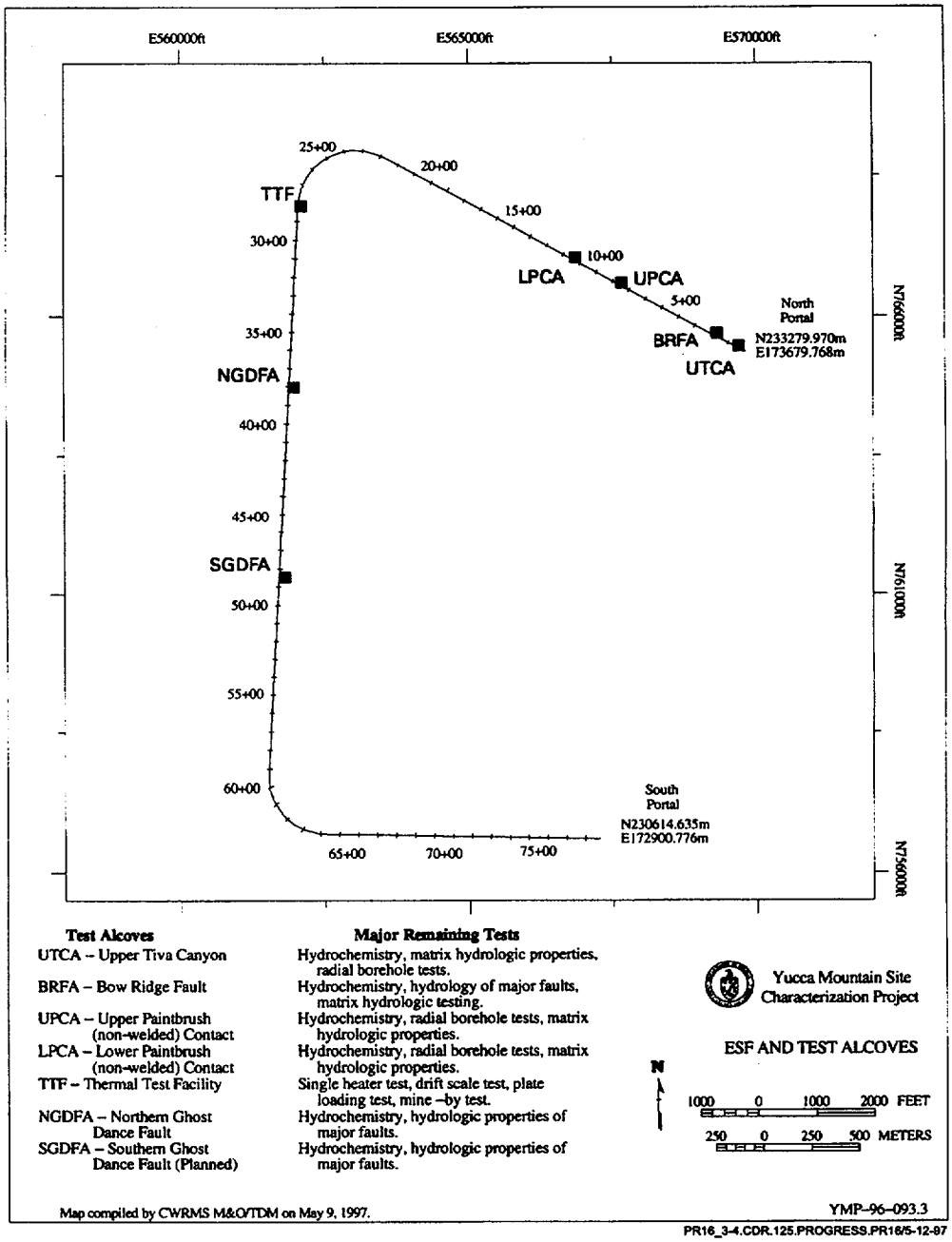

Figure 3-4. Map of Exploratory Studies Facility (ESF) Showing Names and Locations of Test Alcoves and Major Tests Planned for Each Alcove

Table 3-2. Comparison of the Lithostratigraphic, Hydrogeologic and Thermomechanical units of the Paintbrush Group, Calico Hills Formation, and Crater Flat Group Used at Yucca Mountain (Modified from CRWMS M&O, 1996f)

Formal Geologic Stratigraphy (after Sawyer et al., 1994)		Hydrogeologic Units (Modified from Montazer and Wilson, 1984)	Thermal/Mechanical Units (Ortiz et al., 1985)
Qac		Alluvium	UO
Paintbrush Group	Tiva Canyon Tuff	Tiva Canyon Welded Unit TCw	TCw
	pre-Tiva Canyon bedded tuff	Paintbrush Nonwelded Unit PTn	PTn
	Yucca Mountain Tuff		
	pre-Yucca Mountain bedded tuff		
	Pah Canyon Tuff		
	pre-Pah Canyon bedded tuff		
	Topopah Spring Tuff	Topopah Spring Welded Unit TSw	TSw1
			TSw2
			TSw3
pre-Topopah Spring bedded tuff		Calico Hills Nonwelded Unit CHn	CHn1v
Calico Hills Formation			CHn1z
			CHn2z
			CHn3z
Crater Flat Group	Prow Pass Tuff	Crater Flat Unit CFu	PPw
	Bullfrog Tuff		CFun
			BFw
	Tram Tuff		CFMn
			TRw

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3.1 GEOHYDROLOGY (SCP SECTION 8.3.1.2)

The changes to the Geohydrology Program since the SCP was issued are summarized in Appendix A in Section A.1.1.

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

In 1990, the study was modified to emphasize meteorological information needed to develop an infiltration model for Yucca Mountain. At that time, precipitation-runoff modeling was de-emphasized (see Appendix A, Section A.1.1.1. of this progress report).

Closing calibrations for all field instruments used on the weather stations were completed as part of preparing FY 1996 data packages. The weather-station data, collected before disassembly of the remaining two weather stations, were compiled into daily files and technically reviewed.

Closing calibrations for all instruments used in the network of 14 tipping-bucket precipitation gauges were completed, and the timing of 0.1 mm precipitation events was determined. The network of 14 tipping-bucket gauges was transferred to the Environmental Field Program for air quality and meteorology (see Section 3.8 of this progress report). As part of the transfer, all equipment was removed from the field, cleaned, calibrated, and reinstalled for use by the Environmental Field Program. The Environmental Field Program now has assumed responsibility for collecting all meteorological data previously collected under this study.

All meteorological data and supporting documentation from the two weather stations, the tipping-bucket network, and the storage-gauge network have been technically reviewed and submitted to the Records Processing Center and Technical Data Base.

Work under this study was discontinued effective March 31, 1997.

Forecast: All future meteorological data collection will be conducted under the Meteorology Program (SCP Section 8.3.1.12) described in Section 3.8 of this progress report.

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 on its hydrologic flow system; (b) use the streamflow data to describe the runoff characteristics of the area and to assess the response of runoff to precipitation; (c) assess the potential for flood hazards and related fluvial-debris hazards; and (d) provide basic

data and interpretations of surface-water runoff to investigations that evaluate the amounts and processes of infiltration and 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 relation 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, and site-scale water-balance and infiltration modeling.

Monitoring continued at the three continuous-recording streamflow gauges on Fortymile Wash at the Narrows, Fortymile Wash near well UE-25 J#13, and Fortymile Wash near Amargosa Valley. During November 1996 several storms moved across southern Nevada, and minor runoff resulted in the Yucca Mountain area. Small amounts of flow were reported at the Fortymile Wash gauges at the Narrows and near well UE-25 J#13. Stages were too low, however, to be recorded by the monitoring equipment.

Records of data collected during water year 1996 for the three continuous-recording streamflow gauges were processed for publication in the U.S. Geological Survey (USGS) annual water-data report for Nevada.

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: Monitoring will continue at the three continuous-recording streamflow gauges. Data records for water year 1996 will be published in the annual water-data report for Nevada.

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 completed in FY 1996. See Progress Report #15 (DOE, 1997e).

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.

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

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.

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

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.

Forecast: This study was not funded for FY 1997 and no work is planned.

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, to make a qualitative analysis of how the regional and subregional ground-water flow systems function, and to describe the regional saturated zone ground-water flow system.

No activity occurred during the reporting period. Work scope for this activity has been transferred to Activity 8.3.1.2.1.4.4 (see Section A.1.1 of Appendix A of this progress report).

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 by incorporating additional hydrogeologic data.

No activity occurred during the reporting period. Work scope for this activity has been transferred to Activity 8.3.1.2.1.4.4 (see Section A.1.1 of Appendix A of this progress report).

Activity 8.3.1.2.1.4.3 - Subregional two-dimensional cross-sectional hydrologic modeling. The objective of this activity is 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 activity occurred during the reporting period. Work scope for this activity has been transferred to Activity 8.3.1.2.1.4.4 (see Section A.1.1 of Appendix A of this progress report).

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 used to construct the regional ground-water flow model was updated to ensure consistency with the calibrated flow model. Hydraulic-conductivity attributes from the calibrated regional flow model were added to the appropriate framework-model grid cells. The revised framework model was reviewed and submitted to the Records Processing Center. Model output of simulated fluxes along the boundaries of the site saturated zone flow model were extracted from the regional model and reformatted for use in the site saturated zone flow model. Calibration of the regional flow model was completed and documented during the last reporting period (Progress Report #15, DOE, 1997e).

Regional flow modeling focused on simulating past- and potential future-climate scenarios using the existing calibrated flow model. Precipitation data for two climate scenarios were received from the National Center for Atmospheric Research, which is conducting the numerical simulations of future climate. The first data set represents results of the simulation of maximum continental ice cover during glaciation, which is believed to have occurred about 21,000 years ago and are believed to represent the wettest, coolest climate possible at the Yucca Mountain site that might occur during the proposed repository performance period. The second data set represents results of the simulation of a possible future climate scenario in which carbon dioxide concentration in the earth's atmosphere has doubled because of the "greenhouse effect." The simulated precipitation data were reprocessed into distributions of recharge corresponding with the grid for the regional ground-water flow model. This reprocessing was accomplished by kriging precipitation output from the National Center for Atmospheric Research Global Climate Model (see Section 3.1.5 of this progress report) and then applying methods described by Hevesi and Flint (in press). Digitized data-input arrays of recharge for the MODFLOWP simulation code were constructed using the reprocessed recharge distributions. Maps of past-discharge areas were constructed and qualitative estimates of discharge rates for each area were provided by Project scientists. These discharge estimates will be used to evaluate and bound simulations of past and possible future climate scenarios. Simulation began of the past and possible future climate scenarios with the regional ground-water-flow model.

The results of the regional flow model calibration are found in D'Agnese et al., in press[a]. Additional revisions were made to a second report (D'Agnese et al., in prep.) that documents the estimated regional potentiometric surface. A journal article (D'Agnese et al., in press[b])

documenting regional recharge and discharge areas, using regional distributions of vegetation types, was prepared.

Forecast: The simulation of the past and possible future climate scenarios using the existing flow model will be completed. A draft report documenting the results of those simulations will be completed and submitted for review and approval. The report documenting the calibration of the existing regional flow model will be revised and published. The report documenting the regional potentiometric surface will be submitted for approval and prepared for publication.

3.1.5 Study 8.3.1.2.2.1 - Characterization of Unsaturated Zone Infiltration

The objectives of this study are to determine the effective hydraulic conductivity, storage properties, and transport properties as functions of moisture content or potential, and to determine the present and estimate the future spatial distribution of infiltration rates over the repository block.

The primary goal of the reconfigured study is to define the upper-boundary conditions for the site unsaturated zone hydrologic system, in terms of spatial and temporal distribution of moisture flux, for use in site-scale models of unsaturated zone ground-water flow and transport. 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 provide the basis for a stochastic-deterministic simulation of future upper-boundary conditions, including the probability and magnitude of potential fast pathways of net infiltration. Once the infiltration flux at the upper boundary of the unsaturated zone has been defined, the site-scale model will be used to simulate flow across the potential repository horizon for the set of conditions chosen.

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.

This activity was completed in FY 1996. See Progress Report #15 (DOE, 1997e).

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.

Net infiltration is the amount of natural surface-infiltrated water less losses to evapotranspirative and other processes such as circulation of air within the porous rock mass. Study results indicate that the properties and processes most important for determining net infiltration are the timing and amount of precipitation, the storage capacity of the soil (which includes soil depth), the seasonality and amount of evapotranspiration, and the hydrologic properties of the underlying bedrock.

Infiltration Distribution

This part of the natural-infiltration activity was completed in FY 1996. See Progress Report #15.

Infiltration Processes

Analysis to confirm the numerical model of net infiltration was conducted using 15 years of precipitation data and 10 years of neutron-hole moisture data. With minor exceptions, the results presented in Progress Report #15 were substantiated by the additional analysis. The analysis indicated that the principal weakness in the infiltration model is the lack of a module to simulate the generation and routing of surface runoff. Although the overall output of the infiltration model may not be affected significantly, the lack of runoff routing information makes the net-infiltration values produced by the model more difficult to evaluate. Any additional changes to the net-infiltration model, such as the addition of runoff routing, likely will increase the estimates of net infiltration above those currently being generated.

Analysis of two climate scenarios was completed for the regional ground-water-modeling study (see Section 3.1.4 of this progress report). One scenario involves a past climatic condition about 21,000 years ago when glaciation was at a maximum, and the other involves a possible future climatic condition when atmospheric carbon-dioxide concentration might be doubled by the "greenhouse effect." The past climatic condition is important to repository performance assessments because it could recur within the next 100,000 years. Simulated precipitation data for each of these climatic conditions were obtained from the National Center for Atmospheric Research Global Climatic Model (see Section 3.4.6 of this progress report). For each scenario, the ratio of the changed climate scenario to the base case (current climate) was used to produce a "change map" of precipitation. Each change map was produced by kriging the 64 Global Climatic Model modeled points (50-km spacing) covering the Yucca Mountain regional study area. The "change map" was used in combination with the present-day regional precipitation map to produce past and future precipitation maps. The kriged precipitation maps indicated a 71 percent increase in precipitation for the past-climate scenario and a 17 percent increase in precipitation for the future-climate scenario. The climate scenario precipitation maps were then used as input to the Maxey-Eakin method for calculating recharge, which is described in Hevesi and Flint (in press). Given that on a regional basis the recharge at Yucca Mountain is 1 to 2.5 mm/yr, the past climate scenario yielded 10 to 25 mm/yr (a ten-fold increase in recharge) and the future climate scenario yielded 2.5 to 5 mm/yr (a two-fold increase in recharge). Because these values are really averaged over the regional study area, they should not be interpreted as an estimate of net infiltration over the area of the potential repository. Estimated infiltration rates at the potential repository location likely would be larger (Flint et al., in prep.) because of additional runoff routing information.

Activity 8.3.1.2.2.1.3 - Evaluation of artificial infiltration. The objective of this activity is to characterize water movement in the surficial materials of Yucca Mountain under controlled conditions. Experiments designed to determine the total water flux, flow velocities, and flow paths will be performed on the geohydrologic-surficial units under both present-day precipitation rates and simulated higher rates corresponding to wetter climatic conditions.

With the reconfiguration of the study, this activity is now limited to field validation of the infiltration model described in Activity 8.3.1.2.2.1.2 for simulated wetter conditions.

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

Forecast: No additional work is planned under this study for the remainder of FY 1997. A proposal will be prepared to incorporate a stream runoff-routing subroutine into the numerical infiltration model during FY 1998.

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 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 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.

Analyses of Exploratory Studies Facility Samples

As of March 1997, sampling to support FY 1997 deliverables was completed up to ESF Station 69 + 42 (6942 m from the ESF north portal), and analytical data were available up to ESF Station 67 + 90 (6790 m). Results of the analysis of chlorine-36 data for 187 samples were used to assess ground-water travel times and identify potential fast paths for infiltrating water (Levy et al., in prep). Rock samples were systematically collected every 200 m throughout the tunnel [every 100 m starting with Station 61 + 00 (6100 m)], and feature-based samples were collected from specific geologic features such as faults, fractures, lithophysal cavities, and subunit contacts. Chlorine-36 from weapons testing occurs in a few distinct fractured and/or faulted zones, indicating that at least a detectable amount of the water is less than 50 years old. Initial analysis suggested that chlorine-36 from weapons testing appear to be associated with major faults mapped at the surface. Levels of chlorine-36 unambiguously from weapons testing have not been detected in any of the 54 samples collected beyond Station 45 + 00 (4500 m).

A report (Levy et al., in prep.) examining the sampling results primarily focuses on the detailed characterization of the petrologic and structural settings of sample sites, particularly the so-called "fast paths" that contain a component of chlorine-36 from weapons testing. The methodology involves examining relevant field evidence for (a) correlations between surface and subsurface structural features; (b) vertical connectivity and characteristics of the fracture networks in the Tiva Canyon welded (TCw), the PTn, and the Topopah Spring welded (TSw) hydrogeologic units; and (c) possible changes in fracture intensity near fault zones. These lines of evidence indicate the distribution of chlorine-36 in the ESF from weapons testing depends on (a) the presence of faults that cut the PTn hydrogeologic unit, (b) the magnitude of surface

infiltration, and (c) the structural features that produce downward lateral spreading of flow from fault zones.

1. Presence of faults that cut the PTn hydrogeologic unit. The most important structural control seems to be the presence of faults that create breaks in the PTn. Sample locations in the north ramp and main drift of the ESF that show evidence of chlorine-36 from weapons testing are located in the general vicinity of projections of faults mapped at the surface. These include a block-bounding fault (Bow Ridge fault), a probable strike-slip fault (Drill Hole Wash fault), and smaller, intrablock faults (the Sundance fault). The defining characteristic is that the fault must be large enough to break the PTn; fault type, orientation, and amount of offset have no apparent affect on the presence of chlorine-36. This observation is consistent with the results of hydrologic modeling of percolation through the PTn hydrogeologic unit. Model results required a fault through the PTn for at least a small amount of water with the weapons testing signature to arrive at the middle nonlithophysal zone of the Topopah Spring Tuff (main drift of the ESF).

   In some instances, the locations of ESF samples containing chlorine-36 from weapons testing do not appear to correspond to a fault mapped at the surface; yet the presence of chlorine-36 from weapons testing may still be inferred to be the likely result of a fault that cuts the PTn hydrogeologic unit. One example is a sample site located under Diabolus Ridge, which is not obviously associated with a fault mapped at the surface. However, across the central part of Diabolus Ridge, a gently east-dipping reverse fault is mapped at the surface. This fault has about 7 m of offset at the level of the upper portion of the Tiva Canyon Tuff. Projected downward, this fault cuts the base of the PTn hydrologic unit almost directly above the chlorine-36 sample location at ESF Station 26 + 79 (2679 m). Although various other pathways could be envisioned, the simplest explanation for the presence of chlorine-36 from weapons testing is that the fast pathway includes the fault that cuts the PTn hydrogeologic unit above the sample location.

2. Magnitude of surface infiltration. Limited data indicate a correlation between the chlorine-36 signature of a particular fault zone and the surface location of the fault with respect to spatially distributed infiltration. In the main drift of the ESF, faults that have elevated chlorine-36/chloride values indicating a component of chlorine-36 from weapons testing tend to coincide with infiltration highs as defined by Flint et al. (in prep.). For example, both the Sundance fault and the fault on Diabolus Ridge are relatively minor features at the surface, but their surface traces intersect fractured bedrock on topographically high ridge tops that are free of alluvial cover, conditions that may be conducive to elevated infiltration rates. In contrast, faults that do not have elevated chlorine-36/chloride values have surface traces that tend to coincide with infiltration lows. For example, where the surface traces of the southwestern splay of the Drill Hole Wash fault and the southern part of the Ghost Dance fault overlie the ESF, the faults are exposed in topographically low wash bottoms or side slopes with thick alluvial material, conditions associated with low levels of infiltration. These limited data indicate that in the ESF, even faults with relatively minor offset may be

associated with the presence of chlorine-36 from weapons testing, where they intersect zones of sufficiently high infiltration. Conversely, faults of similar, or even greater, offset that intersect zones of low infiltration may not have elevated chlorine-36/ chloride values.

3. Structural features that result in downward lateral spreading of flow away from fault zones. A number of the sample localities along the north ramp of the ESF have elevated chlorine-36/chloride values and are tightly grouped near a single fault or an individual joint. In contrast, ESF sample localities near the Sundance fault with elevated chlorine-36/chloride values form a broad zone encompassing a 300-m distance along the ESF. The Sundance fault is the only known structure mapped in this vicinity that could have served as the pathway through the PTn hydrogeologic unit. Therefore, it is hypothesized that the broad zone of elevated chlorine-36/chloride values north of the fault thus represents downward lateral spreading of flow away from the plane of the fault. Such flow implies a connection between the fault and other structures, either small subsidiary faults or interconnected joints, in the rock mass surrounding the fault.

Levy et al. (in prep.) also describes the attributes of fast pathways that contribute to the formation of distinctive secondary mineral assemblages. Preliminary mineralogic and petrologic analysis of 39 samples in the chlorine-36 data base suggests that fast pathways may have some subtly distinctive mineralogic characteristics. Calcite, a common mineral in the ESF, is even more common in samples containing chlorine-36 from weapons testing, but this criterion alone is insufficient to predict the locations of fast paths. Observations indicate that the calcite deposits in fast-path transmissive features are much thinner than the calcite-opal deposits used for thorium-230/uranium geochronologic studies of mineral deposition and inferred infiltration rates. Opal, unlike calcite, appears to be less common in fast pathways than its overall abundance in the ESF would suggest.

Clay deposits that coat fractures or breccia clasts are assumed to result from aqueous transport of fine clay particles within the fracture network and are unlikely to have been derived from the adjacent rock matrix. The mineralogic data set described in Levy et al. (in prep.) does not indicate a consistent connection between fast paths and the presence of clay/mordenite. Fast-path sites associated with the Sundance fault, however, are correlated with the presence of clay/mordenite deposits. In addition to clay, there are also deposits of coarser particulate materials. The most prominent of these is a deposit in a fracture in the Topopah Spring Tuff with graded bedding that clearly indicates particle settling in a water-filled fracture in the past. This sample has no weapons testing chlorine-36 signature. The material in this deposit was probably transported before the PTn nonwelded tuffs were emplaced on top of the Topopah Spring Tuff. Particulate deposits such as this may relate more to former than to present fast pathways in the Topopah Spring Tuff.

Forecast: The results of this study will be applied to the validation of site-scale hydrologic flow and solute transport models being developed under other activities. Project scientists will continue collecting and analyzing samples from the ESF to test or confirm hydrologic-flow hypotheses made using previous results. Collecting and analyzing of samples

from boreholes will continue, as appropriate. The contribution of the in situ produced chlorine-36 (e.g., from soil calcite) to the subsurface concentrations of this isotope will be evaluated.

Existing chloride and chlorine-36 data for boreholes and the ESF will be interpreted in terms of infiltration rates and identification of fast-transport paths from the surface to the sampled depths. Chlorine-36 distributions will be correlated with lithology, structural features, and past climates. Corrected ground-water travel time estimates will be produced using data from chlorine-36 samples from boreholes and the ESF. Chlorine-36 analyses will be synthesized. Hydrologic analysis and simulation activities will be performed using the Finite Element Heat and Mass (FEHM) code to help interpret chlorine-36 data. Data and interpretations will be provided to hydrologic and solute transport modelers (a) to ensure appropriate use of isotopic results in model validation exercises and in the various hydrology reports, and (b) to ensure consistency in interpretation of results from this activity with those geochemical and isotopic results obtained from other activities.

Elevated chlorine-36 occurrences, possibly from weapons testing, will be corroborated using other environmental tracers such as iodine-129 and technetium-99. Input functions for these tracers will be developed, as appropriate, to compare their timing and magnitude relative to that for chlorine-36 attributed to weapons testing.

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 relation 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.

Locations of most of the boreholes identified in the activities included in this study are shown in Figure 3-2. Symbols for the lithostratigraphic units of the Paintbrush Group exposed at Yucca Mountain (e.g., Tptpmn and Tptpll) are found in Buesch et al. (1996a).

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 ESF samples from all hydrogeologic units in the unsaturated zone to characterize the spatial distribution of hydrologic properties within the unsaturated zone.

This activity has been focused to provide two primary information products: (1) a data base of rock matrix hydrologic properties from a series of boreholes that is qualified for site characterization use, and (2) an interpretation of the hydrologic properties of specific hydrogeologic units. Hydrogeologic units have been determined on the basis of similarities

within and differences between lithostratigraphic units for the purpose of developing hydrologic flow models.

A study was conducted in the ESF main drift to assess the spatial variability of properties within the Topopah Spring Tuff middle nonlithophysal zone (Tptpmn), the host rock for the potential repository. The study addressed several technical concerns of the unsaturated zone site characterization and performance assessment modelers. Typically, rock properties are input into numerical model layers in one of three ways: (1) as a mean value (either arithmetic, geometric, or power-law mean depending on the property); (2) as a random distribution based on a probability-distribution function determined from all measured values of the property; or (3) as the measured mean value and variance of the rock property as an initial condition for inverse modeling to match a hydrologic property, such as saturation. The properties of the rocks also can be distributed spatially using geostatistical analyses for those properties for which there are spatially distributed estimates, such as porosity. Overall, the Tptpmn has low matrix permeability and high in situ saturations.

Seventy rock samples were collected systematically every 40 m along the wall of the ESF main drift to investigate the possible presence of preferential matrix-flow zones within the Tptpmn. Samples were collected along a transect from the top of the unit at ESF Station 28 + 00 (2800 m) through the base of the unit and into the lower lithophysal zone (Tptpll) at ESF Station 58 + 00 (5800 m). To date, only porosity, bulk density, and particle density have been measured. These data have been compared with the lithostratigraphic descriptions, borehole samples collected from nearby boreholes, mineralogy surveys, chlorine-36 measurements, and line fracture surveys. From top to bottom, porosity along the transect within the middle nonlithophysal zone ranges from 9 to 16 percent in an upper lithophysal subzone, porosity then decreases to about 8 to 12 percent through the primary nonlithophysal subzone, increases to 10 to 13 percent in a lower lithophysal subzone (which at this location does not contain lithophysal cavities but merely a higher matrix porosity and which corresponds to the closely spaced vertical fracture zone informally named the Broken Limb fracture zone). Finally, porosity decreases to 7 to 11 percent as the middle nonlithophysal zone transitions into the lithophysal rocks (Tptpll) below. These changes in porosity can be explained relatively well based on lithostratigraphy and vapor-phase activity during cooling of the tuffs and are supported by measurements of samples from nearby boreholes. The significant interpretation of these data is that there are trends indicating areas of higher and lower porosity that are not randomly distributed where water flow may be concentrated in the matrix. Interpretations of mineral-coatings data that might corroborate the matrix-flow hypothesis presently are inconclusive. There is, however, evidence of a relationship between the color in the rock unit and the matrix properties; gray is associated with higher matrix porosity and pink with more massive rock with lower matrix porosity.

Samples collected from various boreholes in ESF alcoves were processed for matrix hydrologic properties in support of borehole pneumatic monitoring, air-permeability testing, gas sampling, moisture-monitoring, and percolation studies. Borehole samples were collected and processed from the Bow Ridge Fault Alcove, Upper Paintbrush Tuff Contact Alcove, Lower Paintbrush Tuff Contact Alcove, and Northern Ghost Dance Fault Alcove. Results of analyses of samples from the Northern Ghost Dance Fault Alcove indicated higher porosities (9 to 11 percent) on the western side (hanging wall) of the fault and lower porosities (8 to 9 percent)

on the eastern side (footwall). Only one sample, collected from the edge of the fault on the hanging wall, exhibited a saturated water content. This sample may be indicative of water flow within the fault, but more likely is evidence of a very localized condition caused by a capillary barrier at the end of the fault zone.

Additional analyses were performed to correlate matrix hydrologic properties of borehole core samples with mineral percentages. Results of analyses indicated that an estimate of the influence of altered minerals on hydrologic properties could be reasonably predicted from measurements of the volumetric water content held in rocks when dried in an oven at 60°C and 65 percent relative humidity. The minerals (generally zeolite) present in a rock that holds 5 percent water content under these drying conditions influence the in situ saturation (usually greater than 90 percent saturation) and saturated conductivity (reducing it by 2 to 3 orders of magnitude).

An important parameter that has not been characterized at Yucca Mountain is unsaturated hydraulic conductivity. Typically, this flow parameter is predicted from equations using moisture-retention data. An ultra-centrifuge has been configured at the Hydrologic Research Facility in Nevada Test Site Area 25 to measure unsaturated hydraulic conductivity directly under steady-state conditions. To date, two core samples have been tested. Moisture-retention curves also were measured, and the van Genuchten/Mualem equation (Van Genuchten, 1980) was used to predict conductivity, which was then compared with the measured data. Results indicated that the prediction of unsaturated hydraulic conductivity was very sensitive to the curve-fitting technique used to obtain parameters from the moisture-retention data. In addition, the unsaturated hydraulic conductivity was predicted most accurately when the estimated residual water content was not used in the data set. The technique somewhat under-predicted the measured values for the two samples of the pre-Pah Canyon bedded tuff (Tpbt2), suggesting that in modeling simulation, using constant flux boundaries, more water will flow through the matrix under unsaturated conditions than would be predicted by moisture-retention data alone. This interpretation is based solely on preliminary analysis of two samples; additional samples need to be measured before any definitive conclusions can be drawn.

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

Drilling

There was no site unsaturated zone drilling activity during the reporting period; this was an unfunded activity.

Vertical Seismic Profiling

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

Borehole Instrumentation and Monitoring

Temperature monitoring in boreholes UE-25 UZ#4 and UE-25 UZ#5 in Pagany Wash indicates reversals in temperature-recovery trends at UE-25 UZ#5 in all instrument stations located above the Pah Canyon Tuff of the PTn (Table 3-2). After a prolonged cooling period, lasting almost 18 months, temperatures in the upper half of the PTn at UE-25 UZ#5 began increasing in November 1996. Borehole UE-25 UZ#5 is located on a hillslope adjacent to Pagany Wash. Temperature trends at UE-25 UZ#4, located in the channel bottom of Pagany Wash, continued to increase or were stable. No temperature reversals below the depth of penetration of surface-temperature changes have yet been noted in UE-25 UZ#4. The effect of the temperature data from the Pagany Wash site on estimates of net infiltration and deep percolation is discussed in Rousseau et al. (in prep.[a]). The recent temperature data from the two Pagany Wash boreholes may indicate the passage of an infiltration front through the Tiva Canyon Tuff and upper half of the PTn at a depth of about 70 m in UE-25 UZ#5.

Monitoring in borehole USW NRG-7a over the past six months indicated a steady recovery of temperature and water potentials in instrument station "D" located in the upper Yucca Mountain Tuff of the PTn. This recovery followed a one-month period of unusual oscillations and instability in the temperature and water potential measurements beginning on May 9, 1996 (see Progress Report #15, Section 3.1.7). The cause of the unusual behavior at USW NRG-7a is not known, but the data clearly indicate that the disturbance was propagated from above the instrument station and not from below. Topographic density-driven air-circulation within the Tiva Canyon Tuff offers one possible explanation to account for the extremes in the observed disturbances.

During January 1997, a leak test for instrument-station integrity was conducted in borehole USW SD-12 to confirm the reliability of pneumatic-pressure measurements from an instrument station located at the base of the lower nonlithophysal zone of the Topopah Spring Tuff. Before the onset of tunnel boring machine interference effects, the residual amplitude and phase lag of the synoptic pressure signal at this instrument station was larger than and led those of all other overlying instrument stations in the Topopah Spring Tuff. This observation has led some investigators to infer lateral (and preferential) communication between the Ghost Dance fault and borehole USW SD-12. The leak test indicated less than complete integrity for the instrument station in the lower nonlithophysal zone of the Topopah Spring Tuff but results were acceptable for all other instrument stations in USW SD-12. Thus, the data from the lower nonlithophysal instrument station cannot be used to infer preferential, lateral communication via the Ghost Dance fault.

The results of borehole monitoring are discussed further in the section below titled "Integrated Data Analysis and Interpretation."

Hydrologic Data Acquisition System

A basic data report was prepared and submitted to the Project Records Processing Center and Technical Data Base in December 1996. This report contains reduced pneumatic-pressure, temperature, and water-potential data for (a) boreholes USW NRG-7a, UE-25 UZ#4, UE-25

UZ#5, USW SD-12, and USW UZ-7a through September 30, 1996, and (b) borehole USW NRG-6 through September 12, 1996. Monitoring of USW NRG-6 was discontinued on September 12, 1996. A raw data package was submitted to the Project Records Processing Center and Technical Data Base in February 1997. This data package contained all raw data collected from August 15, 1996 through December 31, 1996, for the above-listed boreholes.

Surface-Based Air-Permeability Testing

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

Integrated Data Analysis and Interpretation

Work began on a report that describes the results of surface-based monitoring in boreholes USW UZ-7a, USW SD-12, and USW SD-7 (located along the alignment of the ESF main drift), and USW NRG-7a (located near the intersection of the main drift and the ESF north ramp). The most significant findings contained in this report are summarized here.

Pneumatic pressures in all Topopah Spring Tuff instrument stations in boreholes USW SD-12, USW NRG-7a, and USW SD-7 have increased in response to ESF tunnel construction. These pressure increases are on the order of 0.06 kPa in USW SD-12, 0.09 kPa in USW NRG-7a, and 0.035 kPa in USW SD-7. At USW UZ-7a, only the bottom three instrument stations, located on the eastern side (foot wall) of the easternmost trace of the Ghost Dance fault, have shown an increase in mean pressure on the order of 0.020 kPa. Increases in mean pressure in the Topopah Spring Tuff reflect internal pressure adjustments in response to pneumatic bypassing of the overlying, impeding PTn by the ESF. The lack of any significant pressure changes in the Topopah Spring instrument stations located on the western side (hanging wall) of the Ghost Dance fault indicated very little attenuation of the atmospheric pressure signal and very high secondary porosity associated with fracturing in the fault zone.

Temperatures in all Topopah Spring Tuff instrument stations in USW SD-12 also have changed in response to ESF tunnel construction. Before the onset of tunnel interference effects, temperatures in these stations were increasing asymptotically toward their original, pre-disturbed, steady-state values. Following the onset of pneumatic-interference effects, temperatures have been steadily decreasing. These temperature reversals are viewed as an indication of heat loss driven by evaporation and unidirectional gas flow through the Topopah Spring Tuff near USW SD-12. Tunnel-induced temperature changes have not yet been observed in any of the other monitored boreholes at Yucca Mountain. Temperatures in the Topopah Spring Tuff instrument stations in USW NRG-7a, which is closer to the ESF tunnel than USW SD-12, have continued to increase even though pneumatic-interference effects in this borehole were first observed almost four months before those in USW SD-12. Data indicate that significant secondary porosity may be associated with the fracture system in USW SD-12. Indeed, the pneumatic-interference effects that occurred in USW SD-12 took at least two months to fully develop. As reported in Progress Report #15 (DOE, 1997e), pneumatic interference effects in USW SD-12 were initially very subtle and slowly increased over approximately one month. More recent analysis indicated that complete readjustment of the pressure system in USW SD-12 probably did not occur until sometime after April 1996—more than two months after the first indication that pressures had

been disturbed. These data indicate that large volumes of gas were needed to reestablish pressure equilibrium in the vicinity of USW SD-12.

Analysis of the pressure records from the two deepest instrument stations in USW SD-12 (one located below the densely welded, vitric zone of the Topopah Spring Tuff and the other located at the top of the nonwelded Calico Hills Formation), indicate that the static pressure of these two stations is less than that predicted from extrapolating the static pressure profile developed across the Topopah Spring Tuff. The pressure "deficit" in these two stations is on the order of 0.12 kPa, which is much larger than the 0.001 kPa that can be accounted for by a change in the temperature gradient across the Topopah Spring Tuff-Calico Hills Formation contact. The pressure deficit may indicate an oxygen-consuming or reducing environment below the densely welded vitric subunit of the Topopah Spring Tuff. Pressure data from these two stations indicate the presence of a perched-water zone within the densely welded, vitric zone. A synoptic pressure signal is present in the pressure record of the station immediately below the perched-water zone. The amplitude of this signal is less than 1 percent of the surface signal but its phase lag with respect to the surface signal is essentially zero. This synoptic-signal component is superimposed on a seasonal pressure signal that represents a time-averaged composite of seasonal pressure changes occurring at the ground surface. The pressure signal from the underlying Calico Hills nonwelded unit contains no synoptic component, yet this signal leads the time-averaged composite signal in the overlying vitric zone. Taken together, these data indicate an atmospheric loading or strain-induced response associated with the synoptic signal component present in the pressure record of the instrument station below the perched-water zone. This finding indicates that the perched-water zone is of limited areal extent and accounts for the phase of the pressure signal in the deeper station leading the phase of the pressure signal in the overlying station. Furthermore, the synoptic component present in the pressure record of the overlying station represents the effect of local compression and expansion of the host rock that involves no net transport of gas.

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 unfunded activity.

Forecast: The systematic analysis of matrix-properties of the Topopah Spring Tuff middle nonlithophysal zone in the ESF will be extended to include saturated hydraulic conductivity for all samples. Additional samples will be collected in a more detailed transect with 140 samples at 20-m intervals. Fracture densities and apertures currently are being analyzed and will be used with matrix-property measurements to assess the likelihood of preferential pathways for flow, as well as to provide a data base of fracture properties for flow modeling. Additional unsaturated hydraulic-conductivity measurements will be made and compared with values predicted from moisture-retention data using several different techniques. Curve-fitting techniques also will be refined to predict measured data as accurately as possible.

Pneumatic-pressure, temperature, and water-potential monitoring will continue throughout FY 1997 in boreholes USW NRG-7a, UE-25 UZ#4, UE-25 UZ#5, USW UZ-7a, and USW SD-12. Data packages containing raw sensor readings and reduced values of monitoring data will be submitted to the Project Records Processing Center and Technical Data Base as appropriate. Borehole-monitoring data will be reduced and analyzed, including evaluations of barometric-pressure damping and lagging with depth, temperature gradients, and temperature stability. Emphasis will be placed on evaluating the significance of temperature changes induced by the tunnel boring machine in the Topopah Spring Tuff in USW SD-12 and transient temperature changes within the PTn beneath Pagany Wash in UE-25 UZ#4 and UE-25 UZ#5. A major effort during the next six months will be the compilation and writing of several subsections of the hydrology chapter of the Project Integrated Safety Assessment report.

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.

Symbols for the lithostratigraphic units of the Paintbrush Group exposed at Yucca Mountain (e.g., Tpcpul) are found in Buesch et al. (1996a).

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. The purpose of the work is to characterize fluid flow along both undisturbed fractures and those under stress, and to provide these properties to help calibrate models for fluid flow in fractured rock at various scales.

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

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 in fractured tuff units, and to provide experimental data against which the validity of conceptual and numerical models may be tested. In addition, this activity will determine the moisture balance within the ESF and adjacent rock mass in response to water-vapor transport from the ESF because of ventilation associated with ESF construction. This will be accomplished by measuring moisture conditions of the drift walls and rocks, and by monitoring the humidity and temperature of the air in the ESF.

Only the second part of this activity (moisture balance) was funded during the reporting period. This scope was added by Change Request 96/019.

Air temperature, relative humidity and wind speed data were collected in fixed locations within the ESF and on the tunnel boring machine. Three existing sensor stations are located near

the north end of the ESF, and four new sensor stations were installed in the main drift and the south ramp as the tunnel boring machine advanced. Large variations in relative humidity and vapor density were observed, largely associated with variations in the mining operations, especially during weekdays when the ventilation system removes large amounts of construction water and moisture from the drift walls. During the weekends, when construction water was not used and ventilation was continued, the tunnel atmosphere stabilized to lower humidity conditions. Evaporation rates were also lower and variations were less. During weekends when the ventilation was continued, evaporation effectively increased the relative humidity to near saturated conditions. Rock temperatures near the tunnel boring machine were observed to change spatially and temporally and could be related to evaporation from the rock surfaces (Wang et al., 1996). The ventilation operations effectively remove the equivalent of approximately 200 mm/yr (± 100 mm/yr) of moisture. Therefore, these operations mask any possible measurements or observations of seepage into the ESF, which is estimated to be approximately one order of magnitude lower than the current ESF dryout rate (Bodvarsson and Bandurraga, 1996).

In addition, tensiometers and heat dissipation probes were installed in parts of the PTn in the south ramp to measure water potential. Time-domain reflectometry probes were installed in the Upper Paintbrush Contact Alcove to collect water-content data. The use of these "contact" sensors in specific locations has provided the opportunity to collect more accurate and more precise water-potential data than could be collected previously. Initial values of water potential measured in the PTn in the south ramp were -0.01 to -0.3 MPa, which are considerably "wetter" (with respect to a moisture-retention curve relating water potential to saturation) than any in situ measurements reported in the surface-based boreholes in similar zones of the PTn. These relatively greater water potentials suggest a higher flux through the PTn than would have been estimated using the surface-based borehole data. However, the sensors installed near the tunnel wall are drying out at a rate equivalent to 0.5 to 1 mm/day (180 to 365 mm/yr), which is supported by the dryout estimates made from changes in vapor density calculated using the temperature, relative humidity, and wind speed data. Matrix flux in the PTn has not yet been estimated using this new information.

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 phases, and to evaluate the potential for lateral movement of water along hydrologic contacts, as

well as to evaluate the radial extent of excavation effects on the hydrologic properties of the unsaturated hydrogeologic units.

Project hydrologists completed and submitted a technical report to the Yucca Mountain Site Characterization Office (YMSCO) that documents pneumatic monitoring, hydrochemistry sampling, and air-injection and gaseous tracer testing conducted in the north ramp of the ESF between November 1994 and July 1996 (LeCain et al., in prep.). These studies were conducted in the Upper Tiva Canyon Alcove and the Bow Ridge Fault Alcove. Pneumatic monitoring of boreholes in the Upper Tiva Canyon Alcove showed no differential pressure among three boreholes, and between the boreholes and atmospheric pressure, confirming the large fracture permeability of the Tiva Canyon Tuff. In addition, gaseous-phase carbon-14 data indicate a large degree of mixing between atmospheric and rock gas. Matrix-properties testing of cores from boreholes in the Upper Tiva Canyon Alcove indicates that the matrix porosity of the Tiva Canyon Tuff crystal-poor, upper lithophysal zone (Tpcpul) ranges from 0.1 to 0.24, with a mean of 0.15. Matrix air-permeability values range from 1.4 to 120.0×10^{-17} m^2. Bulk permeability values of the Tpcpul from air-injection testing have an arithmetic mean of 28.6×10^{-12} m^2 and a geometric mean of 16.0×10^{-12} m^2. Comparison of the Tpcpul permeability values to the air-permeability values for the Tiva Canyon Tuff obtained form surface-based tests indicates that at shallow depths the Tiva Canyon Tuff is isotropic with respect to air permeability.

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

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

Activity 8.3.1.2.2.4.6 - Calico Hills testing in the Exploratory Studies Facility. The objectives of this activity were intentionally deleted. Testing in the Calico Hills Formation will be described in revisions to other ESF studies.

This activity was deleted from the study plan in Revision 9 of the Site Characterization Program Baseline (DOE, 1995a). (See Appendix H for the Site Characterization Program Baseline history.) Testing in the Calico Hills nonwelded (CHn) hydrogeologic unit may be conducted as part of other ESF testing activities.

Activity 8.3.1.2.2.4.7 - Perched-water testing 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 the flux, flow paths, and travel times.

This activity was completed in FY 1996. See Progress Report #15 (DOE, 1997e).

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 of water in the unsaturated zone by isotope geochemistry techniques; and to determine the extent of water-rock interaction so that geochemical modeling can be performed to deduce the flow path and to understand the geochemical evolution of unsaturated zone water.

In situ pneumatic monitoring and gaseous-phase chemical sampling were conducted in the Northern Ghost Dance Fault Alcove by temporarily instrumenting borehole NAD-GTB#1A with a 32.8-m, flexible, plastic borehole liner. The borehole liner has open ports attached to access tubing such that when the liner is everted into the borehole and inflated, it presses against the borehole walls, thus sealing the borehole and isolating the access ports. This allows discrete-interval pressure monitoring and gas sampling through the access tubing.

Results of gaseous-phase chemistry sampling indicate that essentially all the drilling air was removed successfully from 7 of the 10 sample intervals, as determined by the final concentrations of the SF-6 tracer gas. The three intervals that were not successfully purged of drilling air were near the far end of the hole where the tracer-gas injection system had malfunctioned.

Carbon dioxide concentrations in borehole NAD-GTB#1A ranged from 660 to 1180 ppm. The lowest concentrations were found in the three intervals closest to the access drift from which the hole was drilled, indicating that the rock gas in these intervals has a larger component of atmospheric air. This could be from better communication through the fault zone, better communication with the atmosphere, or communication with the air in the access and main drifts through the ESF walls. Carbon-13/carbon-12 ratios that ranged from -14.11‰ to -16.18‰ (parts per thousand) indicated a mixture of soil gas (-25‰) and atmosphere (-6‰), that is consistent with samples collected throughout the Yucca Mountain area. Gas samples were collected from borehole NAD-GTB#1A for carbon-14 age estimates, but the laboratory results are not yet available.

In other work, pore water extracted from rock samples collected from various locations in the ESF was analyzed for tritium. Although the presence of tritium in pore water does not allow the quantity of flux through the repository horizon to be determined, tritium is an indicator of the spatial distribution of flux. The presence of tritium on the order of 1 tritium unit (TU) indicates that the sample is partly composed of water that entered the ground after atmospheric testing of nuclear weapons started in 1952. Before 1952, background tritium concentrations in precipitation were about 2 to 4 TU. With a half life of 12.5 years, the remnant tritium activity in those waters would be less than 0.25 TU. Twenty-seven water samples for tritium analysis were distilled from (a) core collected during drilling of boreholes RBT#1 and RBT#4 in the Upper Paintbrush Tuff Contact Alcove in the north ramp, (b) core from borehole NAD-GTB#1A in the access drift of the Northern Ghost Dance Fault Alcove, (c) blast rubble obtained during the excavation of the Thermal Testing Facility, and (d) rock samples collected from "wet zones" in the ESF at Stations 7 + 57 (757 m) and 35 + 00 (3500 m).

At the 95 percent confidence interval (two standard deviations of analytical precision), the data indicate that tritium was present in only two samples, both from borehole RBT#4 in the Upper Paintbrush (Non-Welded) Contact Alcove. The presence of tritium near the Upper Paintbrush (Non-Welded) Contact Alcove is expected and is consistent with the concept that, at many locations, water percolates readily from the land surface to the top of the PTn.

However, given that percolating water would be subject to substantial mixing, particularly as it might move laterally within the PTn, any young water percolating downward from the PTn could be expected to have mixed with older water. The mixing would substantially reduce the tritium level in the mixture to an extremely small value. Therefore, consideration of a lower confidence interval of the data might be appropriate to interpret these very low values of tritium. At the 67.5 percent confidence interval, the data indicate that young water might have percolated below the PTn into the Topopah Spring Tuff middle nonlithophysal zone (repository horizon) at three additional locations in the ESF: (1) the Thermal Testing Facility, (2) the wet zone at Station 35 + 00 (3500 m), and (3) two intervals in borehole NAD-GTB#1A in the access drift of the Northern Ghost Dance Fault Alcove. Although at this level of confidence the presence of tritium from weapons testing in percolating water at these depths is somewhat uncertain, the tritium data do not preclude the possibility.

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 in a scientific shaft is no longer planned.

This activity was deleted from the study plan in Revision 10 of the Site Characterization Program Baseline (see Appendix H).

Activity 8.3.1.2.2.4.10 - Hydrologic properties of major faults encountered in the 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 ramps and drifts of the ESF.

Project hydrologists completed and submitted a technical report to YMSCO that documents pneumatic monitoring, hydrochemistry sampling, and air-injection and gaseous tracer testing conducted in the north ramp of the ESF between November 1994 and July 1996 (LeCain et al., in prep.). These studies were conducted in the Upper Tiva Canyon Alcove and the Bow Ridge Fault Alcove. Pneumatic monitoring in the Bow Ridge Fault Alcove indicated that the Tiva Canyon Tuff, Bow Ridge fault breccia, and pre-Rainier Mesa Tuff bedded tuff have high permeability. This conclusion is supported by gaseous-phase carbon-13 and carbon-14 isotopic data. Tritium values of matrix water indicate that within the last 50 years (since atmospheric testing of nuclear weapons), water has moved downward from the land surface along the Bow Ridge fault and mixed with older water resident in the pores of the rock matrix. Data from geothermal logging, however, did not indicate flow in the fault zone. Matrix-properties testing of cores from boreholes in the Bow Ridge Fault Alcove indicated that the porosity of the Tiva Canyon Tuff middle nonlithophysal zone is about 0.1, which is slightly higher than that of the

Tiva Canyon lower lithophysal zone. The matrix porosity of the Bow Ridge fault breccia ranges from 0.08 to 0.24, and the porosity of the pre-Rainier Mesa Tuff bedded tuff averages about 0.5.

Air-injection testing in the Bow Ridge Fault Alcove indicates mean bulk permeability values (arithmetic and geometric) of the Tiva Canyon Tuff middle nonlithophysal zone are 13.9 and 12.2×10^{-12} m^2, respectively, and for the Tiva Canyon Tuff lower lithophysal zone are 1.3 and 1.2×10^{-12} m^2. The three permeability values of the Bow Ridge fault breccia range from 8.0×10^{-12} m^2 to 15.8×10^{-12} m^2. The two permeability values of the pre-Rainier Mesa Tuff bedded tuff are 41.3×10^{-12} m^2 and 22.0×10^{-12} m^2. Cross-hole air-injection test results agree with the single-hole results and indicate that scale differences did not affect the test results. The pneumatic porosity estimate for cross-hole testing for the Bow Ridge fault breccia is 0.13; for the pre-Rainier Mesa Tuff bedded tuff, the estimates are 0.20 and 0.27. Comparison of the Tiva Canyon Tuff middle nonlithophysal permeability values in the ESF with values from surface-based tests indicates that the Tiva Canyon Tuff middle nonlithophysal zone is isotropic. However, comparison of the Tiva Canyon Tuff lower lithophysal permeability values in the ESF with the values from surface-based test indicates that the Tiva Canyon Tuff lower lithophysal zone is anisotropic and has a horizontal-to-vertical permeability ratio of approximately 10:1. Because water redistribution occurred during both the single-hole and cross-hole air injection tests, the capillary pressure of water held in fractures must be less than one atmosphere. Cross-hole gaseous tracer tests indicated effective porosities of 0.22 to 0.52 in the Bow Ridge fault breccia and 0.04 and 0.12 in the Tiva Canyon middle nonlithophysal and lower lithophysal zones, respectively. The tracer tests also indicated adsorption of the tracer in the fault breccia and tortuosity in the Tiva Canyon Tuff.

Borehole NAD-GTB#1A was drilled horizontally from the access drift of the Northern Ghost Dance Fault Alcove to a depth of 60 m to provide testing access to the fault before excavating the access drift through the fault. The entire borehole is located within the Topopah Spring Tuff middle nonlithophysal zone (repository horizon), but the character of the tuff in the 12-m wide fault zone has been altered. At this location, the fault zone includes four fault splays and is composed of a series of intervening clast-supported breccias and matrix supported, fine-grained breccias surrounded by relatively less fractured, welded tuff. Geothermal logging, conducted on November 7, 1996, identified a temperature drop across the fault zone. Following the geothermal logging, the alcove was excavated an additional 30 m reducing the length of NAD-GTB#1A to 30 m. Additional geothermal logging of the 30-m borehole on December 3, 1996 did not show the previously measured temperature drop across the fault zone but did indicate a small temperature increase at the main fault trace. Therefore, the temperature drop measured in November probably was the result of drilling-induced evaporative cooling that dissipated with time. The cause of the small temperature increase at the main trace measured in December is being investigated.

In situ pneumatic monitoring and gaseous-phase chemical sampling in borehole NAD-GTB#1A were accomplished as described in Activity 8.3.1.2.2.4.8. Pneumatic monitoring data indicated that different intervals within the 12-m fault zone have different pneumatic characteristics. All intervals showed attenuation and time lag of the barometric-pressure signal, although differences in lag time were almost imperceptible. Five of the seven monitored intervals in the fault zone, however, seem to have higher permeability values because their

amplitudes are less attenuated. This conclusion is consistent with results of the air-injection permeability testing discussed in the following paragraph. Although the exact pathway of the barometric signal cannot be determined, possible pathways include (a) from land surface down the fault, (b) along the fault zone from the south where the main drift of the ESF intersects the fault, or (c) through the walls of the main drift along intersecting fractures. However, because the attenuation of the barometric-pressure signal is not sequential from the interval nearest to the main drift to the interval farthest from the main drift, the pathway for the barometric signal probably is not from the main drift. Rather, the varying response of the intervals to the barometric signal probably indicates different pathways within the fault zone.

Air-injection testing in borehole NAD-GTB#1A indicated that the permeability of the fault zone is more than an order of magnitude larger than the surrounding tuff. Air-injection testing was conducted on seven 1-m test intervals in the fault zone and five 1-m intervals outside the fault zone. Permeability values of the fault zone range from 1.3 to 11.1×10^{-12} m^2. Permeability values of the surrounding Topopah Spring Tuff middle nonlithophysal zone (repository level) range from 0.06 to 0.63×10^{-12} m^2. The average permeability value of the seven 1-m intervals tested in the fault zone is 5.5×10^{-12} m^2. Air-injection testing of a 12-m test interval that straddled the entire fault zone indicated a fault zone permeability value of 5.7×10^{-12} m^2. The average permeability value of the five 1-m test intervals outside the fault zone is 0.31×10^{-12} m^2. Water redistribution was identified in all five of the test intervals located outside the fault zone and in five of the seven test intervals located in the fault zone. The water redistribution pressures indicate that, although the capillary pressures are less than one atmosphere, they are highest near the main trace of the fault, indicating some drying near the main trace. The dryer zone may be the cause of the small temperature increase identified at the main trace of the Ghost Dance fault during the December 1996 geothermal logging.

Forecast: Collection of air temperature, relative humidity and wind speed data will continue in fixed locations in the ESF and on the tunnel boring machine. Analysis of ESF dryout will be enhanced by the reduction in water use that will occur when excavation of the south ramp is completed and the tunnel boring machine exits the south portal. Additional fixed-location temperature, relative-humidity, and wind-speed sensors will be installed in the south ramp as the tunnel boring machine progresses. The rock-wall instrumentation (heat dissipation probes, tensiometers, and two-domain reflectometry) will be incorporated into the PTn Lateral Diversion Study and the South Ramp Hydrology Study, although these instruments will continue to provide data for the dryout study. Several additional plans have been formulated to study the percolation processes along the main drift. Flow and evaporation testing and monitoring will be executed in short 5-m alcoves (niches) in a controlled environment. Longer borehole arrays (100 m) are planned to form an areal grid for the determination of percolation flux. Following completion of the ESF loop, combinations of monitoring tests in short and long boreholes and drifts will be used to better quantify the moisture balance in the ESF and to improve the assessment of hydrologic and pneumatic perturbations to the surrounding rock.

No work is planned for the second half of FY 1997 under the radial-boreholes testing activity.

The ESF hydrochemistry testing for the second half of FY 1997 will include distilling pore water for carbon-14 age estimates and tritium values from the Lower Paintbrush Tuff Contact Alcove and borehole NAD-GTB#1A in the Northern Ghost Dance Fault Alcove access drift. In situ pneumatic-pressure monitoring and gaseous-phase chemistry sampling will be conducted in the geothermal borehole to be drilled from the Southern Ghost Dance Fault Alcove access drift and in borehole RBT#1 in the Lower Paintbrush Contact Alcove.

Excavation of the Northern Ghost Dance Fault Alcove through the Ghost Dance fault and construction of a cross-hole testing facility will be completed. Testing of the Ghost Dance fault then will proceed with a sequence of geophysical and geothermal logging, pneumatic monitoring, gas sampling, and cross-hole air-injection and tracer testing. The testing will provide values of bulk permeability, pneumatic and effective porosity, and tracer travel times to support a three-dimensional, numerical model of the fault.

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 (TSw) unit at the main test level of the ESF. A diffusion test is also proposed in the Calico Hills nonwelded (CHn) unit.

No progress was made during the reporting period; this was an unfunded study. Work on this study has been suspended.

Forecast: No work is planned for this study during FY 1997.

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 (a) describe the pre-waste-emplacement, gas-flow field in the presence of open boreholes and the ESF excavations; (b) develop an understanding of the factors that produce and affect this flow field, including topographic, stratigraphic, and structural controls; (c) determine transmissive and storative properties for gaseous flow; (d) 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; (e) determine fractured, 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; (f) 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 (g) to develop a preliminary model of the transport of individual gaseous species.

Activity 8.3.1.2.2.6.1 - Gaseous-phase circulation study. The objectives of this activity focus on the collection and interpretation of several types of data, including composite borehole shut-in pressures, downhole gas-flow velocity surveys, gas-column temperature surveys, packed-

off zone shut-in pressures, results from multiple borehole tracer tests, and gas chemistry and isotope chemistry from selected open boreholes and packed-off zones within boreholes. These data will be collected from a number of boreholes on an "as available" basis in order to collect as much data as possible in the boreholes most likely to be affected by ESF construction.

No progress was made during the reporting period. The work scope of this activity has been transferred to Activity 8.3.1.2.2.3.2 (see Section 3.1.7 of this progress report).

Activity 8.3.1.2.2.6.2 - Measurement of near-surface gas flow fields. The objective of this activity 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.

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

Forecast: No work is planned for this study during FY 1997.

3.1.11 Study 8.3.1.2.2.7 - Hydrochemical Characterization of the Unsaturated Zone

The objectives of this study are to (a) characterize the hydrochemistry of the unsaturated zone by determining the transport mechanisms, flow directions, residence times, and travel times for gas and water; (b) determine the extent of water/rock interactions in the unsaturated zone; and (c) develop conceptual hydrologic and geochemical models.

Locations of most of the boreholes identified in the activities included in this study are shown in Figure 3-2.

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.

Gaseous-phase carbon-isotopic data collected in May and July of 1996 from 15 stations ranging in depth from 24.7 to 435.9 m in instrumented borehole USW SD-12 were interpreted. The data generally show decreasing carbon-14 activities (increasing ages) with depth from 91.0 percent modern carbon (pmc) near the land surface to 24.4 pmc near the bottom of the borehole. These pmc values indicate apparent ages of about 800 years and 12,000 years respectively. As discussed in Yang et al. (in prep), these results for borehole USW SD-12 are very similar to those obtained in borehole USW UZ-1 for which it was concluded that the primary gas transport mechanism is downward diffusion of atmospheric gas. Two anomalously high carbon-14 activities of 88.7 pmc and 84.5 pmc at depths of 385.6 m and 435.9 m have been

attributed to a leak in an instrument-station access tube and to contamination of rock gas by atmospheric air during drilling of the borehole. These conclusions were reached through detailed analysis of the time-series pneumatic-pressure data for the two stations (see Section 3.1.7, Activity 8.3.1.2.2.3.2 of this progress report).

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 residence times in the unsaturated zone at Yucca Mountain; to evaluate the extent of water-rock chemical interactions; and to model the geochemical evolution of water in the unsaturated zone.

Recently collected tritium data are discussed in Section 3.1.8 of this progress report under Activity 8.3.1.2.2.4.8.

A report (Yang et al., in prep.) presenting a synthesis of new hydrochemical data obtained during FY 1996, as well as previously unreported data and the results of geochemical modeling was completed and submitted to the YMSCO. Unsaturated zone pore water in the PTn has significantly larger concentrations of major ions and dissolved solids than does perched water or saturated zone water. Recharge of perched or saturated zone waters, therefore, requires rapid flow through fractures or permeable regions in this unit to avoid mixing with the chemically concentrated water contained within the PTn. This conceptual model is consistent with observations of tritium and chlorine-36 in the deep unsaturated zone at Yucca Mountain. Further, occurrence of post-weapons-testing tritium in matrix water away from fracture zones indicates that some of the rapidly infiltrating water has spread laterally and down into nonwelded units.

Since delta deuterium (δD) values are larger than $-99.8‰$, most samples of unsaturated zone water and perched water are isotopically heavier than water from the last ice age, which has δD values of -101 to $-103‰$ and uncorrected carbon-14 ages between 12,000 and 18,000 years. If the matrix water in the Topopah Spring Tuff contained a significant amount of water from the last ice age, the δD values would be more negative. Therefore, pore water of the Topopah Spring Tuff has been interpreted to be of post-glacial origin (2,000 to 10,000 years old). In addition, gaseous-phase carbon-14 data from the Topopah Spring Tuff in borehole USW UZ-1 indicates ages between 2,000 and 10,000 years, which would be expected, assuming that the matrix water and the gaseous phase are in equilibrium.

Geochemical evolution of perched water, as calculated using the mass-balance model NETPATH, indicates the dissolution of volcanic glass in the tuffs at Yucca Mountain and growth of secondary minerals, such as clay (smectite) and zeolite (clinoptilolite) (Yang et al., in prep.). Modeling of the perched water in borehole USW UZ-1 indicates that the majority of dissolved sodium can be derived from two sources: (1) calcium-sodium and/or magnesium-sodium exchange, in which the amount of glass dissolution would be small, and (2) glass dissolution, in which sodium exchange would be small. More mineralogical information is needed from the unsaturated zone to determine which source is dominant. The composition of the perched water in borehole USW SD-9 indicates that significant quantities of glass dissolution and attendant precipitation of silica are required. For the perched water in borehole USW NRG-7a, dissolved

sodium is derived principally from glass dissolution. NETPATH modeling was also used to convert carbon-14 ages for perched water based on the available carbon-13 and carbon-14 data for the mineral-phase carbon dioxide and calcite. The corrected carbon-14 residence times for the perched waters are 2150 to 2650 years for borehole USW NRG-7a; 5260 to 6260 years for borehole USW UZ-14; and 4040 to 5370 years for borehole USW SD-9.

Forecast: Gas samples for carbon dioxide concentrations and delta carbon-13 and carbon-14 analyses will be collected from the Calico Hills Formation in boreholes USW UZ-14 and USW SD-7 using a flexible borehole-liner system. The purpose of these studies is to determine whether or not the gaseous and aqueous phases are in hydrochemical equilibrium at this depth. Additional gas samples also will be collected from instrumented borehole USW SD-12 from those stations for which anomalous carbon-14 results were obtained during FY 1996 (see Activity 8.3.1.2.2.7.1).

The presence of tritium in the unsaturated zone will continue to be investigated by analyzing pore water extracted from rock cores. Cores will be collected from boreholes drilled in the Bow Ridge Fault Alcove, Lower Paintbrush Tuff Contact Alcove, and the Thermal Testing Facility in the ESF, and from boreholes drilled in both the Northern and Southern Ghost Dance Fault alcoves. Some additional tritium analysis will be conducted on pore water from cores of existing surfaced-based boreholes, including USW SD-7, USW SD-9, USW SD-12, and USW NRG-7a.

Carbon-14 residence times of pore water in the very-low-water-content, densely welded intervals of the Topopah Spring Tuff will be investigated by extracting carbon dioxide gas from the pore water using vacuum distillation. The carbon-14 activities of the pore water in the rock matrix will be compared with carbon-14 activities in fracture-derived perched water and fracture mineral coatings in the ESF. These data will be used to determine (a) the partitioning of unsaturated zone flow between the matrix and the fracture network and (b) the water flux through the matrix.

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 memorandum report documenting a three-dimensional, fracture-network, flow model of the Topopah Spring Tuff using data obtained from the ESF was completed and submitted to the YMSCO (USGS, 1997a). The simulated network was calibrated by comparing simulated and mapped fracture intensities. Results showed that all mapped intensities fall within one standard

deviation of the simulated intensities. Also, a visual comparison between simulated and mapped fractures showed that the simulated (representing only one realization) matches well with the mapped.

Preliminary modeling showed that there are three possible fracture sets: (1) striking N 65° W and dipping 85° SW, (2) striking N 3° W and dipping 85° W, and (3) striking N 33° E and dipping 85° NW. Fractures in set 1 are most abundant and fractures in set 3 are least abundant. The number of fracture connections between any two traceplanes in the simulation region, given that there is a connection, was sparse. The mean number of connections ranged from 1 for all scales to 5.7 for the 200-m scale. However, 80 percent of the realizations for the 200-m scale showed no connection from the south face to the north face of the box-shaped model domain. The number and pattern of connections showed little appreciable change with scale. The analysis calculated the number of fracture networks that connect a pathway to each of several traceplanes and the probability of connection.

Rock block analysis was used to help calculate an average rock block size used in dual-porosity simulations using the site-scale unsaturated zone flow model (see Section 3.1.13 of this progress report) to help evaluate potential imbibition surface area for small-scale problems and models.

Net directional permeability was calculated in the direction of gradient using Darcy's law, where the flux calculated from the finite-element analysis was based on assigned fracture-permeability distributions. Values ranged from 4.6×10^{-16} m^2 to 2.7×10^{-14} m^2.

Results of two-phase flow simulations showed that for different saturations, under a unit gradient, flux values ranged from 0.11 mm/yr out the bottom of the flow volume for no-flow boundaries on the edge faces, to 0.006 mm/yr out the bottom for variable-head boundary conditions. Given the in situ water-potential data collected in instrumented, surface-based boreholes (Rousseau et al., in prep.[b]), the flow simulation with no-flow boundaries on the edge faces seems to represent conditions in the Topopah Spring Tuff. For different saturations with no-flow boundaries on the sides, flux values varied by 2 orders of magnitude when comparing transmissivities calculated from low saturations to transmissivities calculated from high saturations. Therefore, the total flux leaving the block was about equally divided between the sides and the bottom when varying head conditions were used at the side boundaries.

Continuum properties of the discrete-fracture flow simulation were evaluated to determine whether the network approached an equivalent continuum with respect to permeability. None of the scales tested (50-m, 100-m, 150-m, and 200-m) approached continuum properties, and only in a few instances did the flux values from opposite directions vary by less than a factor of two. From these results, it is doubtful that the fracture network in the tuffs, as analyzed, would ever approach continuum properties, because of the high degree of heterogeneity of the fracture system.

Activity 8.3.1.2.2.8.2 - Validation of conceptual and numerical models of fluid flow through unsaturated 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: No additional work is planned or funded.

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. For additional details, refer to the study plan.

Locations of most of the boreholes identified in the activities in this study are shown in Figure 3-2.

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 describes 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 years or longer.

Temperature profiles from the unsaturated zone were used to estimate the magnitude of the percolation flux at various locations at Yucca Mountain. This analysis recognizes that as water moves from cooler, shallower depths to warmer, deeper ones, heat is transferred from rock to the water percolating downward so that the downward moving water maintains thermal equilibrium with the surrounding rock. Therefore, the upward heat flow will decrease with increasing elevation along a borehole in a way that reflects the magnitude of the downward percolation flux. Because the decrease in heat flow depends only on the total mass of water moving through the rock, the percolation-flux estimates should reflect both the matrix and fracture components of the percolation flux, as long as the water and rock remain in thermal equilibrium. The analysis relies on estimates of the conductive heat flow at two elevations in a vertical borehole. The conductive heat flow is the product of the temperature gradient and thermal conductivity of the rock over the depth interval in which the temperature gradient is measured. Thus, percolation flux may be calculated as:

$$q_l = (q_{h1} - q_{h2})/\rho c \Delta T$$

where

q_l is the percolation flux in kg/s,

q_{h1} and q_{h2} are the conductive heat flows in W/m^2 at elevations z_1 and z_2 ($z_1 < z_2$),

ρ is the water density in kg/m^3,

c is the heat capacity of water (4.187×10^3 joules per kilogram per degree C), and

ΔT is the temperature difference between elevations z_1 and z_2, in degrees C.

As a first step, temperature gradients were determined for the Topopah Spring Tuff through least-square linear fit to the temperature data for that unit using data contained in Sass et al. (1988) and more recently collected data from instrumented boreholes (see Section 3.1.7 (Activity 8.3.1.2.2.3.2) of this progress report). Average thermal conductivity for the Topopah Spring Tuff was determined from data in Sass et al. (1988) to be 1.93 W/m/°C with a standard deviation of 0.29 W/m/°C. The heat flow at the lower elevation (q_{h1}) was taken to be either the conductive heat flow estimated for the saturated zone in the borehole, as given in Sass et al. (1988, Figure 17a), or the conductive heat flow determined for the Calico Hills Formation. The temperature difference was estimated using the temperatures in the middle of the Topopah Spring Tuff and either the water-table temperature or the temperature in the middle of the Calico Hills Formation, depending on where the heat flow at the lower elevation (z_1) was determined. Only a small subset of boreholes for which temperature data were given in Sass et al. (1988) had both unsaturated zone and saturated zone temperature data. Of these boreholes, only the temperature data from USW H-3, USW G-1, and USW G-3 lacked obvious evidence for the movement of heat through nonconductive processes, such as water movement within or along the borehole, or lateral water movement within the upper part of the saturated zone. Estimates of unsaturated zone percolation flux in these boreholes were 9.1 mm/yr in USW H-3, 23.5 mm/yr in USW G-1, and 4.9 mm/yr in USW G-3. Using temperature data from the Topopah Spring Tuff and Calico Hills Formation, estimates of percolation flux were 1.8 mm/yr in USW G-1 and 4.6 mm/yr in USW G-4. The difference in the two percolation flux estimates in USW G-1 (a) might be reflecting nonvertical flow in the lower part of the unsaturated zone, or (b) might be indicating that, even in the absence of obvious evidence in the temperature profile, nonconductive transport of heat in the saturated zone is introducing bias into estimates of the unsaturated zone percolation flux. If the latter is true, more reliable estimates of the percolation flux might be obtained if heat flows are determined using only data from the unsaturated zone.

A Project initiative titled "Unsaturated-Zone Model Expert Elicitation" began during the reporting period. The purpose of the initiative is to assess quantitatively the uncertainties associated with predictions of the spatial and temporal distribution of percolation flux by the site-scale, three-dimensional, unsaturated zone flow model. A series of three workshops to evaluate unsaturated zone flow characterization and modeling was conducted between November 1996 and January 1997. These workshops culminated in February 1997 in a series of interviews in which each expert estimated a probability distribution for percolation flux using data and interpretations presented in the workshops as well as additional analyses completed by each

expert. The probability distributions were restricted to consideration of the spatially and temporally averaged percolation flux over the potential repository area. At each interview, individual experts also evaluated the reliability of different methods for estimating percolation flux from the reliability and availability of the necessary data, its sensitivity to percolation flux, and its treatment by various conceptual or numerical models.

Experts expressed variable amounts of confidence in any individual method for estimating percolation flux. In general, however, they endorsed the concept that the average percolation flux within the potential repository area could well be within the 5 to 10 mm/yr range and possibly higher. Their conclusions were based on the collective results from infiltration studies, analysis of temperature data, chloride mass-balance studies, percolation fluxes estimated during model calibration to saturation/water potential or isotope data (including carbon-14 and chlorine-36 data), and fracture-coating studies. Many of the experts felt that percolation rates beneath washes are larger than those presently depicted in infiltration maps, both because of surface runoff and as a result of shallow subsurface flow along the alluvium-bedrock contact. The experts felt that neither process was being captured adequately with the one-dimensional model used in the surface water-balance modeling. However, most agreed that significant net infiltration probably occurred only during years of above-average precipitation. They also generally believed that net infiltration probably was relatively low where alluvial cover was thick and vegetation had a greater opportunity to transpire infiltrated water, except where local conditions created focusing of runoff or subsurface flow.

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.

A new scheme for evaluating fracture-matrix interface areas in dual-permeability simulations was proposed and tested using the parameters in the unsaturated zone flow model and the TOUGH2 code. The new scheme correlates effective fracture-matrix interface areas with upstream phase saturation between fracture and matrix systems. The new treatment of the fracture-matrix interface will give physically reasonable approximations to flux calculations for dual-permeability simulations.

A modified form of the van Genuchten equation (van Genuchten, 1980) for capillary pressure has been added as an option in the TOUGH2 code. Linear extrapolation of the dry portion of the function gives greater (less negative) capillary pressures at low liquid saturations.

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 state of the system, and to predict the probable future and past states of the system with regard to changes in environmental conditions.

A comprehensive comparison study investigated the differences in simulated mass fluxes using the equivalent continuum and dual-permeability approaches with one-dimensional and

three-dimensional models. The study results indicated that as long as the local equilibrium condition was reasonably satisfied the equivalent continuum model gave reasonable estimates of mass fluxes.

Spatially varying parameter distributions for porosity, thermal conductivity, rock grain density, and van Genuchten model (van Genuchten, 1980) fitting coefficients were incorporated into the unsaturated zone model (Banduragga et al., 1996). Matrix and fracture permeability and van Genuchten model-fitting coefficient distributions were developed using refined one-dimensional columns from the unsaturated zone model and by performing model inversions against available water potential and saturation data. The boreholes with core sample data included were USW UZ-14, UE-25 UZ#16, USW SD-7, USW SD-9, and USW SD-12. Other boreholes with borehole geophysical saturation data used in the inversions were UE-25 WT#12, UE-25 NRG#4, and UE-25 ONC#1. To provide matrix saturation estimates, the geophysical saturation estimates were corrected for the presence of lithophysal cavities in the Topopah Spring welded (TSw) hydrogeologic unit. The results of the inversions were interpolated to the three-dimensional model grid using geostatistical kriging techniques. Comparisons of modeling results using spatially varying parameters and parameters averaged over the layer were conducted using a two-dimensional vertical, south-north cross-section over the three-dimensional site-scale model domain. The surface boundary was subject to spatially varying infiltration using a mean of 4.9 mm/yr with a range of 0 to approximately 10 mm/yr, based on the infiltration data of Flint et al., in press. The value used for the repository block was 6.9 mm/yr. The simulated matrix liquid saturations from both models were compared with the observation data, which indicated that both models gave reasonable results.

A systematic study was performed to collect and analyze all the available fracture data from the ESF and boreholes. The purposes of this study were to determine fracture properties and their distribution in all the vertical formation layers and to provide fracture data input for the ITOUGH2 inverse modeling estimation of the hydrogeologic properties. An improved set of fracture parameters was developed for use in the unsaturated zone model using the recently available data on fracture geometries and spatial distributions from the ESF (D. L. Barr et al., 1996), borehole fracture frequencies and orientations ("Q"), and permeabilities from air-injection testing in boreholes (LeCain et al., in prep.) A computer code was developed to easily extract fracture statistics from the collected data on the basis of fracture size, orientation, and position in the ESF. The developed "Q" fracture property set based on ESF and borehole data and using air permeability (air-k) test results was incorporated into the unsaturated zone model. The set was used to rerun the combined column inversion (Bodvarrson and Banduragga, 1996) using the spatially varying infiltration map developed by the USGS (Flint et al., in prep.). The available pneumatic data were then used to constrain permeabilities in the PTn and TSw during the model inversions. This work was performed as part of the calibration of the gas model portion of the unsaturated zone model (Ahlers and Wu, 1997).

The development of a fracture property set for the unsaturated zone model continued, focusing on the calculation of van Genuchten parameters (van Genuchten, 1980) for fractures. The fracture hydrologic properties developed for the unsaturated zone model used air-injection permeability measurements performed at a range of spatial scales from surface borehole measurements (LeCain, 1997) as well as measurements obtained in the drift scale test area.

Calculations were performed using the permeability anisotropy and fracture frequencies in the Topopah Spring Tuff from the detailed ESF line survey data. Results were used to evaluate the ESF drift-scale tests. The most recent "Q" data from the ESF for fracture geometries were also incorporated (Wu et al., 1997b).

The three-dimensional site-scale model grid was modified to extend further to the north, 1 km beyond USW G-2, to include the possible higher water gradient effects. The grid was tested using two sets of parameters being developed. The steady-state simulations were performed using both the equivalent continuum model and the dual-permeability formulations, incorporating data from the latest infiltration map (Flint et al., in prep.).

Passive subsurface pneumatic pressure monitoring data were incorporated into calibration of the unsaturated zone model (Ahlers and Wu, 1997). Before this effort, calibrations of the unsaturated zone model had used either saturation plus water potential data or gas pressure data. By combining all three types of data into one calibration, better constraint of the model parameter set was achieved. The ITOUGH2 code was used to perform the inverse calibration. The inverse problem was very sensitive to the initial guess of the model parameter set. In particular, because of the initial guess, fracture parameters were not varied by ITOUGH2. The fracture parameters were restricted from field data, and the new parameters will be used as initial guesses in future calibrations.

A conceptual model for the perched water at Yucca Mountain was developed. This work is considering current isotopic data of waters (strontium-87/86, tritium, chlorine-36, and carbon-14 ages) and water chemistry (chloride) in light of the recent fracture geometry data from the ESF, distributions of infiltration, and relation to faults. Preliminary work was begun on submodels of the site-scale model to test various conceptual models in areas where chemical data from boreholes were obtained.

Development was completed of a near-surface source model for chloride for incorporation into the unsaturated zone site-scale model. This work, along with interpretations of chloride and other geochemical data, is described in Wu et al. (1997a). The geochemical and isotopic data from porewater and perched water are being used in the calibration of the unsaturated zone model. Two-dimensional dual permeability and three-dimensional equivalent continuum submodels were generated to model the chloride chemistry of Yucca Mountain, as well as to model environmental isotopes (chlorine-36) and radiogenic isotopes, such as strontium-87/86, that reflect water-rock interaction. Steady-state equivalent continuum model flow simulations were performed for the initial conditions for later transport simulations (Wu et al., 1997a).

The work performed on perched water can be summarized as follows:

1. The observed perched-water data from six boreholes were incorporated into a three-dimensional perched-water, unsaturated zone flow model. The model used a mean infiltration rate of 4.9 mm/yr, and an infiltration rate range of 0 to approximately 10 mm/yr. The infiltration rate value used for the repository block was 6.9 mm/yr. The vertical percolation flux rate calculated by this simulation was 4.9 mm/yr. The model simulated a stratigraphic diversion for ground water at the zeolitic layer below

the repository horizon. A slight diversion was also simulated at the PTn layer above the repository horizon.

2. The three-dimensional perched-water model was calibrated using observed perched water locations and moisture data from perched-water boreholes. Observed data were compared with the predicted perched-water locations, liquid saturation, and water potential data, and reasonable agreement was obtained. The spatial distributions of perched-water bodies at Yucca Mountain were modeled.

3. Three simulated pumping tests were conducted in boreholes USW UZ-14 and USW G-2, and the simulated water levels of pumping and recovery periods were in good agreement with actual pumping data. From the pumping test analysis, the volumes of the perched-water bodies in USW UZ-14 and USW G-2 were estimated.

4. Perched-water ages were estimated using ground-water travel times through the fracture-matrix system, and the results are in reasonable agreement with residence ages determined from isotopic studies.

5. Historic high infiltration rates were simulated, and the impacts on perched-water level changes were predicted.

6. The mean infiltration rate (4.9 mm/yr) used in the current three-dimensional site-scale model for simulating perched water is generally supported by analyses of average chloride content in the PTn. A model is being developed to simply incorporate chlorides into the unsaturated zone model; this model considers other geochemical data and isotopes.

The calibration efforts using the unsaturated zone model were completed (Wu et al., 1997b). The calibrations used all available data and inverse modeling techniques. The results of initial calibrations with one-dimensional models were put into the full three-dimensional unsaturated zone model for final calibration. Borehole temperature records were matched, resulting in best-estimate parameter sets for thermal conductivity. Best-estimate permeability and van Genuchten parameters (van Genuchten, 1980) for both fractures and matrix were obtained by simultaneously matching saturation and water potential data from core samples and geophysical logging.

Forecast: In the conceptual modeling activity, the temperature data will continue to be analyzed for the purpose of estimating percolation flux. Identifying suitable depth intervals in individual boreholes on which to base percolation-flux estimates will be emphasized. Also, an attempt will be made to determine the probability-density function of percolation flux in a borehole, given the uncertainty in temperature gradients, in thermal-conductivity data, and in temperature differences that form the basis for the estimate.

During the next reporting period, the unsaturated zone flow modeling efforts will work on the three-dimensional permeability field conditioned to field data and information, calculation of infiltration at the drift scale resulting from episodic pulse infiltration, and modeling of future

climate scenarios using the three-dimensional site-scale unsaturated zone flow model. Enhancement of the thermohydrologic modeling capabilities of the unsaturated zone will continue, as will ongoing support to the unsaturated zone flow model abstraction/sensitivity analysis process to the performance assessment activities supporting the viability assessment and License Application. A draft unsaturated zone flow model and a full report will be delivered as a Level 3 milestone summarizing unsaturated zone flow model development and simulations completed from September 1996 through May 1997.

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

The objectives of this study are to determine the internal and external boundary conditions and parameters that can be applied to the site saturated zone flow and transport models, and determine the rates and directions of ground-water flow.

Locations of most of the boreholes identified in the activities included in this study are shown in Figure 3-2.

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 determine hydraulic gradient, to define altitude distribution of uppermost potentiometric surface, to determine long-term water-level trends, and to determine the water-level response to nearby pumping.

Monitoring continued of water levels in the saturated zone at Yucca Mountain. Quarterly or more frequent manual water-level measurements were made in 24 wells that monitored 31 depth intervals. Hourly water-level data are no longer collected as part of the ground-water monitoring network. However, hydraulic and tracer testing at the C-hole complex was supported by recording hourly water levels in wells UE-25 WT#3, UE-25 WT#14, and UE-25 p#1, and in the upper and lower intervals of USW H-4. Continuous pumping of well UE-25 c#3 at approximately 150 gallons (568 L) per minute began on May 8, 1996, and continued through the end of this reporting period.

Manual water-level measurements for 1996 were reviewed and submitted to the Records Processing Center. Water levels in the Yucca Mountain site area remained stable during 1996.

A data report documenting ground-water levels at Yucca Mountain during 1994 (Graves et al., 1996) was published. A similar report on water levels during 1995 (Graves and Goemaat, in press) was prepared.

A report (Graves et al., in press) describing water-level trends at Yucca Mountain in the network of 28 wells and 36 depth intervals from 1985 through 1995 was approved for publication. The report indicates that mean annual water-level altitudes for all wells for 1985-1995 ranged from 727.93 to 1,034.60 m above sea level. The maximum change in water level over the 11-year period was 12.22 m in the lower interval of well USW H-3, and the minimum change was 0.31 m in the upper interval of well UE-25 b#1. In 31 of the 36 depth intervals monitored, the change in water-level was less than 1 m. No seasonal water-level trends were detected in any of the depth intervals monitored, and regional ground-water withdrawals did not appear to cause water-level changes. Most annual water-level fluctuations were attributed to responses to barometric-pressure changes and earth tides. Regional earthquakes, which occurred June 28-29, 1992, appear to have simultaneously affected the water levels in 7 of the depth intervals monitored. The maximum water-level change from the earthquake activity was in well UE-25 WT#6 where a rise in water level of 1.07 m was followed by a drop of 2.66 m. Well hydrographs over the 11 years of record where compared to determine if trends in water-level change could be related to wells completed in the same general area or with the same general water-table altitude. With the exception of wells USW WT-7 and USW WT-10, and to a lesser extent well USW VH-1, all of which are located in Crater Flat, no consistent, correlatable water-level changes are apparent in any two wells.

Continuous monitoring of the recovery data of the single-well aquifer test conducted April 8-25, 1996, in well USW G-2 ended on December 17, 1996. After 236 days of recovery, residual drawdown was 0.5 m. Analysis of drawdown and recovery data for the test indicate that fracture flow, dual-porosity flow, and boundary-effected flow occurred during the test. The Calico Hills Formation was the primary formation tested. Aquifer transmissivity was estimated to be 9 m^2 per day. The residual drawdown indicates that a perched-water body may have been permanently dewatered as a result of pumping. However, the impact of the potential perched water on the observed water level in well USW G-2 could not be determined with the data available from the test.

A report (O'Brien, in press) on the analysis of aquifer tests conducted in boreholes USW WT-10, UE-25 WT#12, and USW SD-7 was approved for publication. The single-well aquifer tests were conducted at the three boreholes between March 1995 and January 1996. The test in borehole USW WT-10, which was completed in the Topopah Spring Tuff, indicated a relatively high transmissivity of 1600 m^2 per day. Borehole UE-25 WT#12 was completed in the Topopah Spring Tuff and Calico Hills Formation and test results indicated a transmissivity of only 7 m^2 per day. The test conducted in borehole UE-25 WT#12 appears to have been significantly affected by well losses and apparently drew water from secondary fractures. Borehole USW SD-7, when tested, had been drilled into the base of the Calico Hills Formation about 4.5 m above the contact of the Prow Pass Tuff. The aquifer test conducted in borehole USW SD-7 was of a perched-water reservoir and test results indicated a transmissivity of 6 m^2 per day. The perched-water reservoir is approximately 150 m above the regional water table and had an estimated reservoir volume of 96,000 L at the time of the test.

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 well at the UE-25c (C-hole) well complex 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 and storage coefficient).

This activity was completed. Results were reported in Geldon (1993), Geldon (1996), Geldon (1997) and Geldon et al. (in prep.).

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 and storage coefficient), and to evaluate the three-dimensional nature of the flow field in the test vicinity.

A long-term pumping test has been under way since May 8, 1996, in the Lower Bullfrog geohydrologic unit at the C-hole complex. The pumping well is UE-25 c#3 and the observation wells are UE-25 c#1 and UE-25 c#2 (at the C-hole complex), and UE-25 ONC#1, UE-25 WT#3, UE-25 WT#14, USW H-4, and UE-25 p#1 at locations ranging from 0.63 to 3.52 km from the pumped well. The pumping rate has been relatively constant at an average of 151 gpm (9.5 L/s). Superposed on this long-term hydraulic test are a sequence of shorter duration tracer tests (discussed under Activity 8.3.1.2.3.1.5).

Hydraulic connection between the C-holes and UE-25 ONC#1, which had been established during the May 1995 open-hole pumping test (Geldon et al., in prep.), was confirmed by the present test. Drawdown in UE-25 ONC#1 was detected about 140 minutes after pumping started and had reached about 0.91 feet (0.28 m) 379,000 minutes (37.6 weeks) after pumping started. In addition to a finite drawdown in UE-25 ONC#1, recirculating about 5 gpm (0.32 L/s) into UE-25 c#2 during tracer tests in May and October 1996 caused the water level in UE-25 ONC#1 (2,800 ft (853 m) away) to rise almost at the same time that the recirculation caused the water level to rise in UE-25 c#1 (about 280 ft (85.3 m) away). Furthermore, the cone of depression was elongated along an axis aligned in a west-north-west direction. The depression had been constructed using drawdown data from UE-25 c#1, UE-25 c#2, UE-25 ONC#1, UE-25 WT#14, UE-25 WT#3, and USW H-4 after 14,000 minutes (9.72 days) of pumping UE-25 c#3 during the open-hole pumping test in May 1995. Recent geologic mapping by the USGS (Day et al., in press) indicates possible discontinuous faults with associated fractures along a part of this alignment, which may be the reason for the hydraulic connections between the C-holes and both UE-25 ONC#1 and USW H-4.

When corrected for the effects of atmospheric-pressure changes, temporary pump shutdowns, tracer injection, and recirculation of water during tracer tests, the time-drawdown data from observation wells UE-25 c#1 and UE-25 c#2 up to 158,000 minutes (15.7 weeks) can be analyzed assuming either a single-porosity (confined, homogeneous, isotropic) or dual-porosity (fissure-block) aquifer. The Theis solution (Theis, 1935) for a single-porosity, confined aquifer produces a transmissivity value of 18,000 ft^2/day (1660 m^2/day), a hydraulic conductivity value of 90 ft/day (27 m/day), and a storativity value of 0.0002 for UE-25 c#1. The Theis solution produces a transmissivity value of 17,000 ft^2/day (1,620 m^2/day), a hydraulic

conductivity value of 180 ft/day (54 m/day), and a storativity value of 0.001 for UE-25 c#2. For the same borehole and time period, the fissure-block solution tends to produce a lower value of transmissivity than the Theis solution. For UE-25 c#1, the fissure-block solution indicated a transmissivity of 12,000 ft^2/day (1150 m^2/day). The fissure-block solution separates hydraulic conductivity and storativity into fracture and matrix components. For UE-25 c#1 after 158,000 minutes, the fissure-block solution indicated fracture hydraulic conductivity of 60 ft/day (18 m/day), matrix hydraulic conductivity of 0.001 ft/day (0.0004 m/day), fracture storativity of 0.0003, and matrix storativity of 0.003. Transmissivity and storativity parameters are needed by performance assessment modeling of the saturated zone to quantify the flow field over which transport models are superposed to calculate radionuclide doses to the accessible environment.

After 158,000 minutes, the drawdown in UE-25 c#1, UE-25 c#2, UE-25 c#3, and UE-25 ONC#1 deviates from that predicted by either the single- or dual-porosity models, leading to speculation that either a barrier-boundary or a zone of reduced permeability in the Miocene tuffaceous rocks might have been reached.

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 to analyze tracer tests, and to evaluate spatial correlation and scale-dependency of transport parameters.

Following establishment of a quasi-steady-state flow field by continuous pumping since May 8, 1996 (see Activity 8.3.1.2.3.1.4), a conservative-tracer test with a radially convergent flow field toward the pumped well, UE-25 c#3, was initiated on January 9, 1997. To begin the tracer test, 3.0181 kg of 3-Carbamoyl-2-Pyridone (Pyridone) and 11.35049 kg of 2,6 difluoro-benzoic acid (2,6 DFBA), each dissolved in 210 gal (795 L) of UE-25 c#3 water, were injected into the Lower Bullfrog intervals of UE-25 c#1 and UE-25 c#2, respectively. Breakthrough of the 2,6 DFBA in the pumped well occurred approximately 5.07 days after injection and was measured at 13.6 ppb. The concentration reached a peak of 251 ppb approximately 14 days after injection and then decreased to the present value of 86 ppb approximately 41 days after injection. No breakthrough of Pyridone occurred during the reporting period.

Preliminary interpretation of the 2,6 DFBA test using the Moench (1995) analytic solution to the advection-dispersion equation for radially convergent tracer tests, produces a fracture porosity of 9.6 percent, a matrix porosity of 21 percent, and a longitudinal dispersivity value of 9 ft (2.74 m). The dimensionless Peclet number, which is defined as the ratio of longitudinal dispersivity to the interborehole distance, was 11. This analysis assumes a dual-porosity medium with primary transport of solute through discontinuous fractures connected by segments of matrix (total porosity of 9.6 percent), and a secondary process of matrix diffusion in which some of the tracer is stored in, and then released from, the pores of that part of the matrix not involved in the primary transport mechanism (porosity of 21 percent). Dispersivity and porosity parameters are needed by performance assessment transport modeling in the saturated zone to quantify the concentrations of radionuclides that would occur in the accessible environment as a result of a release from the proposed repository.

Fahy (1997) describes the analysis of a radially convergent conservative-tracer test in which iodide (as sodium iodide) was injected into the combined Lower Bullfrog-Upper Tram hydrogeologic interval in UE-25 c#2 while UE-25 c#3 was being pumped in February 1996. The paper describes results for the iodide test that are similar to those just summarized for the 2,6 DFBA tracer test.

Results similar to those obtained from the February 1996 iodide test and the January 1997 2,6 DFBA test also were obtained by analyzing the breakthrough curve of another tracer test in which pentafluorobenzoic acid was injected into the Lower Bullfrog interval of UE-25 c#2 in a partial-recirculation test in May 1996 (see Activity 8.3.1.2.3.1.7). All three of these tests were conducted using UE-25 c#2 as the injection well and UE-25 c#3 as the pumping well. The tests seem to produce the same transport parameters for the Lower Bullfrog-Upper Tram interval at the scale of the interborehole distance between these two wells, which is 95 ft (29 m).

Analysis of a tracer test in which iodide (as sodium iodide) was injected into the Lower Bullfrog interval of UE-25 c#1 in June 1996 while UE-25 c#3 was being pumped at 150 gpm (9.46 L/s) yielded a Peclet number of 12 (see Activity 8.3.1.2.3.1.7), similar to the value of 11 obtained from analyzing the three tracer tests between UE-25 c#2 and UE-25 c#3 described above. Because of the interborehole distance of 283 ft (86 m), however, this Peclet number represents a longitudinal dispersivity value of 18.33 ft (5.6 m) instead of the value of 9 ft (2.74 m) for an interborehole distance of 95 ft (29 m). The longitudinal dispersivity values of 2.74 and 5.6 m at interborehole scales of 29 and 86 m, respectively, seem to confirm the scale-dependence of this parameter, as postulated by Gelhar et al. (1992) and closely follow the pattern seen at the other field locations described.

A Windows-based personal computer program was developed to implement the Moench (1995) solution used for the analysis of the tracer tests just described (Umari, 1996). The program facilitates rapid experimentation with input parameters when attempting to match the theoretical Moench curves to the breakthrough curves obtained during a tracer test.

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 out-year 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.

Two conservative tracer tests that were initiated during FY 1996 [see Progress Report #15 (DOE, 1997e) for details] were completed. The first test involved injecting approximately 10 kg of pentafluorobenzoic acid into UE-25 c#2 on May 15, 1996, and the second test involved the injection of approximately 15 kg of sodium iodide (with iodide as the conservative tracer) into

UE-25 c#1 on June 18, 1996. In both instances, UE-25 c#3 was the production well. These tests were conducted primarily to determine which well, UE-25 c#1 or UE-25 c#2, was better suited for injecting a reactive tracer and also to estimate of the mass of reactive tracer needed to conduct a successful test. The plan was to inject the reactive tracer, lithium ion, into whichever hole provided the highest peak concentration response of a conservative tracer because lithium recovery was expected to be lower and more delayed than that of a conservative tracer.

On the basis of the results of the two conservative tracer tests, a reactive tracer test was initiated on October 9, 1996. This test involved simultaneously injecting approximately 180 kg of lithium bromide (about 14.5 kg of lithium and 165.5 kg of bromide), 12 kg of pentafluorobenzoic acid, and about 7 g of 0.36 μm diameter polystyrene microspheres (about 3.5×10^{14} microspheres). The microsphere injection was initiated about 4 hours later than the solutes, but was completed at the same time as the solutes (i.e., a shorter injection duration). The bromide and pentafluorobenzoic acid served as conservative tracers with free diffusion coefficients that differed by about a factor of two. A comparison of the responses of these two tracers is expected to allow an estimate of the amount of matrix diffusion occurring in the system. The lithium response would then be compared with the response of the conservative solutes to estimate lithium sorption parameters in the system. The microspheres were intended to provide both an indication of the potential for colloidal contaminant transport in the system and to serve as a tracer that diffuses only very slowly, if at all, into the matrix.

All the tracer tests were conducted in an approximately 300 ft (91 m) packed-off interval in the lower Bullfrog Tuff extending from approximately 2300 to 2600 ft (701 to 792 m) below surface or 1000 to 1300 ft (305 to 396 m) below the water table at the C hole complex. This interval has the largest hydraulic conductivity of any major zone at the C holes. UE-25 c#3 was used as the production well in all the tests, with the production rate remaining nearly constant at ~150 gal (568 L) per minute. The distance between UE-25 c#2 and UE-25 c#3 at depth was approximately 30 m, while the distance between UE-25 c#1 and UE-25 c#3 at depth was about 80 m. All tests were conducted under partial recirculation conditions, with approximately 4 to 5 gpm (15 to 19 L/min) being recirculated from the UE-25 c#3 discharge into either UE-25 c#1 or UE-25 c#2 (about 4 gpm (15 L pmin) into UE-25 c#1 and about 5.3 gpm (20 L/min) into UE-25 c#2). The partial recirculation was established at least a day before the tracers were injected and was maintained in all instances for at least 16 days after injection. For the reactive tracer test initiated in October, recirculation was continued for 40 days.

Other than the different recirculation durations, the only significant difference between the reactive tracer test and the two conservative tracer tests was that a much larger volume of tracer solution was injected in the reactive tracer test (~12,000 L) than in the conservative tests (~1000 L). The larger volume was necessary in the reactive tracer test because it was desired to maintain approximately the same injection solution density in all tests (the conservative tests involved much smaller masses of tracers than the reactive test). A larger volume was also desirable to keep solute concentrations less than 0.2 M to avoid microsphere aggregation. Note that the volume of the packed-off borehole interval into which tracers were injected was about 4000 L in all tests.

The recoveries of each tracer as of January 30 (preliminary data) were ~56 percent for pentafluorobenzoic acid, ~56 percent for bromide, ~23 percent for lithium, and ~11 percent for microspheres. Each tracer breakthrough curve was bimodal (i.e., two peaks), and the tracer data exhibited clear matrix diffusion "signatures" (i.e., the pentafluorobenzoic acid peaks are higher than the bromide peaks because pentafluorobenzoic acid has less tendency to diffuse into the matrix than bromide, and the bromide tail crosses over the pentafluorobenzoic acid tail because of the greater mass of bromide diffusing from the matrix at late times). The lithium breakthrough curve (relative to the conservative tracers) showed clear evidence of diffusion and sorption in the matrix, as well as possible sorption in the flow pathways (assumed to be fractures).

The double-peak response in the reactive tracer test was markedly different than in the pentafluorobenzoic acid test initiated in May 1996. Project scientists attribute the different responses in the two tests to the different volumes of tracer solution injected, because all other variables were essentially the same in the two tests. Specifically, the injection of approximately three packed-off interval volumes of tracer solution is believed to have resulted in tracers being forced into pathways that were not activated in the May test when only about one quarter of an interval volume was injected. The injection interval had no mixing or tracer distribution system, so possibly the dense tracer solution rapidly sank to the bottom of the interval in all tests. The first peak in October accounted for only about 12 percent of the mass of pentafluorobenzoic acid and bromide, so much of the mass injected in October may have still followed pathways that were activated in May. The June iodide injection into UE-25 c#1 resulted in only ~4 percent recovery of iodide, so UE-25 c#1 was eliminated from consideration for a reactive tracer test. All data discussed in this progress report should be considered preliminary until further quality checks and reviews are conducted.

The reactive tracer test data have been analyzed using a Laplace transform transfer function model to estimate transport parameters by simultaneously "fitting" the breakthrough curves of all solute tracers. The model assumes that the formation is a "dual-porosity" system in which flow occurs only in fractures, but the fractures are embedded in a porous matrix that contains a significant volume of stagnant water into which tracers can diffuse and sorb. The one-dimensional advection-dispersion equation is assumed to apply in the fractures, and diffusion into the matrix is modeled as a one-dimensional process occurring perpendicular to the direction of fracture flow. At least two sets of flow "pathways" had to be assumed to explain the bimodal breakthrough curves (i.e., two separate advection-dispersion equations were used to fit the data).

The interpretation procedure involved first simultaneously fitting the pentafluorobenzoic acid and bromide data by adjusting the following four parameters in each pathway, (1) the fraction of tracer following the pathway, (2) the mean fluid residence time, (3) the dispersivity, and (4) the mass transfer coefficient for matrix diffusion. The fits were constrained because all these parameters had to be the same for both pentafluorobenzoic acid and bromide because the two tracers were injected simultaneously and should have followed the same pathways in the same proportions. The fits were also constrained because the bromide diffusion coefficient in the matrix should have been about twice the pentafluorobenzoic acid diffusion coefficient (based on literature data). These constraints allowed the model parameters to be determined with much

less uncertainty than would have been possible if only a single tracer breakthrough curve were analyzed.

The lithium response was "fitted" by adjusting lithium sorption parameters in both the fractures and the matrix under the constraint that the test- and formation-dependent parameters (i.e., the four parameters listed in the previous paragraph) had to be the same as those determined for the pentafluorobenzoic acid and bromide. Although the lithium fits are not completely unique, they strongly suggest that diffusion and sorption in the matrix occurs in all pathways and that sorption in fractures occurs in most pathways. The fits also suggest that there is good agreement between field- and laboratory-derived lithium sorption parameters. This agreement increases the confidence using laboratory-derived sorption data to predict field-scale transport behavior. Details of the interpretative analyses of the solute data were presented in Reimus and Turin (in prep.). The microsphere data have not yet been quantitatively interpreted.

A poster (Reimus, 1996) was presented at the Fall 1996 American Geophysical Union meeting in San Francisco, California, December 12-16, 1996. This poster summarized experimental work conducted during FY 1995 that showed that significant attenuation of polystyrene microspheres can occur over residence times of several hours in flow through porous media. The observed attenuation in a laboratory experiment may help explain the relatively low recovery of microspheres in the October reactive tracer test. The laboratory test results also indicated that smaller (~0.3 μm diameter) microspheres were less attenuated than larger (~1 μm diameter) microspheres, which suggests gravitational settling as a possible attenuation mechanism. This result prompted project scientists to use only small (~0.36 μm diameter) microspheres in the field tracer test.

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: During the remainder of FY 1997, site water-level monitoring will include at least quarterly manual measurements in the saturated-zone network. Water-level data for 1996 will be reduced and organized into tables and hydrographs for publication. A report on the analysis of aquifer tests conducted in borehole USW G-2 during 1996 will be completed and submitted to DOE for concurrence and to the USGS Director for approval.

Conceptualization and analysis of drawdown after 158,000 minutes will be refined as drawdown data from UE-25 c#1, UE-25 c#2, UE-25 ONC#1 and other monitored observation wells continue to be evaluated.

In the multiple-well interference testing activity, pumping from well UE-25 c#3, and monitoring of wells UE-25 c#1, UE-25 c#2, UE-25 ONC-1, UE-25 WT#3, UE-25 WT#14, USW H-4, and UE-25 p#1, will continue until July 1, 1997. At that time, wells UE-25 c#2 and UE-25 c#3 will be reconfigured to allow hydraulic and tracer tests to be conducted in the Prow Pass

hydrogeologic unit. Testing in the Prow Pass hydrogeologic unit will commence around September 1, 1997, and will provide estimates of hydraulic and transport parameters of a relatively low-transmissivity hydrogeologic interval. The Prow Pass hydrogeologic unit is important because it is one of the first horizons in the saturated zone that would be penetrated by radionuclides should they escape from a possible future repository at Yucca Mountain.

The Pyridone and DFBA conservative tracer test in the Lower Bullfrog began on January 9, 1997 and will continue until July 1, 1997. At that time, wells UE-25 c#2 and UE-25 c#3 will be reconfigured to allow hydraulic and tracer tests to be conducted in the Prow pass tuff, low-transmissivity interval. Testing in the Prow Pass will commence around September 1, 1997, and will provide estimates of hydraulic and transport parameters for this important low-flow interval.

Laboratory experiments will be conducted to assess the transport of lithium and other potential reactive tracers in artificially fractured C-hole cores and to measure the diffusion coefficients of various tracers used at the C-hole complex in relevant tuff matrices (from C-hole cores). In conjunction with these experiments, batch sorption and crushed tuff column transport experiments will be conducted to establish sorption parameters and to assess the applicability of these sorption parameters to fracture transport. The information derived from reactive tracer tests at the C-hole complex and from the supporting laboratory experiments will be integrated into the site-scale saturated zone transport model.

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.

This activity has not been implemented. See Section A.1.1.3 of Appendix A of this progress report.

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.

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

Activity 8.3.1.2.3.2.3 - Regional hydrochemical tests and analyses. The objective of this activity 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.

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

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 unfunded activity.

Forecast: Selected existing saturated-zone hydrochemical data will be analyzed with a hydrochemical flow-path model to identify pertinent chemical processes and determine where in the saturated-zone flow system additional hydrochemical data would be most beneficial. New water samples will be obtained from well USW WT-17 plus two additional boreholes using techniques that ensure the representativeness of the samples. These samples will be analyzed for pH, Eh, major dissolved constituents, and isotopes of carbon, oxygen, hydrogen (including tritium), strontium, and uranium. Based on the results obtained from these new samples and the hydrochemical modeling, a sampling and analysis strategy for additional wells will be designed.

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.

Locations of most boreholes identified in the activities making up this study are shown in Figure 3-2.

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. This activity includes development and calibration of the numerical, site-scale, saturated zone flow model prior to its application in Activity 8.3.1.2.3.3.3.

A report describing the conceptual model of the saturated zone flow system (Luckey et al., 1996) was published.

Work continued on updating the preliminary, site hydrogeologic framework model. The updates included refining the grid-cell size from 1500 m to 250 m, including cross-sectional data from the Nevada Test Site, and including the upper surface of the Paleozoic carbonate aquifer along the east-west seismic line from Crater Flat to Jackass Flats as interpreted by Hunter et al. (1996).

Problems with mesh-generation software used during previous model scoping runs were identified and corrected. A new mesh was generated and tested for use with the ground-water simulation code FEHMN, and model-input data arrays were constructed. Potentiometric data for the area were evaluated, screened, and incorporated into the new mesh. Over 100 potentiometric data points were identified for use in the model for comparison against simulated hydraulic pressures (hydraulic heads). Alternate meshes also were generated that contain alternate conceptual models for the potentiometric surface in the Yucca Mountain area. Scoping runs were made on preliminary meshes using the parameter-estimation software, PEST. To provide faster simulation times, the model domain was re-evaluated and scaled down to a rectangular box 30 km wide, 45 km long, and 1.5 km thick surrounding Yucca Mountain. Calibration simulations began toward the end of the reporting period.

Work resumed on analyzing water-level fluctuations to estimate aquifer hydraulic characteristics. Data from 11 zones in 6 wells have been evaluated and analyzed. Preliminary results indicate that, although the method was developed for porous-media aquifers rather than the fractured-rock aquifers that dominate flow at Yucca Mountain, the method provides values of transmissivity and storativity that are consistent with values previously obtained using other aquifer-test methods. A comprehensive table of hydraulic-characteristic data for the Yucca Mountain area was compiled.

Work began on writing a synthesis report that documents the results (through April 30, 1997) of the site-scale, saturated zone, flow modeling. An annotated outline for the report was prepared and reviewed.

Work began on planning a workshop to discuss the abstraction and testing of saturated zone process models (flow and transport) for use in performance assessment modeling.

Activity 8.3.1.2.3.3.2 - Development of fracture network model. The objectives of this activity are to relate results of hydraulic and conservative tracer tests in wells to fracture-network flow characteristics at Yucca Mountain, to develop methods to analyze hydrologic data to determine fractured rock flow characteristics, and to model flow in the saturated zone in the vicinity of the C-hole complex.

Confirm Saturated Zone Hydrologic Flow Models. In recognition of the need for a better understanding of saturated zone flow at the scale of Yucca Mountain to support the waste containment and isolation strategy, this new sub-activity was developed and funded for the first time in FY 1997. The objectives of this activity are to develop analytic capabilities to design and analyze saturated zone hydraulic tests in the immediate Yucca Mountain site area and to test hypotheses concerning ground-water flow in the saturated zone in the site area to support the development and application of the site-scale, three-dimensional ground-water flow model that is

being constructed to support the total system performance assessments for viability assessment and license application.

To meet the objectives, a sub-site-scale, three-dimensional, numerical, ground-water flow model of the saturated zone hydrologic system is being developed. The model domain covers approximately 100 km^2 (12 km x 8 km area) that encompasses the area beneath the potential repository, the large hydraulic gradient zone, the Solitario Canyon fault, Fortymile Wash, and the area immediately down-gradient from the potential repository. The model is being developed as an analytical tool to test hypotheses of saturated zone ground-water flow in the immediate site area and to analyze the results obtained from aquifer tests at the C-hole complex and at other sites. The model is intended to simulate hydrologic conditions and processes at a small scale such that it can be applied in designing and analyzing results from the planned second saturated zone test complex. All available geologic, hydrologic, and hydrochemical data are being used to develop, calibrate, and test the model.

A plan for developing the subsite-scale model was submitted in October 1996 (Cohen et al., 1996). The plan defined the model boundaries and discussed the vertical layering scheme. Also discussed in the plan were the grid scheme, boundary conditions, and initial conditions, and treatment of features of interest (e.g., large hydraulic gradient, Solitario Canyon fault, C-hole complex) by finer discretization of the mesh in these areas. The plan discussed data needs for model parameters and data limitations, if known. Features or processes included in the model, and upon which sensitivity analyses will be performed, include temperature, hydrochemistry, potential upwelling from carbonates, and the role of faults.

The three-dimensional subsite-scale model grid was constructed and fault properties and characteristics thoroughly assessed to determine which faults to include in the model. Hydrochemical data were analyzed at the subsite-scale and compared with major ion and isotope patterns found in data at the regional scale. Hydrochemical signatures were contoured at two depths in the lower volcanic aquifer, which is included in the Crater Flat hydrogeologic unit (CFu) (Table 3.2). [Note: The "lower volcanic aquifer" is a collective reference to the combination of the Prow Pass Tuff, the Bullfrog Tuff, and the Tram Tuff of the Crater Flat Group (Table 3-2). Data about these units are being collected by the C-hole testing.] The contours delineated areas of recharge and showed a distinct change from higher to lower concentrations of many ions across the Solitario Canyon fault. The contours, however, did not discern local flow domains because of the paucity of saturated zone hydrochemical data near Yucca Mountain, as compared with the regional scale. Cohen and Simmons (1997) reviewed and evaluated relevant saturated zone features and processes at the subsite-scale (including temperature, upflow along faults from thermal convection, hydrochemistry) and cursorily examined mixing between layers. The report provided initial insights at the subsite-scale for predicting flow down-gradient from the repository.

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.

Forecast: The sub-site-scale three-dimensional numerical model of saturated zone flow will be delivered in August 1997 and will include the numerical model (input and output data sets) and a report describing the model, the degree of model calibration, and model uses and limitations. The report will examine data from the C-hole complex and will include recommendations for design of the second saturated zone test complex. The model will be used as a tool to help determine the optimum location of the test and test configuration, and to predict results of the hydrologic flow and transport tests to be conducted. A progress report on the model will be completed in May 1997 that will identify any unexpected results or difficulties encountered.

The site hydrogeologic framework model will be reviewed and approved for release to the Records Processing Center. Water-level fluctuations will be analyzed to estimate hydraulic characteristics of the aquifers and submitted for review. The site flow model will be calibrated to the extent possible by April 30, 1997. A synthesis report describing the preliminary site flow model, with model results to April 30, 1997, will be completed and submitted for review and approval. After April 30, 1997, work will begin on refining the calibration of the site flow model. A workshop to discuss the abstraction and testing of the site flow and transport models, for use in performance assessment modeling, will be held and recommendations concerning the abstraction and testing processes will be made.

3.1.17 Related International Hydrological Work

No progress occurred during the reporting period. As of November 8, 1995, the subsidiary agreements under which the cooperative work had been conducted were terminated and all international collaboration was discontinued.

The Office of Civilian Radioactive Waste Management (OCRWM) had bilateral agreements with Canada (Atomic Energy of Canada Limited [AECL]), Switzerland (Swiss National Cooperative for the Storage of Radioactive Waste [Nagra]), and Sweden (Swedish Nuclear Fuel and Waste Management Company [SKB]) and has participated in activities of international organizations such as the Organization for Economic Cooperation and Development/Nuclear Energy Agency (OECD/NEA), the European Commission (EC), and the International Atomic Energy Agency (IAEA).

3.2 GEOCHEMISTRY (SCP SECTION 8.3.1.3)

The changes to the Geochemistry Program since the SCP was issued are summarized in Appendix A, Section A.1.2.

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.

Work focused on integrating the conceptual models of controls on ground-water chemistry (discussed above) into the mountain-scale transport model. The impact of evapotranspiration on chloride concentrations in waters has been incorporated and soil-zone precipitation reactions, such as calcite and/or silica precipitation, are being incorporated into the transport model.

Forecast: Work will continue on incorporating conceptual models for controls on ground-water chemistry into transport models. In addition, field work designed to measure the oxidation-reduction potential in waters from several saturated zone wells will be planned.

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 Tuff. 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.

Core samples from drillholes along the path of the ESF were being analyzed to determine mineralogic stratigraphy in the densely welded, devitrified Topopah Spring Tuff. Analytical data on quantitative mineralogy were being collected from drillholes USW NRG-7, USW SD-12, and USW SD-7, representing the north-to-south run of the main drift of the ESF. Particular attention was being given to the zonation with depth of the major silica minerals (tridymite, cristobalite, and quartz) because of (a) the impact that high cristobalite contents have on determining the need for respiratory protection and (b) the importance of silica mineral type in estimating silica solubility in waters released under thermal loading of a repository. Preliminary data from USW NRG-6 core suggest that ratios of quartz to tridymite plus cristobalite can be used to quantify lithophysal character within the chemically homogeneous host rock.

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 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 Formation).

A report on the three dimensional mineralogic model of Yucca Mountain (Chipera et al., 1997) describes the accompanying computer model, including a description of the data sources, software, assumptions, derived mineral volumes, and the model limitations. The report also discusses the magnitude of expected increased model uncertainty if non-"Q" data are excluded. The model, in its preliminary form, focuses on mineral volumes and distributions important to site performance. Minerals and mineral groups described include smectite + illite, the sorptive zeolites, analcime, cristobalite + opal-CT, and tridymite. Distributions of glass were also included in the model. The model included all available quantitative x-ray powder diffraction data from the surface down to the Paleozoic basement. The model has been produced in a format that is amenable for use in process-level flow and transport models using the FEHM and TOUGH2 computer codes. The geologic and lithologic stratigraphy used in the model is consistent, to the extent possible, with the Reference Information Base Section 1.12(a), Stratigraphy.

The three-dimensional mineralogic model is currently being used in developing abstraction methodologies to treat variability in site mineralogic properties. A proposal for testing to address the effects of mineralogy and heterogeneity on radionuclide transport was developed for the workshop on unsaturated zone radionuclide transport, held in February 1997 (see Section 3.2.5 of this progress report).

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.

Recent work (Vaniman and Chipera, 1996) shows that the trace-element geochemistry of calcites at Yucca Mountain provides important information about transport processes in fractures. Fracture calcite occurs in both saturated and unsaturated hydrologic zones in the tuffs at Yucca Mountain, Nevada. In the upper unsaturated zone, the major constituents of the calcite crystal structure (carbon, oxygen) originate at the land surface. At greater depth there is a "barren zone," straddling the water table, where calcite is rare and mixing of surface and subsurface sources may occur. Deep in the saturated zone, distinctive manganese calcites reflect deep sources, including calcium released as analcime and albite formed or carbonates derived from underlying Paleozoic rocks. In the unsaturated zone and in the barren zone, above the deep manganese calcites, variations in calcite lanthanide chemistry can be used to distinguish rhyolitic from quartz-latitic sources. Lanthanide ratios and strontium contents of calcites record the chemical evolution of waters flowing through the unsaturated zone and upper saturated zone. Variations in calcite chemistry in the unsaturated zone and in the barren zone show that (a) strontium, which is readily exchanged with clays or zeolites, is essentially removed from some flowpaths that are in contact with these minerals and (b) traces of manganese oxides found in the tuffs significantly affect ground-water chemistry in the unsaturated zone and in the barren zone by removing almost all cerium from solution (evidenced by characteristic cerium depletions in calcite throughout this zone). Extreme cerium removal may be a result of cerium oxidation (cerium+3 or cerium+4) at the surfaces of some manganese oxides, particularly rancieite. Higher strontium contents and lack of cerium depletions in the deeper manganese calcites reflect different ages, origins, and transport systems. The calcite record of lanthanide and strontium transport in the unsaturated zone shows that minor minerals (clays and zeolites) and even trace

minerals (manganese oxides) will affect the compositions of ground waters that flow over distances greater than a few tens of meters.

A suite of sample splits was collected for mineralogic and geochemical analysis based on the results of isotopic analyses, particularly of calcite carbon-14 ages, strontium-87/strontium-86 ratios, and carbon-13 values. The goals of this parallel sample analysis, with splits collected for mineralogic and trace-element analysis taken from well-characterized generations of calcite, include determining

1. The geochemical significance of early versus late mineralization. (Has the geochemical environment of calcite deposition changed over time? Did some calcite precipitate from early, warm aqueous systems during the cooling of the tuffs?)

2. The stratigraphic controls on calcite trace-element chemistry. (Is the model of Vaniman and Chipera (1996) valid, indicating the validity of using natural geochemical tracers to infer effective transport distances for sorption within fractures?)

3. Alternative possible explanations for the geochemical anomalies in calcite compositions at Exile Hill.

4. Variations in calcite composition that correlate with zones where chlorine-36 from weapons testing is evident.

5. Whether absence of cerium anomalies at or above repository depth indicate pathways that bypass the upper vitrophyre of the Topopah Spring Tuff.

Preliminary results show that early-formed calcites may be significantly restricted in lanthanide-element contents, suggesting one specific depositional environment that communicated widely throughout the site, possibly operating soon after tuff emplacement. In addition to the splits of calcite and opal collected additional materials are being analyzed, either of other mineralogies (clays, manganese-oxides) or from other localities. The other localities include other stations in the ESF and drill cores (USW NRG-6, USW NRG-7, USW SD-9, and USW SD-12) that lie near the path of the ESF. These additional samples will be used to place the data to be obtained from the ESF samples in vertical stratigraphic context.

Forecast: Additional data will be incorporated into the three-dimensional mineralogic model of Yucca Mountain as more analyses of core become available. Comparative geostatistical and mineralogic model sections will be prepared. The results will be used to support the total system performance assessment for the viability assessment. Further studies involving microautoradiography, combined with fracture-flow studies and traditional batch sorption studies, will be used to obtain the information needed to determine the impact of trace minerals, such as smectite, for modeling the retardation of radionuclide transport. Staff will continue to analyze and interpret on textural and geochemical bases the origin of calcite, opal, manganese-oxide, and clay minerals from the ESF. Samples from cores collected from boreholes near the ESF (especially USW SD-7, USW SD-9, and USW SD-12) will also be analyzed to provide information on mineral variability with stratigraphic level. This information is needed to

interpret the data from the ESF horizon. Mineralogic analyses are being obtained for an additional 175 borehole samples, including specific intervals of USW NRG-7/7a, USW UZ-14, USW SD-7, USW SD-9, and USW SD-12 (with supporting data from USW H-3) to fill gaps in the three-dimensional mineralogic model of Yucca Mountain. Particular emphasis will be placed on the distributions of minerals important in transport and repository thermal loading analysis and, in the repository horizon, the abundances and distributions of regulated hazardous minerals (e.g., crystalline silica). The three-dimensional mineralogic model will be used in meeting the needs of performance assessment in unsaturated zone radionuclide transport modeling, particularly in developing the testing of abstraction methodologies.

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, zeolites, and glass. Processes range from deep-seated past hydrothermal alteration to ongoing 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 activity are to constrain the timing, geochemical transport, and paleohydrology of hydrothermal, digenetic, and epigenetic alteration; to estimate the long-term thermochemical stabilities of important sorptive phases, such as clinoptilolite; and to investigate the natural evolution of phases such as silica polymorphs that can influence water composition, rock hydrologic properties, and the stabilities of other silicate minerals.

Research focused on correlating mineralogy and alteration in the PTn hydrogeologic unit with measured hydrologic properties of the unit. Mineralogic characterization of the same samples that have been used for hydrologic-property measurements makes it possible to evaluate differences in moisture content as determined by different methods because these differences are likely to correlate with hydrous mineral content. Beyond this immediate use, progress was made on developing a conceptual model of alteration in the PTn that will be used to predict the distribution of hydrologic properties within the unit using mineralogic and hydrologic property variations resulting from alteration processes.

A milestone progress report (Levy and Chipera, in prep.) provided descriptions and examples of natural alteration that have been identified and studied. Examples were found of both rootless hydrothermal alteration related to the cooling of the pre-Tiva Canyon tuffs or of the overlying Tiva Canyon Tuff and ambient-condition digenetic alteration. One hypothesis of alteration to be tested is that ongoing argillic alteration is occurring in the pre-Tiva Canyon tuffs and that localization of this alteration reflects differences in surface infiltration above the pre-Tiva Canyon tuffs. The report included a discussion of criteria for evaluating this hypothesis, as well as pertinent preliminary data from the ESF south ramp and drillholes USW UZN-31 and USW UZN-32.

Another aspect of the correlation of mineralogic alteration and hydrologic properties is the use of mineralogic alteration to identify fractures and faults within the PTn that have hosted fluid flow. Cooling-stage alteration of the pre-Tiva Canyon tuffs is of particular interest as an indication of possible changes to be expected from repository-induced alteration of this unit. Products of alteration associated with cooling probably included quartz/chalcedony, opal-CT, opal-A, heulandite-clinoptilolite, and smectite. Several processes related to mineralogic alteration probably altered the hydrologic properties of the rock. These processes include localized devitrification along fracture boundaries, fracture spallation (with alteration of fracture aperture), pore cementation, and selective genesis or deposition of smectite along fractures and faults.

Information about the transmissive pathways through the pre-Tiva Canyon tuffs is required to help interpret the chlorine-36 isotopic data from the ESF and drillholes. Mineralogic and textural characteristics of faults and fractures cutting the pre-Tiva Canyon tuffs were studied. It is uncertain whether the examples examined to date represent bounding or typical attributes of faults in the pre-Tiva Canyon tuffs. Minor faulting or fracturing in minimally consolidated vitric nonwelded pre-Tiva Canyon tuffs produced very little breakage of rock grains, but this was apparently sufficient in some instances to allow fluid transport that resulted in localized mineral deposits.

Activity 8.3.1.3.2.2.2 - Smectite, zeolite, manganese minerals, and 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.

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

Forecast: This study will continue to correlate variations in alteration with existing and new data on hydrologic properties and to identify needs for additional measurements. The work will require analysis of samples from the ESF, especially from a series of short drillholes in the north ramp PTn exposures, and from unanalyzed drill cores. Assumptions about mineral distribution and field-scale mineralogic and textural features (e.g., vitric-zeolitic transition, syngenetic alteration zones) will be evaluated. The evaluations and documentation will incorporate ESF data on the abundance of transmissive features identified by mineralogic and textural studies to help define and support selection of input terms for infiltration into the TSw. This effort will be closely integrated with the studies of hydrologic properties by performing mineralogic-petrologic analysis of hydrologic-properties samples. The study will also be integrated with chlorine-36 isotopic studies of the water movement test (e.g., Study 8.3.1.2.2.2; see Section 3.1.6 of this progress report).

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 hydrothermal 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 an effort to consolidate work scopes, this study plan will not be written because much of the work overlaps activities in Study Plans 8.3.4.2.4.1 and 8.3.1.20.1.1 (discussed in Sections 5.2.2 and 3.14, respectively, of this progress report). Much of the work is a compilation effort to select analog site(s) combined with testing and/or calibration of the EQ3/6 code to reduce uncertainties in EQ3/6 applications.

No progress was made during the reporting period; this was an unfunded study. Work scheduled in support of this study has been suspended.

Forecast: No activity is forecast for this study.

3.2.5 Study 8.3.1.3.3.2 - Kinetics and Thermodynamics of Mineral Evolution

The objectives of this study have been revised to determine experimentally the kinetics and thermodynamics of mineral alteration at Yucca Mountain and to produce a model for past and future mineral alteration at Yucca Mountain. The model is intended to explain the natural mineral evolution resulting from the transformation of metastable mineral assemblages to more stable assemblages and to predict the possible effects of emplacement of radioactive waste in a repository.

The revised study plan for Kinetics and Thermodynamics of Mineral Evolution at Yucca Mountain was accepted by the Project on December 11, 1996. This study now combines previous Studies 8.3.1.3.3.2 and 8.3.1.3.3.3 and will investigate the thermodynamics of clinoptilolite, mordenite, analcime, silica minerals, and, to a lesser extent (because of their much smaller abundance), smectite and illite.

A report (Carey and Bish, in prep.) describes the enthalpy of hydration of natural clinoptilolite as determined by isothermal immersion calorimetry. The data in this paper represent the first direct measurements of the energetic consequences of hydration and dehydration reactions that can occur at Yucca Mountain. The measurements were made on natural clinoptilolite that was cation exchanged to produce calcium-, sodium-, and potassium-end members. Heats of immersion of clinoptilolite were determined and compared with the enthalpy of hydration determinations from a thermogravimetric study on the same samples (Carey and Bish, 1996) are similar to but of smaller magnitude than the values of enthalpy of hydration. Because of the data collection and analysis methods used, the heats of immersion data are believed to be more accurate and more precise because of the lower uncertainty in the measurements. The effects of dehydration of clinoptilolite on the thermal evolution of the potential repository at Yucca Mountain were considered by comparing the amount of energy consumed by dehydration with the energy necessary to heat rocks lacking hydrous minerals. The energy consumed on heating clinoptilolite from 25 to 200°C is between 70 and 80 percent above that required for nondehydrating materials. These results indicate that accurate

thermohydrologic-hydrologic modeling of rock units at Yucca Mountain should consider the thermal effect of dehydration-hydration processes in clinoptilolite and other hydrous minerals, in addition to the water produced or adsorbed during heating or cooling.

Bish (1996) emphasized the variety of ways in which mineralogy may be important in the long-term isolation of radioactive wastes, including the importance of minerals in retarding the migration of actinides and other radionuclides that form large, complex aqueous species. Minor and trace minerals, such as smectite and iron and manganese oxides and hydroxides, are particularly important in retarding the migration of complex actinide species such as neptunyl.

Carey et al. (1996) described the effect of cation exchange and dehydration on clinoptilolite-analcime equilibria as applied to conditions at Yucca Mountain. Primary calorimetric data for clinoptilolite and analcime were extended by a modified thermodynamic estimation procedure and combined with recent cation-exchange (Pabalan, 1994) and hydration (Carey and Bish, 1996) studies to yield the thermodynamic properties of arbitrary compositions of clinoptilolite and analcime. The equilibrium breakdown of clinoptilolite to analcime was calculated assuming cation-exchange equilibrium with aqueous solutions of variable sodium to calcium and sodium to potassium ratios, as functions of temperature and silica activity. The results show that the strong affinity of clinoptilolite for potassium or calcium over sodium limits the stability region of analcime to silica-poor, sodium-rich solutions. The clinoptilolite stability field is maximized for aluminous compositions in equilibrium with siliceous analcime. Increased temperatures decrease the stability field of clinoptilolite, but this effect is moderated slightly by the loss of water from clinoptilolite. Estimates of uncertainty in these results were derived by comparison of predicted and measured calorimetric data for clinoptilolite and analcime. The uncertainties are significant with respect to the predicted stability field of clinoptilolite.

An analysis has been completed of the parameters affecting calculations of the kinetic evolution of minerals. The analysis is an integrated summary of the relation between theoretical and experimental kinetics and the implementation of numerical evaluations of kinetic evolution at Yucca Mountain. One difficulty in this implementation is that, unlike the experiments, the natural environment has poorly constrained surface areas for reacting minerals and poorly understood effective diffusion constants for aqueous species. Laboratory experiments used samples with measured surface areas exposed to a vigorously stirred aqueous solution. The natural system consists of minerals with unmeasured surface areas that are incompletely exposed to an aqueous solution having concentration gradients over distances that have not been characterized.

The magnitude of the uncertainty for the reactive surface areas of minerals in the natural environment is a function of the surface roughness and the relative exposure of the mineral grains to pore fluids. Surface roughness increases the reactive surface area by a factor as large as 1×10^3 relative to the geometric surface area (e.g., the surface area of a sphere). The relative exposure of a mineral grain to pore fluids may be bounded by considering the difference between minerals exposed only along a fracture and close-packed spherical minerals. The exposed surface area differs by 1×10^5 in this instance. Considering an average situation, the estimated surface areas of reactive minerals in the natural environment (including Yucca Mountain) have

an uncertainty of 1×10^2 to 1×10^3 which translates directly into an uncertainty of 1×10^2 to 1×10^3 in the mineral reaction rates.

An analysis was completed of the reaction mechanisms of the silica polymorphs at Yucca Mountain. Several contrasting views of silica polymorph evolution have been outlined (Duffy, 1993). These include processes governed by:

1. dissolution and precipitation rate constants as exemplified by the experimental work of Rimstidt and Barnes (1980);

2. an Ostwald ripening process in which the polymorphs evolve in a step-wise process from opal-A to opal-CT to quartz as suggested by Murata et al. (1977);

3. a defect-concentration model proposed by Duffy (1993); or

4. diffusion-limited reaction of the silica polymorphs (application of process 1 in a nearly closed-system environment). All these models have been evaluated with respect to the observed distribution of silica polymorphs at Yucca Mountain. These natural data show that nucleation kinetics are not significant because quartz is present throughout the stratigraphic column. However, opal-CT/cristobalite disappears at depth in a manner that is perhaps consistent with either process 3 or 4.

Staff participated in the workshop on unsaturated-zone radionuclide transport in Albuquerque, New Mexico, February 5-7, 1997. At this workshop, an abstraction-testing draft proposal was formulated for sensitivity studies to examine the effects of mineral alteration on unsaturated zone radionuclide transport. Results suggest that repository-induced alteration of the existing minerals and glasses in Yucca Mountain tuffs may change the hydrologic properties (permeability and porosity) and geochemical properties (sorption capacity, composition including H_2O) of the natural media over time. In addition, the workshop determined that simulations of radionuclide transport in the unsaturated zone should consider the possible changes in rock properties.

Forecast: The updated conceptual model of mineral evolution will be completed. This update will integrate information for mineral evolution at Yucca Mountain using kinetic, thermodynamic, field, and analytical studies of mineral, glass, and water reactions. Data will be compiled from other studies and from the literature, as appropriate. This activity will define and bound important mineral reactions in the host rock that may affect transport of radionuclides. This activity will support transport model development and calculations, as well as near-field studies. The conceptual model will be incorporated into a transport and thermohydrologic model such as FEHM, and a sensitivity analysis will be conducted of the effects of individual mineral reactions on radionuclide transport. Information obtained in these studies will be combined with the FY 1997 preliminary three-dimensional mineralogic model for Yucca Mountain (Chipera et al., 1997) to produce an updated conceptual model of mineral evolution within a mineralogic framework that is an improved representation of Yucca Mountain. The effort will summarize the potential geochemical and mineralogical effects of thermal loading and the possible impacts on radionuclide containment and rock properties. This work will culminate in a model of the

expected behavior of the secondary phases at Yucca Mountain as functions of time, temperature, water and mineral composition, and water-vapor pressure.

Abstractions for the total system performance assessment will continue through this fiscal year in an attempt to include in the assessment the effects of mineral alteration on unsaturated zone radionuclide transport. Staff will use existing Project thermohydrologic models to determine temperature and saturation as a function of time and depth at various locations throughout the repository block. Using this information, potential locations of mineral and glass reaction will be predicted. The sensitivity analysis may couple data on mineral alteration with the thermohydrologic models to model mineral alteration effects more explicitly. This procedure is expected to develop a history of the evolution of properties in the unsaturated zone for use with unsaturated zone radionuclide transport modeling to test the effects of predicted mineral alteration on transport. The thermohydrologic model will be used as input to the conceptual model of mineral alteration. The product will consist of a sensitivity analysis using a coupled mineralogic-thermal-chemical model (one- or two-dimensional) to determine if thermal mineral alteration should be considered in the total system performance assessment. If so, staff will provide an appropriate abstraction that represents the future properties of the unsaturated zone flow and transport regime below the repository horizon.

3.2.6 Study 8.3.1.3.3.3 - Conceptual Model of Mineral Evolution

The objectives of this study are to formulate a model to explain the observed distributions of minerals in Yucca Mountain. The evolution of framework silicates (feldspars, zeolites, and silica polymorphs) will be emphasized. The model will also address the general chemical evolution of vitric tuffs and will be used to predict future mineral evolution in the mountain caused by both natural processes and development and operation of a repository.

This study has been combined with Study 8.3.1.3.3.2; see Section 3.2.5 of this progress report. Forecast for the combined study is reported in Section 3.2.5 of this progress report.

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.

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 the zeolitic and vitric tuffs of the Calico Hills nonwelded hydrogeologic unit, on devitrified tuffs, and on pure minerals representative of the minerals present in the rock and fractures of the repository block.

Project geochemists have initiated studies to validate the sorption data base for whole rocks. Microautoradiography studies of selected radionuclides and lithologies that are important to performance have begun. Radionuclides for these studies are uranium, plutonium, and americium; rock types include vitric, zeolitic, and devitrified tuffs.

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 aqueous 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.

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

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.

Software was written to ensure accurate and efficient transfer of experimental data to the sorption data bases. This software also provides data analysis and statistical interpretation capabilities. The sorption data bases have been formally submitted to the Project. These data bases provide fast access to and selection of data needed to evaluate the effects of various parameters on sorption. The data bases contain information on the solid and water used, the test atmosphere, temperatures, radionuclide concentrations, experiment durations, and whether experiments were sorption or desorption experiments. All data needed to calculate the K_d are also incorporated as are data necessary to provide traceability to the original data sheets. The statistical uncertainty in the K_d arising from analytical uncertainties is calculated and presented. K_ds are calculated using both the initial radionuclide concentration of the experiment and the final concentration in a parallel control experiment done without solid present. These K_d values are used along with uncertainties to assess acceptability of the data. The data bases provide an accessible, easily searchable, and easily sortable resource. This resource can be used to develop sorption isotherms or solid phase mineralogy to investigate the effect of parameters, such as radionuclide concentration, by sorting for mineral composition and comparing the K_d variation within a given mineralogy to the variation among different mineralogies. Thus, appropriate K_ds can either be selected for transport modeling or a determination can be made that additional data are needed.

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.

Project scientists initiated a set of batch sorption experiments to study the reversibility of radionuclide sorption onto colloids. The experimental matrix consists of two types of colloids (clays and iron oxides), bicarbonate ground waters (UE-25 J#13 and UE-25 p#1), and two chemical forms of plutonium (polymeric and soluble).

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) that most profoundly affect 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: This study will integrate the radionuclide solubility, sorption, and transport synthesis reports submitted in FY 1996 to identify the most technically valid models that should be used to describe these processes in the performance assessment. Sorption data will be collected on plutonium batch experiments using the minimum number of experiments needed to produce defensible plutonium sorption values. The effects of organics on actinide sorption will be assessed, and available ground water data will be evaluated to address potential deficiencies in the sorption data base. Sorption data will be collected for minerals and ground-water chemistries resulting from planned thermal loads.

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 wastes (i.e., effects on transport) and to determine if microbial activities play a role significant enough to be included in a performance calculation for Yucca Mountain. The objectives will be accomplished by combining the results of laboratory experiments investigating the different mechanisms of microbial effects on transport (chelation, sorption, and colloidal interactions) with microbial analysis of samples collected from the ESF that will determine the numbers, metabolic activity, identity, and diversity of the indigenous population in Yucca Mountain.

A paper (Hersman, in prep.[a]) is being developed that describes the biological sorption and transport field and laboratory studies, presents an overview of the current literature, and summarizes the results of the work discussed in Kieft et al. (in prep.) and Ringelberg et al. (in prep.).

A report (Kieft et al., in prep.) discusses the distribution of heterotrophic microorganisms within Yucca Mountain. Generally, with increasing distance in the ESF, the population of microorganisms decreases, and a greater percentage of gram negative microorganisms is present in the samples. Ringelberg et al. (in prep.) describes the phospholipid fatty-acid analysis performed on the ESF samples. The major findings indicate that sulfate reducers are present in

Yucca Mountain, which is significant because of the role that these microorganisms play in the corrosion of primary containers.

Chelated transport of iron through columns of unsaturated tuff is described in Story et al. (in prep.). The major finding of this report is that chelation significantly affects the transport of iron in crushed tuff. Therefore, transport of radioactive wastes may be enhanced by chelation.

Forecast: Planned work will support development of process models for site-scale unsaturated zone transport and waste package degradation that will be used in the total system performance assessment for the viability assessment. The work also supports the process model for site-scale saturated zone transport and parts of the waste containment and isolation strategy that concern limited corrosion and low humidity. The work identifies key actinide concentrations that may be reduced by depletion and dispersion.

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.

Project geochemists summarized the data needs for sorption modeling in performance assessment. These data needs include the following:

- Isotherms for cation exchange between the alkali metals and alkaline earths present in UE-25 J#13 water and the minerals contained in Yucca Mountain Tuff.

- A predictive model for cation exchange based on mineralogy. A mineralogy based model of cation exchange will allow the use of the enormous and extensive mineralogy and petrology data base to arrive at a more accurate K_d as a function of stratigraphy.

- A hard-soft acid base model for bidentate attachment mechanisms. Bidentate attachment is possible for any multivalent metal ion. The consequence of a bidentate attachment mechanism is a heightened sensitivity to competition by metal ions that attach by a monovalent mechanism.

- Stoichiometries for the surface complexation of radionuclides on minerals and tuff. Measurements of the pH dependence and electrolyte concentration dependence of radionuclides are needed to develop a predictive surface complexation model.

- Measurements of the competition for surface complexation sites. Competitive surface complexation experiments are needed to fully understand the consequences of changes in ground-water composition on sorption.

- Cause of the wet sieving effect. The observed reduction in sorption upon wet sieving could mean that the in situ sorption coefficient is significantly larger than laboratory measurements indicate. If the effect is caused by site saturation by trace components of ground water, ground-water analyses may have to be remeasured with specific attention to those components.

Forecast: This study will summarize the mechanistic models for sorption of radionuclides onto Yucca Mountain minerals. A summary report (describing the findings to date from Studies 8.3.1.3.4.1 and 8.3.1.3.4.3) will be prepared. For Study 8.3.1.3.4.3 the summary report will be on (a) summarizing available surface complexation models to describe radionuclide sorption, (b) evaluating the predictive capability of surface complexation models to describe radionuclide sorption onto pure minerals and whole rock, (c) assessing the value of spectroscopic studies for direct measurement of sorbed species and surfaces, and (d) describing the effects of organics on radionuclide sorption.

3.2.10 Study 8.3.1.3.5.1 - Dissolved Species Concentration Limits

The objective of this study is to determine the solubilities and speciation of important radioactive waste elements under conditions characteristic of the repository and along flow paths from the repository into 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 conducted and then measure solubility limits of important waste elements under these conditions.

Project chemists continued to characterize neptunium and plutonium solid precipitates from solubility experiments from oversaturation. No evidence for a Np (IV) solid, either crystalline or amorphous, has been found. Furthermore, adding excess ferrous chloride to a neutral de-aerated solution of Np(V) in 3 mM sodium bicarbonate (to simulate UE-25 J#13 water conditions) showed no reduction to a Np(IV) solution/precipitation at room temperature. While a couple of solubility experiments from undersaturation have started using neptunium solids from oversaturation experiments, the main experiments using well characterized neptunium oxides (Np_2O_5 and NpO_2) solids in UE-25 J#13 and in sodium perchlorate ($NaClO_4$) electrolyte solutions are about to begin.

The importance of the oxidation state of the solubility-limiting solid (i.e., Np [V] versus Np [IV]) is that Np (IV) solids would have solubility 2 to 3 orders of magnitude less than NP (V) solids; so any evidence of formation of Np (IV) solids would benefit system performance.

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. Such thermodynamic information is essential to model the solubility of key radionuclides as described in Activity 8.3.1.3.5.1.3.

This activity has been deferred because of a lack of funding.

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

This activity has been deferred because of a lack of funding.

Forecast: Work will determine whether Np(IV) species may form under natural conditions at Yucca Mountain. Forcing conditions, including high temperature and control of oxidation-reduction potential, will be imposed and are intended to constrain both the kinetics and thermodynamics to test whether natural conditions at Yucca Mountain might be expected to produce Np(IV). Completion of these experiments should identify the final constraints on neptunium solubility.

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: Further work on this study has been deferred because of funding constraints.

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.

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

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.

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

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.

Neptunium experiments (to expand the data base) under varying degrees of saturation, were initiated using two tuff types (zeolitic and devitrified) and two bicarbonate waters. The purpose of the experiments was to expand the neptunium data base.

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.

Experiments were initiated to expand the data base for the fractured rock column experiments to increase confidence in findings on radionuclide retardation in fractures. Project scientists used autoradiography to assess the fracture-matrix coupling for alpha emitting radionuclides flowing through fractures.

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.

A paper (Degueldre et al., in prep.) is being prepared that presents ground-water colloid results from various geologic formations ranging from crystalline to sedimentary, saturated to unsaturated, organic rich to organic depleted. Colloid presence and mobility are explained on the basis of stability properties in the ground waters studied. Colloid concentration is a function of pH, oxidation-reduction potential, cation and organic carbon concentrations, and the status of the chemical and physical steady state of the hydrogeochemical system.

Forecast: The results of transport experiments consisting of eluting radionuclides through saturated and unsaturated, crushed, fractured, and solid tuff columns will be summarized. This summary will assess the validity of using batch sorption distribution coefficients to describe the migration of radionuclides through fractured and solid tuff under various degrees of saturation. This summary will also assess the results of eluting colloids through tuff columns and the implications of those results for performance assessment calculations of radionuclide transport.

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 the length to which 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.

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

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 observing the migration of radionuclides through slabs of Topopah Spring Tuff and Calico Hills zeolitic tuff.

Five diffusion experiments began. In each experiment, a diffusion cell was set up in which radionuclides are in contact with a coated fracture in one of the two chambers of the cell. In the other cell chamber (which is in contact with the tuff matrix) arrival of the radionuclides (which have diffused through the fracture and the matrix) was monitored. Evaluation and interpretation of results are in progress.

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 block of the Topopah Spring Tuff or the Calico Hills Formation, 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.

Experiments were started to measure diffusion coefficients as a function of saturation in zeolitic and devitrified tuffs for sorbing and nonsorbing radionuclides.

Forecast: A report will be prepared that summarizes the results of the diffusion experiments and provides diffusion coefficients as a function of hydrologic unit, tuff moisture content, and temperature. The report will describe the use of diffusion data to develop diffusion coefficients for radionuclides migrating through fractures into the tuff matrix in the presence of fracture coatings.

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 which data are most important to make the cumulative, integrated transport

calculations needed to meet the U.S. Nuclear Regulatory Commission (NRC) and U.S. Environmental Protection Agency regulations. Another important function of this study is to provide process models from which performance assessment abstractions and simplifications can be made.

The study is the focal synthesis activity for hydrology, mineralogy/petrology, sorption, dynamic transport, and solubility/speciation tasks by incorporating information from all these sources into abstracted site-scale transport models for both the unsaturated and saturated zones.

Activity 8.3.1.3.7.1.1 - Analysis of physical/chemical processes affecting transport. The objectives of this activity are to analyze processes that may affect transport, geochemical, physical, particulate, heat-load effects, and coupled phenomena; to support and develop those laboratory experiments needed to examine the physical and geochemical processes affecting radionuclide transport and other experimental activities under this program and the ESF tests; and to correlate and validate results obtained from laboratory, ESF, and field experimental results with transport calculations.

Development of the saturated-zone model continued to mature. Several different representations of stratigraphy, water-table, and boundary conditions were created in the Stratamodel geologic modeling packaged and converted into numerical grids using the GEOMESH grid-generation software. The main objective of this work was to include the most reliable data on water levels based on well observations, as well as the most up-to-date geologic interpretations. Grid resolution was kept relatively coarse so that a parameter estimation routine (PEST) could be used efficiently for the calibration. The PEST software requires numerous simulations to obtain the fit to the data, and thus computational efficiency is important.

Comparisons were begun of structured and unstructured grids as the result of an update meeting on Performance Assessment held the week of February 3, 1994 in Denver.

Following the meeting, a backup model was generated based on structured (finite difference) grids representing the same volume as the unstructured mesh (finite element). In addition, a resolution study was underway to determine the grid resolution necessary for saturated-zone studies. Using constant head-boundary conditions, the change in flux at the south boundary (and near a regulatory compliance boundary) was monitored as grid resolution was increased. Analysts determined that fluxes vary as much as 50 percent from the values computed at the coarsest resolution. This variation indicates that relatively fine grids will be required for the final calculations. Therefore, the approach to model calibration will be to perform a coarse-grid calibration to determine an approximate permeability distribution that will be used as the initial state for the final fine-grid calibrations.

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.

The transport of neptunium-237, one of the key radionuclides in the inventory, was simulated using a comprehensive geochemical transport model (Viswanathan et al., 1977). The laboratory-scale speciation and sorption data for neptunium-237 were replicated using the reactive transport module of FEHM. The model correctly simulated the transition from sorbing neptunyl cation to non-sorbing carbonate complexes at higher pH values in typical Yucca Mountain fluids.

Furthermore, the effect of carbonate concentration in the fluid (varied by performing experiments in both UE-25 J#13 and UE-25 p#1 water) on speciation is also correctly represented in the model. An ion exchange sorption model was developed to capture the competitive sorption effects of major cations such as sodium, magnesium, and calcium. When speciation calculations are performed during simulations of transport through the unsaturated zone, the calculations directly incorporate the effects of geochemistry on transport of neptunium-237. Significant retardation of radionuclides occurred in the zeolitized CHn units as long as the unsaturated zone fluid had a carbonate concentration that resembled that of UE-25 J#13 fluid. Recent bicarbonate ion measurements for unsaturated-zone pore fluids reported by Yang et al. (1996) confirm this observation. Project hydrologists have corroborated retardation of neptunium-237 in the zeolitized CHn units using this reactive transport model, thereby reducing an uncertainty for one of the crucial radionuclides in the inventory.

Project scientists also investigated the influence of repository heat on the transport of neptunium-237. Together with the geochemical transport model discussed above, scientists examined whether the period during which thermohydrologic effects are likely to be most vigorous (the first 5000 years after waste emplacement) changed the transport predictions for neptunium-237 significantly from predictions that assumed isothermal conditions. Results indicate that since most of the neptunium-237 inventory is released from the repository in a period that exceeds the most important thermohydrologic effects, the influence of waste heat on radionuclide movement is minimal. This conclusion simplifies the execution of radionuclide transport predictions since it suggests that the predictions can be made assuming that isothermal conditions prevail.

The main caveat to this conclusion is that the influence of possible permanent changes to the hydrologic and transport properties needs to be studied. An activity to examine changes to the permeability and porosity distribution due to rock-water interactions is planned.

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).

Several code modifications were made to FEHM to accommodate needs of saturated-zone users. The first was to incorporate hydraulic head input and output instead of pressure. This will be very useful for linking this site-scale model to the USGS regional-scale model. The second modification was to implement an option for general time-varying boundary conditions. A sophisticated approach was necessary because multiple time-step adjustments were required to get cyclic fluxes in different parts of a model domain. A Bousinesq approximation was also

incorporated as an option for saturated zone flow simulations. Lastly an output module for the PEST parameter estimation code was added.

Improvements to the reactive-transport model in FEHM increased the efficiency of simulation of the transport of multiple, interacting species in the solid, aqueous, or gas phases (Viswanathan et al., 1997). Equilibrium and kinetic reactions were recast as systems of equations that can be solved as algebraic equations at each node to improve computational efficiency. This code development effort allowed the simulation of the geochemical transport behavior of neptunium-237 (see previous discussion under Activity 8.3.1.3.7.1.2).

Forecast: The importance of uncertainty in conceptual models and parameters for flow and transport in the unsaturated and saturated zones will be tested in support of performance assessment. Information from hydrology, mineralogy-petrology, sorption, dynamic transport, and solubility-speciation studies will be incorporated into abstracted site-scale transport models for both the unsaturated and saturated zones. Model studies will be performed to create abstractions suitable for performance assessment, including testing the use of simple sorption and solubility models against complex, reactive transport models. Reactive transport models for neptunium, uranium, and technetium will be developed for the unsaturated zone. For technetium in the saturated zone, a model will be developed to test whether simple solubility/speciation and sorption models can be used in model abstraction. The reactive transport models will include solubility-speciation, dissolution-precipitation, and reduction-oxidation reactions in the presence of repository waste heat and the introduction of manmade materials.

Process models for radionuclide transport will be revised by incorporating and summarizing progress through FY 1996 and the first half of FY 1997. This work will include updating documentation of transport codes, meshes, etc., as well as developing intellectual insights into the processes involved in the migration of radionuclides through the natural barrier. Processes that affect the transport of radionuclides at Yucca Mountain will be studied to support the development of simplifying assumptions made by performance assessment for transport models. Retardation processes and specific data accuracy requirements will be identified; these specifications will help assess whether site characterization data-gathering activities performed to date have been adequate.

Information will be incorporated from hydrology, mineralogy-petrology, sorption, dynamic transport, and solubility-specification tasks into site-scale transport models for the unsaturated zone. Where data are unavailable or insufficient to accurately set parameter values, sensitivity analyses will be performed to determine the effects that variations in parameters or processes have on transport from the potential repository. Numerical flow and transport models developed for performance assessment will be used, along with enhancements, including reactive chemistry, that have been developed in previous years in this task. Predictions of radionuclide migration will be produced, along with uncertainties that will point to further data needs in the sorption, dynamic transport, hydrology, and geological framework tasks.

Two reports will be completed. One will include a conceptual model of the transport of radionuclides in the unsaturated zone at Yucca Mountain, including two- and three-dimensional integrated transport calculations and sensitivity analyses. Both equivalent-continuum and dual-

permeability calculations will be made, incorporating discrete structural features as available and appropriate. The model will incorporate and consider isotopic data indicative of processes and rates of fluid flow or residence times in the mountain. The model will update three-dimensional transport simulations for radionuclides including, but not limited to, neptunium, plutonium, and technetium under ambient and thermally perturbed scenarios for two future climates and accompanying infiltration fluxes. The report will also be coupled to appropriate near-field source term and thermal model(s). Where necessary, reactive transport models for key radionuclides such as neptunium and uranium will be developed to better capture the solubility-speciation and sorption data available for these radionuclides.

The second report will summarize development and implementation of the model for the reactive transport capabilities of the FEHM computer code. New options will be summarized, including speciation, complexation, and sorption reactive transport capabilities. Updated user documentation will also be provided, along with a series of example problems.

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 unfunded 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.

Two sites have been identified as possible locations for an unsaturated zone transport test: P-tunnel and Busted Butte. P-tunnel scoping calculations demonstrate the feasibility and benefits of an unsaturated zone transport test to the project partially completed prior to license application. Field reconnaissance of the northern and southern Busted Butte areas conducted in March 1997 identified the southern section as a favorable site for unsaturated zone testing in the Calico Hills Formation.

A summary of the results from the first C-wells reactive tracer tests completed in early 1997 was submitted to the Spring 1997 American Geophysical Union meeting (Turin and Reimus, in prep.). The objective of the test was to provide a field validation of reactive tracer transport in saturated, fractured tuffs at Yucca Mountain immediately east-southeast of the

footprint of the potential repository site. Detailed description of the results can be found in Milestone No. SP2370M4 (March 14, 1997). A forced-gradient field tracer test involving simultaneous injection of nonsorbing solute tracers of different diffusivities (pentafluorobenzoic acid and bromide), a sorbing solute tracer (lithium ion), and a colloidal tracer (polystyrene microspheres) was conducted at the C-Hole complex in saturated, fractured tuff in the vicinity of Yucca Mountain, Nevada. The test objectives were to (1) test and validate a conceptual model for contaminant transport in fractured media, and (2) assess the validity of using laboratory-derived sorption parameters to predict reactive tracer transport at the field scale in unsaturated tuffs. All tracer breakthrough curves were bimodal in nature, indicating multiple flow pathways. Matrix diffusion was apparent in each pathway based on differences in the breakthrough curves of the two nonsorbing solutes. Sorption of lithium ion was deduced by comparing its response to the response of the nonsorbing tracers. Parameters for dispersion, matrix diffusion, and sorption in each major pathway were estimated by simultaneously fitting the data for all solute tracers using a semi-analytical model. The recovery of microspheres was significantly lower than that of the solutes, but a small fraction of them arrived earlier than the solutes. The sorption parameters obtained for the lithium ion were in good agreement with laboratory measurements.

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.

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: For the unsaturated zone, a test plan was being prepared and will be submitted for review (SP343TM4; 6 Jun 97); the testing program will support the development, calibration, and validation of the unsaturated zone transport process model to be asbstracted for total system performance assessment and for the license application. The southern Busted Butte area, south of the potential Yucca Mountain repository, has been recommended as a favorable site where rocks from the Calico Hills Formation are exposed.

For the saturated zone, the Project is considering several activities to assess the ability to predict sorbing tracer transport at the field scale using laboratory derived sorption parameters in conjunction with conceptual transport models for FY 1998. The effectiveness of matrix diffusion as a solute retardation mechanism and the potential for colloid transport in the saturated zone will also be evaluated. Continued testing at the C-Hole complex supports evaluation of key attributes of the draft DOE Waste Containment and Isolation Strategy that is concerned with dilution, dispersion and retardation in the saturated zone as well as development of the saturated zone

flow and transport model needed to support total system performance assessment for the viability assessment and total system performance assessment for the license application.

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.

No study plan will be developed; the scope of this study is encompassed by Study 8.3.1.2.2.6 and Activity 8.3.1.3.7.1.3; see Sections 3.1.10 and 3.2.14 of this progress report.

Forecast: Further work on this study has been deferred because of funding constraints.

3.2.17 Related International Geochemical Work

No progress occurred during the reporting period. As of November 8, 1995, the subsidiary agreements under which the cooperative work had been conducted were terminated and all international collaboration was discontinued.

The OCRWM had bilateral agreements with Canada (Atomic Energy of Canada Limited [AECL]), Switzerland (Swiss National Cooperative for the Storage of Radioactive Waste [Nagra]), and Sweden (Swedish Nuclear Fuel and Waste Management Company [SKB]) and has participated in activities of international organizations such as the Organization for Economic Cooperation and Development/Nuclear Energy Agency (OECD/NEA), European Commission (EC), and the International Atomic Energy Agency (IAEA).

3.3 ROCK CHARACTERISTICS (SCP SECTION 8.3.1.4)

The changes to the Rock Characteristics Program since the SCP was issued are summarized in Appendix A, Section A.1.3.

Symbols for the lithostratigraphic units of the Paintbrush Group exposed at Yucca Mountain (e.g., Tptpln, Tptpv3) are found in Buesch et al. (1996a).

3.3.1 Activity 8.3.1.4.1.1 - Development of an Integrated Drilling Program

The objectives of this activity are to (a) 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, and (b) integrate and prioritize surface-based activities to produce a schedule that best addresses representativeness and efficacy concerns, given resource constraints.

There will be no study plan developed for this activity.

A Daily Field Activity Report has been distributed throughout YMSCO and to NRC.

Field Work Packages are being developed for the following activities:

- C-Hole Complex Period 3 Tracer Testing
- Installation of Seismic Gauges at USW UZ-14, USW SD-7 and Large Block Test Site
- Installation of SEAMIST™ System at USW UZ-14
- Crest Borehole USW SD-6
- Surface Based Borehole Security at YMP
- Surface Based Borehole Monitoring & Testing
- Seismic Monitoring for YMP
- Borehole UE-25 WT#17 & UE-25 WT#3 Cleaning, Rehabilitation and Testing
- Borehole USW WT-24 Drilling and Testing.

Forecast: Drilling activities for FY 1997 and FY 1998 have been prioritized on the basis of the needs of the hydrology, geology and repository program. Distribution of planning documents for the following activities is expected during FY 1997:

- C-Hole Work Period 3-Tracer Testing
- Borehole Workover and Pump Testing at UE-25 WT#17 & USW WT#3
- FY 1997 Master Plan for Trench and Test Pit Reclamation.
- Flexible borehole liner installation at USW UZ-14
- Crest Borehole USW SD-6
- 2nd Crest Borehole (not yet named)
- USW WT-24 Drilling & Testing

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.

Tasks in geophysics focused on evaluating existing geophysical data through processing and modeling. Most of the emphasis was placed on the aeromagnetic data and regional seismic lines. The evaluation of the magnetic data showed that the survey was not of sufficient quality to

allow the determination of the depth to basement. Most of the information contained in the data came from shallow structures and from the lithology above the basement. After review of the seismic reflection data, an independent evaluation concluded that further processing of the data would not significantly improve the results. Modeling is in progress to assess the confidence in the current interpretations.

Records packages were organized, cataloged, reviewed, authenticated, and submitted for the following Yucca Mountain boreholes:

USW NRG-7/7A
USW SD-7
USW SD-9
USW SD-12
USW ONC#1
NRG boreholes (supplement)

Records packages for the three FY 1996 reports were organized, cataloged, reviewed, authenticated, and submitted (CRWMS M&O, 1996g, 1996h, and 1996i).

Records packages for the following Yucca Mountain boreholes remain to be completed:

UE-25 c#3
UE-25 UZ#16

Forecast: No new surface geophysical data collection is planned in FY 1997. The near-term focus will be on cataloging and storing all acquired borehole geophysical logging data for future use. Efforts will continue to integrate geophysical data with geological information and interpretations to develop an understanding of the geological framework that is consistent with the total data set. The modeling discussed in the preceding paragraph will be completed and documented in April 1997. The results will be discussed in Progress Report #17.

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.

Symbols for the lithostratigraphic units of the Paintbrush Group exposed at Yucca Mountain (e.g., Tptpln, Tptpv3) are found in Buesch et al. (1996a).

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 Group, Calico Hills Formation, Crater Flat Group, and possibly older volcanic rocks within the site area.

One of the primary purposes of this activity is to understand the lateral variations in hydrogeologic properties of various units within the Tertiary volcanic sequence. Recent techniques applied to correlate lithologic features with hydrogeologic properties, coupled with newly calculated porosity and saturation logs, have provided a means for determining the vertical and lateral continuity of potentially significant hydrogeologic layers (some of which are locally less than 1 m thick) and for correlating units across a site where only selected boreholes have been cored. Linkage of lithologic features, hydrogeologic matrix properties, and geophysical logs helps to constrain variations in matrix and bulk-rock porosity, pore-space geometry, fracture-induced porosity, and water occurrence in pore space or as structurally bound water. All these features influence the flow of moisture through the site. Some recent results of these studies were presented in Buesch et al. (1996b)

Several key findings of the studies involving correlation of lithostratigraphic and geophysical logs were described in a memorandum report submitted to YMSCO (USGS, 1997b). These findings are summarized here:

1. Hydrogeologic and thermal-mechanical unit models traditionally have relied on the spatial position of moderately to densely welded intervals to define thicknesses of altered and unaltered zones. Several formations, particularly the Tiva Canyon Tuff, Topopah Spring Tuff, and Prow Pass Tuff, have been the focus of matrix hydrogeologic properties studies, and have significantly thick sections of partially to densely welded rocks that have experienced vapor-phase alteration or corrosion and mineralization. [Note: Vapor-phase alteration or corrosion are terms intended to refer to dissolution of pumice fragments by hot vapors before moderately welded tuffs cool. Recently, the word corrosion has been used to distinguish this micro-scale process from the larger-scale formation of lithophysal cavities.] These intervals are minimally altered and characteristically have physical properties that more closely resemble crystallized and welded rock sections.

2. Contacts between vitric and crystallized boundaries (including zones of vapor-phase alteration and mineralization) in several formations commonly are marked by intervals several millimeters to several meters thick that contain clay alteration and may have hydrologic significance.

3. The contact between the Calico Hills Formation and the Prow Pass Tuff in borehole USW G-2 is an erosional-depositional contact and not a fault contact as previously interpreted. Therefore, a total thickness for the Calico Hills Formation can be derived from this borehole. This finding requires at least some modification of the geometric relation of faults beneath and parallel to Sever Wash.

4. The entire thickness of the Topopah Spring Tuff occurs in borehole UE-25 p#1. On the basis of this interpretation, no significant fault (currently shown with about 200 m of offset) is required within the uppermost part of UE-25 p#1 to juxtapose the Tiva Canyon Tuff and Topopah Spring Tuff.

5. A distinctive and abrupt decrease in density and corresponding increase in calculated porosity at the Topopah Spring Tuff crystal-poor lower nonlithophysal zone-vitric/densely welded interval contact (Tptpln-pv3) occurs commonly throughout Yucca Mountain and can be used to identify as much as several meters of intensely argillic and zeolitic rock near the top of the Tptpv3. This feature has been noted as a petrophysical zone on geophysical logs, but the occurrence of clays and zeolites at or near the Tptpln-pv3 contact has been documented previously in only a few boreholes. This interval of alteration commonly is coincident with "wash outs" in many boreholes and, therefore, its mineralogic control and lateral extent has not been previously mapped in the subsurface. In several boreholes, this alteration occurs extensively along fractures in the vitric densely welded rocks (Tptpv3). An important implication of this occurrence is that lower densities of the alteration minerals would tend to produce anonymously higher porosities, if calculated porosity models do not account for these minerals.

6. The contact between the densely welded vitric rocks near the base of the Topopah Spring Tuff and pervasively zeolitic rocks of the Calico Hills nonwelded hydrogeologic unit (CHn) (referred to as the vitric-zeolitic boundary) has been interpreted in several boreholes to occur coincident with the Tptpln-pv3 contact, based on the abundance of zeolite-filled fractures in the Tptpv3. Therefore, this contact is not exclusively confined to the CHn hydrogeologic unit as previously thought.

7. Boreholes UE-25 WT#14 and UE-25 p#1 in Midway Valley indicate that the entire section of rocks from the Tiva Canyon Tuff down to the pre-Pah Canyon bedded tuff has been eroded.

8. Several contacts indicate that bedded tuff overlies crystallized rocks of the subjacent formation. This relation indicates that the upper vitric, nonwelded to partially welded tuff was eroded before deposition of the overlying bedded tuffs. This conclusion is predicated on the assumption that rocks did not weld and crystallize to the very top of formations.

Lithostratigraphic descriptions have been provided to support several mapping activities in the southern part of the main drift and south ramp of the ESF (see Section 3.3.4 of this progress report, Activity 8.3.1.4.2.2.4). Many of these same rocks have been traversed in the north ramp and along the main drift. In support of matrix-hydrologic properties testing (Section 3.1.7 of this progress report, Activity 8.3.1.2.2.3.1), staff geologists have provided possible lithostratigraphic and structural context for the relatively systematic increases and decreases in porosity that have been documented in rocks from the middle nonlithophysal zone of the Topopah Spring Tuff (repository horizon) exposed in the main drift of the ESF. Variations in porosity might result from (a) small amounts of trapped, intergranular gas (vapor) associated with the occurrence of the lithophysae-bearing subzone of the middle nonlithophysal, even though there are no well developed macroscopic lithophysae in the main drift, (b) small amounts of trapped gas (vapor) that result from slightly different cooling regimes associated with the formation of the close-spaced high-angle fractures, or (c) microscopic fracturing associated with possible tectonic adjustments of the close-spaced, high-angle fractures.

Project geologists examined three vertical boreholes in the crown of the northern and southern Ghost Dance Fault alcoves and confirmed that the contact of the upper lithophysal (Tptpul) and middle nonlithophysal (Tptpmn) zones of the Topopah Spring Tuff is within 1 m of the contact predicted by the three-dimensional lithostratigraphic model YMP.R2.0 (Buesch et al., 1996b). Staff geologists also examined a horizontal borehole in the Northern Ghost Dance Fault Alcove to establish the location of the Ghost Dance fault. The length of this borehole was 60 m. The eastern end of the borehole extension penetrated to about 165 m east of the ESF main drift. The video log and core from the borehole indicated the main trace of the Ghost Dance fault was located approximately 154 m east of the ESF main drift; the extended boring penetrated approximately 11 m into the footwall of the fault. The hanging wall (west side) of the fault consists of an 11-m wide zone of variably broken rocks with five breccia zones and the foot wall (east side) consists of 1 m of broken rock adjacent to the main trace. This geometry of distributed fracturing is consistent with observations at the land surface. Also, projection from the surface to the alcove intercept indicates that the fault is very nearly vertical. This work will support ESF design and the air-permeability and hydrochemistry tests in the Northern and Southern Ghost Dance Fault Alcoves, respectively (Section 3.1.8 of this progress report).

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.

Evaluation of the high resolution seismic data (Majer et al., 1996) in the repository region identified no seismic reflections from the interface between Paleozoic and Tertiary units. The lack of reflections is still attributed to the combination of the small amount of energy penetrating to depth (high attenuation of the tuffs), and possibly a smaller contrast in the acoustic impedances between the Paleozoic rocks and the overlying tuffs.

The amount of offset of the Paleozoic-Cenozoic unconformity remains indeterminate, because geologic control is lacking (DOE, 1997e) and the energy sources for the shallow seismic work were not strong enough to unequivocally resolve such a deep feature. Three-dimensional gravity models are consistent with minimal offset of the unconformity beneath the repository block (comparable to surface offsets of a few meters), but data from regional seismic reflection studies (DOE, 1997e) were previously interpreted as a reflector corresponding to an offset of the unconformity of about 1500 m by the Ghost Dance fault (Brocher et al., 1996). In a meeting of the scientists on December 16, 1996, at the Lawrence Berkeley National Laboratories, it was agreed that the possible escarpment interpreted in the Paleozoic unconformity under Yucca Mountain could not possibly be the Ghost Dance fault. The orientation and geometry of this feature are not compatible with that of the Ghost Dance fault.

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.

Data in the borehole-fracture data base that was collected between 1979 and 1985 by inspecting borehole walls using borehole television cameras and later technically reviewed in 1995, was reviewed for compliance with the technical review, reformatted to a standard,

organized, and submitted to the Technical Data Base. The borehole data base includes fracture data from 23 boreholes at Yucca Mountain. Boreholes include USW G-2, USW G-4, USW H-3, USW H-4, USW H-6, USW UZ-1, USW WT-1, USW WT-10, USW WT-11, USW WT-2, USW WT-7, UE-25 C#1, UE-25 C#2, UE-25 C#3, UE-25 UZ#4, UE-25 UZ#5, UE-25 WT#14, UE-25 WT#15, UE-25 #16, UE-25 #17, UE-25 WT#18, UE-25 WT#4, UE-25 WT#6.

A comprehensive data transcription verification was completed for the digital data base of geophysical logs collected from boreholes at Yucca Mountain prior to 1991. The transcription verification relied heavily on the assessment performed in August 1995 by the Borehole Geophysical Data Technical Assessment Committee (see Activity 8.3.1.4.2.1.3 in Section 3.3.3 of Progress Report #15). Two methods were used to perform the transcription verification. The first method consisted of six steps: (1) locate the original field copies of the borehole geophysical logs; (2) sort logs based on type, time, and run; (3) identify those logs used in the data base; (4) review the pattern of each trace throughout its length; (5) measure and compare selected point values from the image files, the original field prints, and the digital data; and (6) document the results of the transcription verification on review sheets for each borehole. The second method was applied only to logs that had a linear horizontal scale and involved use of a FORTRAN program and scale-manipulation tools of AutoCad to scale digital data from the data base back to the original scale of the field prints. Once properly scaled, the generated log traces were overlain onto the original field prints to make direct comparisons. Inconsistencies between the original field prints and the information in the data base were rare. Of about 400 log intervals of 41 boreholes checked, only 6 log intervals did not match the data base. These included two epithermal neutron porosity logs of UE-25 a#4, an electric log of UE-25 b#1, a caliper log of USW UZ-6, a dielectric log of UE-25 WT#17, and a gamma ray log of USW VH-1. However, only the log from UE-25 WT#17 had been used to calculate porosity and water content.

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 the 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.

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

Forecast: Stratigraphic information will be provided for continued development of the three-dimensional, geologic-framework model. This activity will consist of continued correlation of lithostratigraphic features, borehole geophysics, and borehole video logs for the 32 lithostratigraphic contacts in 100 boreholes that are used in the 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.

Symbols for the lithostratigraphic units of the Paintbrush Group exposed at Yucca Mountain (e.g., Tptpll, Tptpmn) are found in Buesch et al. (1996a).

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.

Field checking and revision of a preliminary site area map at 1:24,000-scale was initiated. The site area coincides with the area encompassed by the three-dimensional geologic framework computer model, version ISM2.0 (see Section 3.3.5 of this progress report). The study area extends from approximately the Prow of Yucca Mountain on the north to Busted Butte on the south, and from Windy Wash on the west to Fortymile Wash on the east. The new mapping effort concentrates on areas that may hold keys to both the structural and stratigraphic development of Yucca Mountain. Areas mapped in detail during the reporting period include Busted Butte, Fran Ridge, Alice Point, Dune Wash, UE-25 WT#12 basin, Iron Ridge, Crater Flat, upper Black Glass Canyon, upper Fortymile Wash, upper Yucca Wash, upper Teacup Wash, upper Fatigue Wash, Castellated Ridge, and the Prow.

The new mapping is delineating the structural complexities associated with both the hanging wall and footwall deformation associated with the major block-bounding faults, such as the Solitario Canyon, Fatigue Wash, Windy Wash, and Iron Ridge faults. These well known north-trending, block-bounding faults often are linked together by northwest-trending "relay" faults and associated structures that act to disperse the regional tectonic strain across several of the faults. Relay faults at Yucca Mountain are northwest-striking faults that intersect north-striking block-bounding faults and transfer displacement between two block-bounding faults. Relay faults provide a kinematic link between adjacent block-bounding faults. The block-bounding faults generally are west-dipping, down-to-the-west fault zones with numerous secondary faults that separate large blocks of east-dipping volcanic strata. Previous workers recognized that within the fault zones there are west-dipping structural panels. Because the trailing edges of the hanging walls of the north-trending block-bounding faults are commonly intensely faulted and more easily eroded than adjacent rock, they are buried in the wash bottoms. However, the new mapping has better defined the footwall (eastern margin of the fault zones) deformation.

In general mapping associated with the FY 1996 central block map (Day et al., in press), as well as the current FY 1997 mapping campaign for the site map, has revealed that numerous intrablock faults, such as the Ghost Dance Fault, the Abandoned Wash Fault, and the Busted Butte Fault, are narrow zones at depth that "horsetail" toward the surface into a series of bifurcating faults. The new mapping has shown that this same pattern also exists for the block-bounding faults. The block-bounding fault zones are west-dipping, upward-widening zones with

dips that vary from relatively shallow (45-50°) to relatively steep (75-85°). The total offset associated with the block bounding faults is a combination of down-to-the-west normal faulting and sinistral strike-slip motion, resulting in a net oblique-slip motion down to the southwest. In response to this oblique-slip motion, northwest-striking fault segments are the sites of releasing bends, commonly characterized by a gentler overall fault dip and a dramatic increase in the number of secondary normal faults preserved in the footwall. Northeast-striking fault segments are the sites of restraining bends, and are characterized by overall steeper, narrower fault zone that locally exhibit high-angle reverse faults.

The importance of this fundamental understanding of the fault geometry can be applied directly when trying to understand the amount of footwall deformation associated with the Solitario Canyon fault, which bounds the western margin of the repository area. The deformation within the footwall of the Solitario Canyon fault varies greatly, albeit systematically, along its trace. The footwall contains areas with relatively high and relatively moderate amounts of rock damage and associated fracturing along its trace. Further, fracturing of the footwall rock mass increases near the northwest-trending relay faults (south of the repository area). The bulk permeability should increase in the rock mass adjacent to and within these areas of high amounts of deformation. This higher bulk permeability might significantly affect the amount of percolation flux at the repository depths, as well as the coherency of the rock mass.

In addition to the more general question of the geometry of faults at Yucca Mountain, the new bedrock geologic mapping has delineated the structural complexities associated with the Dune Wash graben. The Dune Wash graben is a northwest-trending structure bounded on the east side by the down-to-the-west, block-bounding Dune Wash fault. The western margin of the graben is bounded by a down-to-the-east block-bounding fault zone with at least 122 m of down-to-the-east displacement, which is equal to or greater than that of the more widely known Dune Wash fault. The down-to-the-east fault zone is approximately 100 m wide and consists of tectonically brecciated and juxtaposed units of the Topopah Spring Tuff. Areas within the fault zone exhibit higher degrees of oxidation and alteration, as well as silicification, relative to other faults in the vicinity. This fault zone splays to the south into several faults with down-to-the-east displacement southwest of borehole UE-25 WT#17. The splays each have more than 33 m of displacement. Within the interior of the graben are numerous smaller horst-and-graben structural blocks with strata dipping dominantly to the east. The interior of the graben is highly complex with numerous, discontinuous, steeply dipping faults. The northern end of the Dune Wash graben dies out just south of Abandoned Wash (south of borehole USW WT-1). The deformation within the graben merges with that typical of hanging wall deformation associated with the Dune Wash fault. This style of hanging wall deformation associated with block-bounding faults is similar to that on the Bow Ridge and Solitario Canyon faults inasmuch as the dips of the strata increase, or roll over, into the block-bounding faults. The southern end of the Dune Wash graben, which is buried beneath Quaternary deposits southwest of Busted Butte, seems to terminate against the down-to-the-west Paintbrush Canyon fault.

As well as the structural insights gained, the new mapping has placed important constraints on the stratigraphic and regional tectonic history of Yucca Mountain. Mapping of areas containing the Rainier Mesa Tuff in Dune Wash and Solitario Canyon (Plug Hill) has revealed that the angular unconformity between the 12.7 million-year-old Tiva Canyon Tuff and

the 11.45 million-year-old Rainier Mesa Tuff is relatively minor. There is no evidence to support a major angular unconformity at the top of the Tiva Canyon Tuff at Plug Hill. Flattening foliations within the Tiva Canyon Tuff dip at about 12 degrees to the east, which is similar in magnitude to the dip of the welding contact in the overlying Rainier Mesa. This is contrary to mapping by Scott and Bonk (1984) who depicted the basal contact of the Rainier Mesa Tuff as wrapping around and down cutting into the top of the Tiva Canyon Tuff, which implies a significant amount of erosion and post-Tiva Canyon Tuff, pre-Rainier Mesa Tuff regional deformation. The "down cutting" depicted by Scott and Bonk (1984) is simply a down-to-the-southwest fault that cuts the Tiva Canyon and Rainier Mesa tuffs, with the same amount of relative offset of units within each formation. Therefore, there is no significant amount of erosion at this contact.

There is a 5- to 8-degree structural unconformity at the base of the Rainier Mesa Tuff in the exposures at the south end of Dune Wash. There, an erosional unconformity between a bedded tuff and the top of the Tiva Canyon Tuff is exposed. These two units have the same dips, which implies there was no significant deformation between the deposition of these two units. Above the bedded tuff lies a nonwelded massive horizon of the Rainier Mesa Tuff, and there is a 5- to 8-degree structural discordance in their dips. Therefore, there was a modest amount of regional structural deformation that post-dated deposition of the Tiva Canyon Tuff but pre-dated that of the Rainier Mesa Tuff in the southern end of the Dune Wash graben.

Study of Fracturing Related to Faulting at Busted Butte

Collection of fault and fracture data (orientation, length, termination, aperture characteristics, etc.) has been initiated along the south side of Busted Butte as part of a detailed study of the interaction between faulting and fracturing associated with block-bounding faults, as well as to supplement ongoing site fracture studies. Fracture data have been collected in parts of the lower vitric section of the Tiva Canyon Tuff, the undifferentiated bedded tuffs underlying the Tiva Canyon Tuff, and the crystal-rich and upper lithophysal units of the Topopah Spring Tuff from the hanging wall of the major fault cutting Busted Butte. Sketch mapping and drawing of preliminary cross sections of the major fault have begun, with detailed mapping to commence following receipt of detailed orthophotographic base maps from the technical data base. Preliminary cross sections through Busted Butte were prepared, and a spreadsheet was formatted to store the fracture data. Data analysis began with various stereographic projections and rose diagrams of the fracture-orientation measurements and histogram analysis of other parameters.

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 potential hydrologic 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.

A report has been prepared that integrates all quality-assured fracture data from surface studies, the ESF, and from boreholes (Sweetkind et al., 1997). These data have been compiled, integrated and interpreted to define fracture characteristics of each model layer within the site-scale, three-dimensional, unsaturated-zone flow model (see Section 3.1.13 of this progress

report). Only a very limited amount of non-quality-assured data from boreholes (USW G-1, USW G-3/GU-3, and USW G-4) was used in this analysis. These borehole fracture data were selected for comparison with the quality-assured fracture data because (1) both television logs and core data are available for these boreholes, (2) these boreholes penetrate lithostratigraphic units equivalent to almost all of the model units in the site-scale unsaturated zone flow model, and (3) these data are readily available in published form. Preliminary comparison of the various data sets reveals general correspondence between various data collection methods and highlights the importance of lithostratigraphic controls, such as degree of welding, on fracture character. These integrated field data also are a critical part of the calculation of input parameters to three-dimensional fracture-network models, including number of fracture sets, mean orientation of each set, and dispersion about the mean; fracture trace-length distribution; a measure of fracture intensity; and a spatial model of fracture-network geometry (Sweetkind et al., in press).

In support of hydrologic models of the unsaturated zone at Yucca Mountain, new fracture data have been collected from the zeolitized rocks of the Calico Hills Formation from surface outcrops and borehole television logs. Surface fracture data consist of about 260 measured discontinuities from outcrops in the Prow Pass area to the northwest of Yucca Mountain. An additional 40 discontinuities were identified from borehole television logs from wells near the potential repository. Surface and subsurface data reveal the presence of two principal fracture sets, a prominent northwest-striking set and a slightly less well-developed northeast striking set. Perhaps the most important fracture characteristic within the zeolitized Calico Hills Formation is that joints appear to occur in zones. This characteristic was observed in the vicinity of Prow Pass where the northwest-striking joints occur in widely spaced northwest-trending zones. Each zone consists of a number of northwest-striking joints that are typically large (5 to 10 m long) and closely spaced (0.5 to 1 m). These northwest-trending zones are spaced from 50 to more than 100 m apart; in between the zones the spacing of the northwest-striking joints is 2 to 4 m or more. A zone of northeast-striking joints is present in borehole USW UZ-14 at a depth of 1477 to 1500 ft (450 to 457 m). These joints appear to be large (in many instances being continuous for 1.5 m or more within the hole), and have true spacing (corrected for the intercept angle between the borehole and the fracture set) of between 0.3 and 0.6 m. No evidence for a closely spaced zone of joints was found in either borehole USW SD-7 or USW SD-12.

Fracture data also are being used to evaluate the structural significance and characterize the possible hydrologic pathways used by water that has carried chlorine-36 from weapons testing to sample locations in the north ramp and main drift of the ESF (see Section 3.1.6 of this progress report).

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.

Work under this activity is being conducted in conjunction with the surface-fracture network studies, Activity 8.3.1.4.2.2.2.

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.

Mapping continued in the ESF south ramp, the Thermal Testing Facility, and the Northern Ghost Dance Fault Alcove. Progress for the individual components of the underground mapping are as follows:

South Ramp:

- Stereophotography completed to Station 72 + 08 (7208 m)
- Full-periphery geologic maps completed to Station 72 + 10 (7210 m)
- Detailed line surveys completed to Station 72 + 07 (7207 m)
- Calculation of Rock Quality Designation (RQD) completed to Station 71 + 22 (7122 m)
- Calculation of rock-quality (Q) and rock-mass-rating (RMR) coefficient completed to Station 70 + 55 (7055 m).

Thermal Test Facility:

- Stereophotography, full-periphery geologic maps, and detailed line surveys completed within the facility.

Northern Ghost Dance Fault Alcove:

- Stereophotography, full-periphery geologic maps, and detailed line surveys completed to Station 1 + 30 (130 m).

Geology of the North Ramp—Station 4 + 00 to 28 + 00. A report has been completed that describes the results of structural and stratigraphic studies of the various lithologies exposed in the ESF north ramp (D. L. Barr et al., 1996). The rock units penetrated by the ESF tunnel along the north ramp include the pre-Rainier Mesa Tuff, Tuff "x," Tiva Canyon Tuff, Yucca Mountain Tuff and Pah Canyon Tuff and associated bedded tuffs, upper Topopah Spring Tuff, and the crystal-rich, middle nonlithophysal zone of the Topopah Spring Tuff, which is the host rock for the potential repository. Included in the report are summary descriptions of lithostratigraphic units, statistical analyses of 3735 fractures measured during geologic mapping, detailed line surveying, an analysis of the geotechnical and engineering characteristics of the tunnel, Upper Paintbrush Tuff Contact Alcove, and the Lower Paintbrush Tuff Contact Alcove.

The exposures in the north ramp, Upper Paintbrush Contact Alcove, and Lower Paintbrush Contact Alcove clarified and confirmed several lithostratigraphic relationships that were

previously inferred from studies of drill core, downhole video, and hydrologic properties. In particular, intervals of intense vapor-phase alteration, unusually large lithophysal cavities, and quartz-latite pumice blocks that were described in borehole logs of the Topopah Spring Tuff were shown to have stratigraphic significance in north-ramp exposures (D. L. Barr et al., 1996). The report outlined a preliminary geologic history for a localized zone of degassing and intense vapor-phase alteration that was exposed at the top of the pumice-fall deposits that overlie the Topopah Spring ignimbrite. Exposures of the disrupted distal edge of the Yucca Mountain Tuff and the zeolitically altered lower portion of the Pah Canyon Tuff were also described.

The fracture network from Station 4 + 00 (400 m) to Station 21 + 87 (2187 m) in the north ramp was divided into three structural sets using cluster analysis. The first set was composed of east-west-striking cooling fractures that occur primarily in the Tiva Canyon Tuff and Topopah Spring Tuff. A second set, which occurs in all geologic units, had fractures with north-south strikes and steep, westward dips that represent the dominant tectonic fracture direction. A third set of fractures comprised shallowly dipping, subhorizontal features, such as vapor-phase partings, that occur mostly in the Tiva Canyon Tuff and Topopah Spring Tuff. These fracture sets were less clearly defined from Station 21 + 87 (2187 m) to Station 28 + 00 (2800 m) where the tunnel orientation changes in the turn from the north ramp to the main drift.

Maximum-variance, principal-component analysis of the detailed line survey data set indicated that fracture length and/or maximum aperture could be used to characterize these tuff units. Factor scores were used to divide the tunnel into eight distinct zones, seven of which correspond to lithologic contacts or welding breaks. The analysis less clearly defined four additional boundaries, two of which correspond to lithologic contacts and one that occurred at a break in vapor-phase alteration.

Geotechnical characterization of the ESF north ramp focused primarily on rock-mass quality and rock-mass mechanical properties. Descriptions are based on two empirical rock-mass classification systems, rock quality (Q system) and rock-mass rating. Data on rock quality (Q) and rock-mass rating were used to divide the north ramp of the ESF into ten sections of variable length, each of which was defined using geotechnical characteristics. The section with the highest average ratings is located from Station 7 + 95 (795 m) to Station 8 + 80 (880 m). This section, which consists of the nonwelded to partly welded, crystal-poor vitric zone of the Tiva Canyon Tuff and underlying pre-Tiva Canyon Tuff bedded tuff, has an average Q value of 30 and an average rock-mass rating value of 75, both of which are designated as "good." The section with the poorest average ratings is located from Station 10 + 70 (1070 m) to Station 11 + 80 (1180 m). This section, which consists of a faulted zone of the Topopah Spring Tuff crystal-rich vitrophyre, has an average Q value of 1.2 and an average rock-mass rating value of 55, which were designated as poor and fair, respectively.

Geology of the Main Drift—Station 28 + 00 to 55 + 00. A report (Albin et al., 1997) describes the results of structural and stratigraphic studies of the ESF main drift. The main drift is excavated almost entirely within the Tptpmn with only small exposures of the underlying Tptpll beyond Station 53 + 00 (5300 m). The comparison of the pre-construction geologic cross section of the main drift and the as-built geologic cross section shows strong agreement between the geology predicted and that encountered. The discontinuities (faults, joints, shears, and

fractures) were divided into four sets on the basis of orientation, with a significant number of random orientations. Three of the sets occur throughout the ESF main drift, but the fourth set occurs only between Station 28 + 00 (2800 m) and Station 37 + 00 (3700 m). Set 1 was by far the most prominent, consisting of discontinuities striking generally between 100° and 150° and dipping 70° or more southwest. Set 2 consisted of discontinuities striking between 200° and 230° and dipping 70° or more northwest. Set 3 consisted of discontinuities striking between 280° and 330° and dipping less than 40° northeast. Set 4 consisted of discontinuities striking between 270° to 330° (similar to Sets 1 and 3), and dipping between 40° to 60° northeast (intermediate between Sets 1 and 2).

The ESF main drift was divided into four domains on the basis of structural characteristics. The first domain, extending from Station 28 + 00 (2800 m) to Station 37 + 00 (3700 m), was the only domain in which Set 4 fractures were found in significant numbers. In the second domain, Sets 1, 2, and 3 were well defined with relatively few random fractures. The third domain was defined by the intensely fractured zone that extends from Station 42 + 00 (4200 m) and to Station 51 + 50 (5150 m) and is dominated by Set 1 fractures. The fourth domain, from Station 51 + 50 (5150 m) to Station 55 + 00 (5500 m), consists predominantly of Set 1 and Set 2 fractures and has a high density of Set 1 and Set 2 faults and shears. Cluster analysis (using the computer program Clustran) also was performed and resulted in four sets of discontinuities. Three of the sets were in general agreement with the sets identified through other analytical methods. The fourth set (Set 4) was identified by cluster analysis. The two main differences between the cluster analysis and the other methods used are: (1) Clustran groups all the discontinuities into the four sets without a "random" category and (2) the sets identified by cluster analysis include a wider range of orientations both in terms of strike and dip.

Maximum-variance, principal-component analysis also was performed on the main drift detailed line survey data. The analysis indicated that the most useful parameters for characterizing the crystal-poor, middle nonlithophysal zone of the Topopah Spring Tuff (repository horizon) are maximum aperture, followed by infilling thickness and fracture length. A two-factor solution was obtained. Factor 1 scores are a function of infilling thickness, maximum aperture, and fracture length. Factor 2 scores are a function of fracture dip and minimum aperture. Both factor 1 and 2 scores were used to identify significant structural heterogeneities within the ESF main drift. Statistical correlations between strike and factor scores identified strike ranges with similar characteristics.

Geotechnical characterization of the main drift focused primarily on rock-mass quality and rock-mass mechanical properties. The averages of all the rating systems yield ratings of poor to fair for all of the main drift. The average rock quality ratings are fair in the first domain, and then generally decrease to poor southward in the main drift.

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.

Interpretation of the amount, style, depth, and continuity of faulting in the proposed repository volume were continued using previously collected geophysical data. The most closely examined area was in the vicinity of the Ghost Dance fault. Evaluation of data from vertical seismic profile, surface seismic, gravity, ground magnetic, and magnetotelluric surveys (Majer et al., 1996) continued. Continued interpretation of the high resolution seismic data (Majer et al., 1996) in the repository region identified no seismic reflections from the interface between Paleozoic and Tertiary units. The amount of offset of the Paleozoic-Cenozoic unconformity remains indeterminate, since geologic control from drilling has not been established. Furthermore, the energy sources for the shallow seismic work were not strong enough to unequivocally resolve such a deep feature. In addition, three-dimensional gravity models remain consistent with minimal offset of the unconformity beneath the repository block (comparable to surface offsets of a few meters).

The results of the regional geophysical surveys (Brocher et al., 1996) continue to indicate that in this area the faulting is a classic example of steeply dipping Basin and Range extensional faulting with cross-cutting faults intersecting the normal faulting. Interpretation of data from regional seismic reflection studies were previously interpreted [see Section 3.3.3 of Progress Report #15 (DOE, 1997e)] as a reflector corresponding to an offset of the unconformity of about 1500 m by the Ghost Dance fault. In a meeting of the scientists on December 16, 1996, at the Lawrence Berkeley National Laboratories, it was agreed that the possible escarpment interpreted in the Paleozoic unconformity under Yucca Mountain could not possibly be the Ghost Dance fault. The orientation and geometry of this feature are not compatible with that of the Ghost Dance fault.

Interpretation of data from surface and borehole velocity studies across Yucca Mountain continue to indicate that in addition to local heterogeneity, a general trend of increasing seismic velocity exists from north to south. This trend continues to imply increasing porosity to the north.

Forecast: Scheduled work includes the initial field work, compilation of the linework gained by the field work, digitization of the lines and symbols (strike and dips, lineations, breccia symbols, etc.), development of the underlying topographic coverage, and preparing a report that contains an overview of the geology and structural history of Yucca Mountain and rock-unit descriptions. Geologic mapping of the remaining part of the site area at 1:24,000-scale probably will be completed by May 1997. The cartography, symbols, digitization, and compilation of the topographic coverages for the geologic map probably will be completed by mid-June; writing of the report will begin in April.

Geophysical work during the remainder of FY 1997 will focus on synthesis and modeling. This work will include the depth-to-magnetic-basement work and the final evaluation of the surface seismic data from both the repository and regional lines (Majer et al., 1996; Brocher et al., 1996, respectively). The significance of alternative interpretations of the amount of offset of the Paleozoic surface at depth will be further evaluated. In particular, the need for additional control from deep drilling will be evaluated. Documentation will be complete in April 1997. The results will be discussed in Progress Report #17. Beginning in the next reporting period,

seismic tomography data that have already been collected from UE-25 UZ#16 will be reprocessed.

In fracture studies, evaluation of the structural significance of sample locations in the ESF that show chlorine-36 from weapons testing will continue (see Section 3.1.5 of this progress report). Activities will include evaluating sample localities along the south ramp of the ESF, evaluating possible influence of fracture orientation on preferred flow paths, and further evaluation of the interplay between structural features and spatially distributed percolation.

In the ESF mapping activity, Project geologists expect to accomplish the following during the second half of FY 1997: (1) complete mapping of the ESF south ramp including full-periphery geologic mapping, detailed line survey, stereophotography, and rock-mass classification; and (2) complete mapping of the Northern and Southern Ghost Dance Fault Alcoves. In addition, a report will be prepared on the geology of the ESF south ramp, including results of stratigraphic and structural studies similar to those documented for the ESF north ramp and main drift.

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 to serve as a framework for subsequent rock properties, mineralogic, hydrologic, flow, and transport models. Additionally, rock properties and mineralogic models are integrated into the geologic framework to form an Integrated Site Model (ISM). Model development involves synthesis of the results of other geologic and geophysical studies.

The three-dimensional geologic framework and integrated site model of Yucca Mountain, version ISM2.0, was completed along with a report (CRWMS M&O, 1997a). The geologic framework used the results of geologic mapping; borehole and outcrop data including lithologic logs, measured sections, and geologic maps; surface geophysics; borehole geophysics; and ESF studies. Lithostratigraphic horizons included in the framework were determined from discussions with model users, including those modeling rock properties, unsaturated zone hydrology, mineralogy, radionuclide transport, and performance assessment. Forty-four faults were included in ISM2.0. All fault geometries (including dips) were formulated through extensive workshops and iteration with geologists. The framework model covers the site area from the topographic surface down to the top of the Paleozoic section and includes 34 lithostratigraphic horizons. The top of the Paleozoic was selected after evaluation of two interpretations: those of Majer et al. (1996) and Brocher et al. (1996). Majer's interpretation was selected based on its ability to provide the best fit to various geologic and geophysical data and was considered detailed enough to meet the needs of the users of the model. Three-dimensional mineralogic and rock properties models were integrated into the geologic framework to form the integrated site model. Modeled rock properties include bulk porosity, thermal conductivity, matrix porosity, density, and hydraulic conductivity in the Tiva Canyon Tuff, Yucca Mountain Tuff, Pah Canyon Tuff, Topopah Spring Tuff, Calico Hills Formation, and Prow Pass Tuff (see Section 3.3.6). Modeled mineral abundances include zeolites, crystobalite, trydimite, and smectite.

Forecast: Work will continue to support model users. The three-dimensional integrated site model (version ISM3.0) will be developed. Additional geophysical data will be synthesized to be incorporated in the geologic framework, including seismic reflection profiles and magnetic interpretations. Work will focus on supporting other modeling activities, providing model products for use in management decisions and other Project activities, and compiling new information and revising old information to construct version ISM3.0. Key elements to be incorporated into version ISM3.0 include the site area geologic map, final ESF geologic mapping, and revised borehole lithostratigraphic contacts. New boreholes will be used both to evaluate version ISM2.0 and to construct version ISM3.0.

3.3.6 Study 8.3.1.4.3.1 - Systematic Acquisition of Site-Specific Subsurface Information

The objective of this study is to systematically acquire physical rock samples, analytical data, and basic descriptions of the subsurface geology of the repository site. 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 objective of the Systematic Drilling Program is to acquire rock samples, analytical data, and basic descriptions of the subsurface geology of the potential repository block for characterizing and evaluating the three-dimensional distribution of rock characteristics, and hydrological and geochemical variables. Core samples taken from selected drillholes provide information related to the design of the exploratory studies facility main test level and relevant geologic information required for understanding the deeper portions of the repository block.

No drilling or other field-based site characterization activities were conducted under this study during the reporting period.

Two comprehensive data reports describing the geology of the USW SD-7 (Rautman and Engstrom, 1996a), and USW SD-12 (Rautman and Engstrom, 1996b) drillholes were published and issued. These reports describe (a) geology, quantitative and semiquantitative information on fractures, lithophysae, core recovery, and rock-quality measurements; (b) framework bulk and hydrologic properties; (c) geophysical well logs; and (d) x-ray diffraction mineralogic data. The report for drillhole USW SD-9 (Engstrom and Rautman, 1996) has been revised to incorporate minor editorial and format changes. The content of this drillhole report is the same as that for the reports on drillholes USW SD-7 and USW SD-12 (Rautman and Engstrom, 1996a and b).

Work products were provided to support several data synthesis reports and performance assessment analyses.

Forecast: Borehole USW SD-6 is planned to be drilled during the next fiscal year. Additional data collected will be integrated into the assessment of the Systematic Drilling Program.

3.3.7 Study 8.3.1.4.3.2 - Three-Dimensional Rock Characteristics Models

The objective of this study is to produce numerical models of rock 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 the 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.

The rock properties models described in Progress Report #15 (DOE, 1997e) and incorporated into the Integrated Site Model, version 1.0, have been completely regenerated for ISM 2.0 (see Section 3.3.5 of this progress report) to incorporate additional conditioning data not previously available. In addition, secondary property models were generated using the expanded data base, and a modestly revised version of the linear coregionalization algorithm. The following secondary property models are now available for the entire Yucca Mountain extended site area:

For the upper PTn model unit (nominal 250 × 250 × 2-m grid spacing):

- porosity
- bulk density
- saturated hydraulic conductivity.

For the TSw model unit (including the repository horizon; nominal 250 × 250 × 10-m grid spacing):

- matrix porosity (excludes effect of lithophysae)
- lithophysal porosity (includes effect of lithophysae where present)
- bulk density
- thermal conductivity
- saturated hydraulic conductivity.

For the combined Calico Hills-Prow Pass (CH-PP) model unit (nominal 250 × 250 × 10-m grid spacing):

- porosity
- bulk density
- alteration category ("zeolitic" versus unaltered)
- saturated hydraulic conductivity.

Uncertainty estimates were also generated this fiscal year for all material properties models (except bulk density), and these were included in the ISM 2.0 release.

The new data incorporated in the ISM 2.0 release models were essentially all computed porosity values derived from processing borehole geophysical measurements. Geophysical logs from almost all "older" (pre-1986) drillholes have now been converted to computed porosity values (Nelson, 1996); the holes included were the G- and H-series (8 drillholes) in addition to the previously available WT-series holes. Computed porosity values are now also available for the entire suite of "modern" (site characterization) boreholes (CRWMS M&O, 1996h).

Several "old" drillholes (USW G-2, USW WT-2, USW WT-10, and USW WT-12) were relogged using modern geophysical tools. The data from relogging provided some quantitative correlation of porosity values between logging methods. Other new data consist of direct mineralogic indicators of zeolite alteration incorporated into the indicator modeling of rock type for the Calico Hills-Prow Pass combined stratigraphic unit (Chipera et al., 1996).

The creation of the rock property models for ISM 2.0 followed essentially the same process outlined in Progress Report #15 (DOE, 1997e). Porosity data were compiled, and the measured values were associated with stratigraphic coordinates for each of the three model units. "Stratigraphic coordinates" attempt to place the conditioning data values back into their original depositional position within a rock unit by measuring positions relative to the base (or top) of the model unit. Differences in "total" porosity and "water-filled" porosity were used to identify intervals within the Calico Hills-Prow Pass stratigraphic interval that are likely to have been zeolitized; these altered intervals were coded using indicator flags (ones and zeros). Horizon-specific mineralogic data for drillholes USW SD-7, USW SD-9, and USW SD-12 (Chipera et al., 1996) were incorporated directly at the appropriate stratigraphic elevations.

Spatial correlation patterns were then quantified by computing experimental variograms (separately for each model unit) in different directions. Spatial correlation for porosity is strongly anisotropic vertically, as is expected for layered rock sequences. Nested three-dimensional anisotropic variogram models exhibited at least two, and more frequently three, different ranges of spatial continuity. Correlation patterns for the altered-unaltered indicator categories are also strongly anisotropic.

These variogram models and the conditioning data served as input to the geostatistical modeling algorithms. Sequential gaussian simulation was used to generate 100 replicate, statistically indistinguishable, plausible models of porosity for each of the three model units. These simulated models reproduce the measured data at data locations (subject to discretization limits), the overall distribution of relevant porosity values (histograms), and approximate the variograms exhibited by the data. Where there were departures of the input modeled variogram from the variogram of the completed property model, the departures were observed to be more like the original experimental spatial continuity pattern. Modeling of the zeolitic and non-zeolitic lithologies within the Calico Hills-Prow Pass combined interval used sequential indicator simulation in the categorical mode.

Forecast: Most of the remainder of FY 1997 will be dedicated to completing and closing out the scientific notebook associated with the modeling for ISM 2.0. A comprehensive report describing the modeling activities, the data used, and the resulting three-dimensional models is currently being prepared.

Future rock-properties modeling in support of revisions to ISM 2.0 will most likely be focused on specific problems, rather than generalized revisions to the gross distribution of properties throughout the extended site area. Specifically, evaluation of porosity data from the PTn model unit during the data compilation stage early in the reporting period identified the presence of some form of hydrous-mineral alteration at particular stratigraphic levels within the PTn. Given the high relative structural position of the PTn unit in most locations with respect to the present and former water tables, it seems most likely that this hydrous-phase alteration involves montmorillonitic clays, rather than zeolites as in the Calico Hills-Prow Pass interval. Although the presence of clay alteration has been noted previously in and adjacent to this stratigraphic interval (e.g., Buesch et al., 1996b), the influence of such alteration on hydrologic properties in predictive modeling has not been addressed systematically.

A second topic of focused modeling activity is likely to be the production of a quantitative model of fracturing within the site. Fractures are important both as potential fast flow paths and as flow barriers within the unsaturated zone because of capillary effects between matrix pores and the "pores" formed by fracture apertures. Other modeling will likely be of smaller volumetric scope and related directly to specific performance assessment needs.

3.4 CLIMATE (SCP SECTION 8.3.1.5)

Changes to the Climate Program since the SCP was issued are summarized in Appendix A, Section A.1.4.

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 for an analysis and interpretation of isotopic data from modern precipitation to provide an understanding of its seasonal and spatial variability.

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

Forecast: No activity is planned for this study during FY 1997.

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, 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.

Activity-level descriptions for this study have been combined because they are so closely interrelated. The results of this study are being integrated with the results of Study 8.3.1.5.1.3 (Section 3.4.3 of this progress report). Results of both studies are being synthesized under Study 8.3.1.5.1.5 (Section 3.4.5 of this progress report).

The higher resolution analysis of Owens Lake diatom and ostracode stratigraphy at Owens Lake, California, was nearly completed. Approximately 450 new diatom samples from about 1000 total and about 600 new ostracode samples from about 1400 total have been added to the data set. Paleolimnologic and paleoclimatic data from this record now extend back to 500 ka, with a 500-year resolution between 200 and 0 ka and a 750-year resolution between 500 and 200 ka. The results from both the diatom and ostracode high-resolution records indicate that limno-climatic changes at Owens Lake were extremely rapid; the lake often varied between a full and overflowing, freshwater system and a closed, saline or even dry system in less than a millennium. Such short-term, rapid changes are more characteristic of interglacial and transitional periods than of glacial periods. Core and sample coverage exists to further refine and document the transition time between specific climate modes at Owens Lake.

The distribution of freshwater planktic diatoms, which prosper in the late summer, have been interpreted to indicate increased late summer precipitation in the Owens Lake area (Bradbury, in press). Summer precipitation preferentially occurred during transitions between glacial and interglacial periods, presumably when maximal summer insolation produced strong thermal gradients between the Subtropical High and Great Basin Low to deliver precipitation from the eastern Pacific Ocean to the region. Summer precipitation in the Owens Lake and Yucca Mountain area may have distinctive geomorphic and infiltration consequences compared with past intervals of increased winter precipitation.

The principal new ostracode data come from samples of cores at the top of the stratigraphic section. The distribution of ostracodes in those cores dating from about 55 ka through the Holocene (10 ka to present) show very rapid (decadal) shifts from dry climates like those of today to brief periods of warm but wet climates probably supported by summer rain. The appearance of full glacial climate (25 ka) was also rapid, but this condition persisted for several millennia. Full glacial climate was characterized by precipitation levels well above those of today and by mean annual air temperatures well below those of today.

The aquatic microfossil data from Owens Lake and elsewhere are now being integrated into climate scenarios. Discussions with climatologists from Scripps Institute of Oceanography, La Jolla, California, have provided modern climate scenarios that might be partial modern analogs for summer precipitation regimes in the Owens Lake area. Information also has been assembled that provides insights into surface- and ground-water sources available for the lake in different climates. The integration of aquatic microfossil records of past seasonal climatic conditions with site specific records of past vegetation [packrat (*Neotoma sp.*) middens] and past hydrology (paleodischarge deposits) will document a broader range of paleoenvironmental scenarios for Yucca Mountain. These scenarios will provide a basis for forecasting future

climate and actual boundary conditions suited for input to the hydrologic models designed to evaluate the performance of the potential repository.

Comparison of the Owens Lake record with other lacustrine records has supported and extended paleoclimatic interpretations for the Great Basin. For example, a comparison of glacial and interglacial climates at Owens Lake (36°N) with those at Tule Lake (42°N) indicates that wet, glacial climates at Owens Lake correspond to dry glacial climates at Tule Lake, reflecting the southern displacement of storm tracks by the Cordilleran and Laurentide ice sheets. Interglacial climates at these sites are also antithetical; dry at Owens Lake, but wet at Tule Lake (Smith et al., 1997). This comparison helps to place the Owens Lake record within the context of hemispheric climate change that has been explored by global climate models and the integration of paleoclimate information derived from pollen analysis in western North America.

A comparison of the Owens Lake record with the uranium-series-dated record at Death Valley, California, shows correlative changes of the past hydrologic balance at both sites. This correlation helps support the extrapolated Owens Lake chronology: a long and very wet penultimate glacial period and increased summer precipitation during periods of transition between glacial and interglacial climates. During the penultimate glacial period, both Owens Lake and Death Valley contained large lakes that persisted for much of about 40 k years, punctuated by drier periods of one to three millennia. Surprisingly, lakes persisted in both Death Valley and at Owens Lake at the beginning of the last interglacial (130 ka) when marine records suggest minimal glacial ice (less than today) and high sea-level stands. The persistence of lacustrine conditions in the southern Great Basin in early interglacial climates may reflect summer precipitation derived from the eastern Pacific Ocean. The new data suggest that in the last interglacial summer precipitation was extensive enough to both maintain runoff and become recharge.

During the reporting period, ostracode data collection was completed for sites in the Las Vegas and the Indian Springs Valleys. The existing data set is composed of about 650 samples from three principal stratigraphic sections. Ostracode subsamples are now being collected for stable isotope analyzes. Existing stable-isotope and ostracode data suggest that the wetlands were supported by winter precipitation and probably were through-flow systems. The kinds of ostracodes found in deposits indicate that spring discharge emanated from both the alluvial and regional-carbonate aquifers near Corn Creek Flats in the upper Las Vegas Valley. Discharge appears to have come largely, but not exclusively, from alluvial aquifers in the Indian Springs Valley.

Radiocarbon-age control shows that deposition in the paleowetlands was more episodic than originally believed. Although preliminary, the current interpretations at low elevation in packrat (*Neotoma sp.*) middens suggest a correspondence of sediment accumulation and the existence of white fir (*Abies concolor*), which is believed to identify the wettest episodes during the last glacial period (40 to 10 ka). This would imply that the local water-table elevation only rose above the surface of the valley bottom during century- to millennium-long wet periods.

The Las Vegas Valley deposits, specifically those from Corn Creek Flats, appear to contain relatively old, possibly penultimate glacial (170 to 130 ka) sediments. The Owens Lake

record, and now the paleowetland records, indicate that the penultimate glacial period was substantially wetter than the last glacial period (40 to 10 ka).

Activity 8.3.1.5.1.2.1 - Paleontologic analyses. The objective of this activity is to assemble and interpret, in paleoclimate terms, detailed fossil records from ostracodes, diatoms, and pollen, along with other types of fossils as warranted by specific paleoclimate questions.

See the discussion under the heading for Study 8.3.1.5.1.2.

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.

See the discussion under the heading for Study 8.3.1.5.1.2.

Activity 8.3.1.5.1.2.3 - Geochemical analyses of lake, marsh, and playa deposits. The objective of this activity is to assemble and interpret, in paleoclimate terms, detailed records of stable isotopic, trace metal, and mineralogical data. The resulting interpretations provide the climate framework within which Yucca Mountain infiltration, percolation, recharge, and water-table elevation may be understood in climate terms.

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

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.

See the discussion under the heading for Study 8.3.1.5.1.2.

Forecast: Closer-interval sampling and analysis of the Owens Lake and other data from other regional and local climate records will be required to resolve the timing, rate, and magnitude issues of climate change. Data sets will be aligned with each other along a time axis and then integrated to obtain some composite perspective of past climate change. Time permitting, ostracode subsamples will be collected from the Owens Lake record for stable isotope analyzes. Collection will continue of ostracode subsamples for stable isotope analyses from the wetland deposits at Corn Creek Flats in the Las Vegas and Indian Springs Valleys.

3.4.3 Study 8.3.1.5.1.3 - Climatic Implications of Terrestrial Paleoecology

The objectives of this study are to provide quantitative estimates of changes in climatic variables (e.g., precipitation and temperature) for the southern Great Basin; develop transfer

functions, response surfaces, or both by statistically comparing modern climate to the vegetation data; and reconstruct climates from the paleovegetation data using these equations.

Activity 8.3.1.5.1.3.1 - Analysis of packrat middens. The objectives of this activity are to use radiocarbon dated macrofossils of climate indicator plant species to (1) identify periods of greatest late Quaternary precipitation, (2) determine durations of these periods, and (3) determine the rates of onset and demise of these periods.

No progress was made during the reporting period; this was an unfunded activity. Remaining statistical analysis and integration of data are being conducted under Study 8.3.1.5.1.5 (Section 3.4.5 of this progress report).

Activity 8.3.1.5.1.3.2 - Analysis of pollen samples. The objectives of this activity are to use high frequency pollen records from southern Nevada to (1) determine the frequencies, rates and magnitudes of current Holocene climatic change, and (2) provide baseline data for the generation of analogs or transfer functions of high resolution climate change for the interpretation of less complete Pleistocene paleoclimatic proxy records.

No progress was made during the reporting period; this was an unfunded activity. Remaining analysis and integration of data are being conducted under Study 8.3.1.5.1.5 (Section 3.4.5 of this progress report).

Activity 8.3.1.5.1.3.3 - Determination of vegetation-climate relationships. The objective of this activity is to translate the vegetational records provided by packrat midden and palynological investigations and available dendroclimatalogical data into qualitative estimates of past climatic variables.

No progress was made during the reporting period; this was an unfunded activity. Remaining statistical analysis and integration of data are being conducted under Study 8.3.1.5.1.5 (Section 3.4.5 of this progress report).

Forecast: This study was not funded in FY 1997. Remaining interpretation and integration of data are being conducted under Study 8.3.1.5.1.5 (Section 3.4.5 of this progress report).

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.

In situ cosmogenic beryllium dating techniques have been used to demonstrated that the vertical bedrock erosion rate on the climatically insensitive and erosionally resistant welded tuffs of Yucca Mountain is approximately 1 m per million years. This is less than half of the erosion rate of unconsolidated materials on the hillslopes of Yucca Mountain. This erosion rate on the resistant bedrock ridges of the mountain supports the contention that erosion proceeded very slowly by weathering of large blocks of tuff during the colder, wetter climatic periods in the Quaternary. Additional data on the timing of the deposition and later incisement of the alluvial fills in Fortymile Wash indicate that deposition of the material forming the higher terrace probably occurred between 200 to 250 ka during oxygen isotope stage 7, and the final incision of these alluvial materials began about 150 ka ago during the colder and much wetter climate of oxygen isotope stage 6. (For depiction of oxygen stages, see for example, Forester et al., 1996a Figures 8 and 9.)

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 Poohed 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 paleoecology, 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 unfunded 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.

This activity was completed in FY 1996. See Progress Report #15 (DOE, 1997e).

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 years; 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 unfunded activity.

Forecast: No activity is planned for this study during FY 1997.

3.4.5 Study 8.3.1.5.1.5 - Paleoclimate-Paleoenvironmental Synthesis

The objective of this study is to compare the paleoclimate estimates from the various proxy data sets and provide data synthesis in the formats required for future climate and paleohydrology investigations.

Relevant paleoclimate data sets are being finalized and interpreted. Coherent patterns of the timing, duration, character, and magnitude of climate change in the southern Great Basin are emerging. One particularly important finding is the approximate correspondence of the isotope record at Devils Hole (about 45 km south of Yucca Mountain, Figure. 3-1.) with the paleoclimate records from Owens Lake, California. Further, both of these records correspond to the marine oxygen isotope records, which document global changes in the temperature and ice volume of the earth. While not perfect, the correspondence means the timing and rate of change of past climate in the Yucca Mountain area coincided with the large, cyclic changes in global climate throughout the Quaternary. Because global climate records are closely linked to astronomically derived changes in solar insolation, and future changes in solar insolation can be accurately determined, forecasting the timing of climate change in the Yucca Mountain area is possible. Similarly, because the magnitude of regional climate change within particular segments of the solar insolation cycle is beginning to be understood, it also is possible, in general terms, to forecast the magnitude of future climate change in the Yucca Mountain region. In particular, the present-day segment of the insolation cycle resembles that which occurred 400 thousand years ago. Consequently, the characteristics of climate that happened about 400 thousand years ago and onward could reasonably be expected to recur, in some general way, in southern Nevada, and at Yucca Mountain, in the future.

A correspondence has also been recognized between the Owens Lake climate record and local records near Yucca Mountain, including data on packrat (*Neotoma sp.*) middens, paleodischarge sites, and wetland deposits. The correspondence supports the interpretation of local, cyclic climate changes above the possible repository and provides specific information about the magnitude of local climate change. Although the local hydrologic setting of Owens Lake ensures that it is and was generally wetter than Yucca Mountain, packrat midden and ostracode analogs indicate precipitation at Yucca Mountain was commonly two times greater than present when Owens Lake was fresh and overflowing during the last glacial period. Paleotemperature estimates from packrat middens near Yucca Mountain suggest mean annual temperature depressions of 5 to 10°C. This information has been correlated with diatom and ostracode assemblages and with sedimentological evidence of drop stones at Owens Lake that indicates that ice cover was present at Owens Lake throughout much of the winter during the last ice age. Uranium-series dates on terrace deposits also indicate incision at Fortymile Wash at the same time (30 to 20 ka), which implies increased vegetation cover and considerably higher winter precipitation. Spring discharge sites near Yucca Mountain became active as water tables rose and wetland communities of plants and animals flourished throughout southern Nevada.

A working group of paleoclimate specialists was formed to interpret and integrate paleoclimate proxy data sets and to interpolate those results to a grid system throughout the Yucca Mountain precipitation area. The group met during December and discussed the strengths and weaknesses of the principal fossil climate proxy groups, which are packrat midden data,

pollen, diatoms, ostracodes, and mollusks. Although each fossil group records past climate in a different way and reveals different aspects of the climate system, there are remarkable similarities in the nature of past climate interpretations within the Yucca Mountain region. A common and important theme of the records of all proxy groups was that the last climate cycle was not a singular, wet, cold event. Instead, the period from about 40 to 10 ka was a complex sequence of climates ranging from very wet and only somewhat cooler than today (about 33 to 31 k radiocarbon years) to very dry, possibly drier than today, but very cold at the full glacial maximum (about 18 k radiocarbon years). Change in climate style often appears to have been very rapid, at decadal scales, and the duration of particular climate states ranged from a century to a millennial time frame.

The packrat midden data base has been compiled and placed in a single spread sheet for analysis. A key component of the analysis was the identification of where various combinations of tree and shrub species live today versus locations of middens, in the Yucca Mountain area, containing the same species. That information provides the basis for estimating past climate parameters and provides historic meteorological records from analog sites for use in modeling annual variability in past climate in the Yucca Mountain area. For example, the infiltration model developed by Flint et al. (in prep.) requires not just estimates of the magnitude of climate change, but also a measure of how that magnitude might have been expressed over several decades. A preliminary reconstruction for the wettest episode (33 to 31 ka) in the region during the period from 40 to 10 ka suggests the mean annual precipitation was about four times modern and the mean annual temperature was about 6°C cooler than today. That analysis did not include many of the smaller shrub species that, when accounted for, likely will lower the precipitation estimate and might decrease the temperature estimate.

Forecast: The second half of FY 1997 will be devoted to preparing reports on the paleolimnological and paleoclimatic changes from the Owens Lake record, as well as several papers dealing with marsh and wetland deposits. Past climate will be interpreted using packrat midden data for four different episodes in the period from 40 to 10 ka. The episodes range from very wet and cool to very dry and cold. Those estimates will then be interpolated along a grid system covering the region. The magnitude of climate change will be determined using a change in the elevations of the key plant taxa and compared with the analog estimations. The results of the packrat-midden analysis will be integrated with the diatom and ostracode work as new information becomes available.

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 evaluate climate parameters for local Yucca Mountain scenarios over the next 100,000 years, with emphasis on the next 10,000 years for local climate scenarios that are both reasonably probable and relevant to repository performance.

Activity 8.3.1.5.1.6.1 - Global climate modeling. The objectives of this activity are to identify a set of global climate states (global boundary conditions) that are reasonably likely to occur over the period of concern, that are relevant to system performance, and that are pertinent

to understanding global climate effects; and to use one or more carefully chosen global general circulation models with these selected global climate states to provide time-dependent boundary conditions for use as input to regional models.

With the selection and qualification of the modeling codes reported in Progress Report #13 (DOE, 1996f), and the preliminary identification of modeling states defined in the study plan, this activity is considered complete (see Progress Report #13, Section 3.4.6).

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 to develop a capability to model future climate-induced conditions for use in modeling net future infiltration in the Yucca Mountain area.

Evaluation and validation of the nested climate model was completed, and this activity is considered complete. (See Appendix A, Section A.1.4.1 of this progress report.)

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.

The relevant aspects of this activity, originally planned as part of the future climate modeling study, are presently being addressed by the infiltration and unsaturated hydrologic modeling studies (Studies 8.3.1.2.2.1 and 8.3.1.2.2.9, Section 3.1.5 and Section 3.1.15, respectively, of this progress report). Activity 8.3.1.5.1.6.3 is therefore considered complete.

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 years.

The climate scenario selected for modeling during FY 1997 was a simulation using an atmosphere having six times the carbon dioxide concentration of the present-day atmosphere. This state represents the maximum possible future carbon dioxide concentration and represents an extreme state not seen in the paleoclimate record. Results of the simulation were submitted late in the reporting period (Thompson et al., 1997).

Forecast: A final summary report of the future climate modeling activity and results will be prepared for submittal by May 19, 1997

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 in the vicinity of Yucca Mountain.

Symbols from lithostratigraphic units of the Paintbrush Group exposed at Yucca Mountain (e.g., Tptpll and Tptpmn) are found in Buesch et al. (1996a).

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 unfunded activity.

Activity 8.3.1.5.2.1.2 - Quaternary unsaturated zone hydrochemical analysis. The objectives of this activity are to determine the past infiltration and 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.

The scope of this work was transferred to Activity 8.3.1.2.2.7.2 (Section 3.1.11 of this progress report).

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 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.

Paleodischarge deposits in southern Crater Flat and the central Amargosa Valley were the focus of field study and sample collection. These deposits, within 15 to 20 km of Yucca Mountain, represent the nearest down-gradient discharge from the potential repository, and an understanding of the timing and volume of their past discharge and recharge sources is important to performance assessment. Project personnel sampled several stratigraphic sections 5 to 6 m in thickness from deposits in the Amargosa River Valley at the distal part of the Fortymile Wash fan (informally known as the Stateline deposits). In all instances, the sections consisted of fine-grained sediments (clays to fine sands) with variable amounts of authigenic carbonate or silica cementation. Additional samples were collected from discharge deposits along Highway 95 and in Crater Flat to verify their depositional ages and sources of discharging ground waters. To address these issues, 109 samples or subsamples were collected for geochronologic, stable and radiogenic isotopic, paleontologic, and geochemical study.

Preliminary data collected from these samples and the field investigations indicate the following:

1. The deposits making up the toe of the Fortymile fan record a variety of settings including marsh and lacustrine environments; fairly pure limestones that cap the sequence may have formed in spring-fed ponds in a setting similar to the modern-day Ash Meadows area. The relation between the Fortymile Wash and Amargosa fluvial systems and the absence of interbedded alluvial deposits in the section at the toe of the fan indicate that the wetlands generally maintained a positive topographic expression during the late Pleistocene.

2. The delta carbon-13 ($\delta^{13}C$) and delta oxygen-18 ($\delta^{18}O$) values of calcite cements and nodules from the Fortymile Wash fan deposits are compatible with spring discharge. The values are comparable to those from the Crater Flat and Highway 95 discharge sites, and both locations have some oxygen-18-enriched calcite that may indicate evaporative concentration of depositing waters.

3. Some of the samples from the Fortymile Wash fan contain water-soluble minerals. Such minerals might reflect episodes of drier climate during deposition of some of these sediments, or they might represent evaporative deposition from pore waters under the modern climate regime.

4. A 6-m-thick sequence of limestones and calcareous siltstones from near Scranton Well has $\delta^{13}C$ values that also are compatible with deposition from waters of spring discharge origin. Therefore, they might record a long history of ground-water discharge in the Amargosa Valley region.

5. Discharge deposits at the toe of the Fortymile Wash fan contain diatom assemblages similar to those at the Lathrop Wells diatomaceous deposit; the hydrochemistry and temperature of the discharging waters at the two locations also probably were similar.

6. Resampling and further thorium-230/uranium dating of sediments that bracket an apparent unconformity within the Lathrop Wells diatomaceous deposits verifies the age discontinuity between upper, diatom-rich units with ages less than 33 to 55 ka and underlying green sandy units with ages greater than ~130 ka.

7. Sediments from outlying outcrops of the Lathrop Wells diatomaceous deposit have diatom assemblages consistent with growth in the same waters that formed the main part of the deposit.

Regional-scale maps (1:250,000) of discharge sites active during the last full glacial (10 to 30 ka) and brief descriptions of the type of discharge system and sources of water were prepared in support of the three-dimensional, regional saturated zone hydrologic model (Section 3.1.4 of this progress report).

Studies of thermoluminescence dating of surface deposits near Yucca Mountain (Mahan et al., 1996) and Death Valley ostracode glacial-lake hydrochemical history (Forester et al., 1996b) reported the results of uranium-series dating, strontium isotopes, sedimentology, evaporite mineralogy, and ostracode assemblage studies. These studies indicated that during the last glacial Death Valley hosted a moderate-to-large lake supported by discharge from the Amargosa River. The maximum depth of that lake, probably about 90 m, was only maintained for a few centuries. Depths of a few tens of meters were more typical.

During the penultimate glacial, however, a much larger lake existed in Death Valley. The maximum depth of that lake would have placed its shorelines outside of Death Valley. That lake appears to have been largely supported by discharge from the Amargosa River, although some discharge may have come from the Owens River drainage. Hydrochemical constraints, as well as calcite delta carbon-13 values and diatom assemblages from the Tecopa Lake beds near Shoshone, California, indicate a significant contribution of ground-water discharge to the fluvial system.

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.

This activity was terminated in FY 1994; see Progress Reports #10 (DOE, 1994e) and #11 (DOE, 1995b) for details.

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.

Beginning in FY 1995, the emphasis of this activity shifted to determining the spatial and temporal distribution of flux through the repository block using isotopic ages and measured distributions of low-temperature calcite and opal fracture and cavity fillings that were deposited from downward percolating water and that are exposed in the ESF.

A report was submitted to DOE-YMSCO that summarized results to date of analysis of calcite and open fracture- and cavity-filling deposits in the ESF (Paces et al., 1996a). Radiocarbon ages of the low-temperature minerals range from 44 to 16 ka with the greatest number of ages distributed between 38 and 28 ka. Thorium-230/uranium ages, however, for subsamples from the same surface range from 28 ka to greater than 500 ka, with most between 50 and 400 ka. Both radiocarbon and thorium-230/uranium ages from secondary minerals near or within discrete zones of elevated chlorine-36 showed similar distributions relative to those in zones with background levels of chlorine-36. Oxygen-18, carbon-13, and strontium-87/strontium-86 values for the outermost calcites vary over limited ranges and reflect the compositions of modern calcite-rich soils and fractionation due to present geothermal gradients. However, data for the earliest calcite indicate that geothermal gradients may have been steeper, methane may have been the carbon species controlling carbon fractionation in the subsurface, and strontium was derived from a less-radiogenic source than the current soil reservoir. Assuming that all calcium was extracted from waters percolating through the unsaturated zone

enroute to the water table, a minimum value of flux of about 2 mm/yr was obtained as an average over the last 12.7 million years. This value is considered provisional and is intended only to show the viability of this approach for calculating the temporal and spatial variability of past fluxes and possibly estimating future changes in flux. Surface records from the Yucca Mountain area indicate that the regional climate over the last million years was wetter and cooler relative to the present for as much as 80 percent of the time. However, there is no indication in the subsurface that deposition rates of calcite and opal varied greatly during this period even though higher waste tables throughout the region reflected greater recharge. These observations suggest that percolation through the Topopah Spring Tuff may have been buffered from variations in infiltration except in zones of high permeability and highest flux.

Samples of opal and calcite were collected from 28 sites in the ESF between Station 57 + 71 (5771 m) and Station 69 + 42 (6942 m). Relatively slow progress by the tunnel-boring machine during this reporting period limited the number of suitable sites available for sampling. In addition to sampling, line surveys to quantitatively assess the abundance of calcite and opal in fractures and cavities were completed between Station 35 + 00 (3500 m) and Station 69 + 30 (6930 m). A data base was constructed to store sample and mapping data. Forty additional samples of calcite and opal have been dated by the uranium-series method and yield finite ages between 50 ka and 430 ka. (Note: Two samples were older than 500 ka, which is the limit of the method.) Most of these samples were obtained from the outermost (youngest) parts of the specimens. Sixteen additional carbon-14 analyses were determined by accelerator mass spectrometry on calcite samples. These analyses yielded calculated ages between 25 ka and 52 ka, the latter being beyond the limit of the method. Two blank samples of old calcite were analyzed, and these yielded calculated ages greater than 50 ka and 51 ka. Most of the samples analyzed for carbon-14 also were obtained from the outermost (youngest) parts of crystals.

An additional dating technique was tested on calcite and opal deposits. The uranium contents of opal from the ESF are sufficiently large (up to approximately 300 ppm) that, in principal, the uranium-lead (U-Pb) dating technique could be used to determine ages of deposition if laboratory blanks are exceedingly low. Accordingly, collaborative work was started with the Jack Satterly Geochronology Laboratory at the Royal Ontario Museum in Toronto, Canada, to investigate the suitability of these opal deposits for U-Pb dating. Early results obtained on opal samples from the ESF were sufficiently encouraging to proceed with this dating technique, and 37 U-Pb ages now have been obtained for samples from the northern part of the ESF main drift, the northern bend, and the northwestern part of the north ramp. The dated subsamples were distributed approximately equally between outermost occurrences and occurrences embedded within the deposits. Ages obtained range from 100 ka to 9 Ma. The utility of this dating method is threefold: (1) for the younger samples, the U-Pb ages provide independent checks on the U-series ages, (2) the U-Pb ages provide further constraints and testing of the continuous-growth model described in Paces et al. (1996a), and (3) reliable ages of the embedded opal allow the calibration of the depositional stratigraphy of these deposits. Temporal calibration of the depositional stratigraphy of the calcite and opal occurrences is essential for calculating accurate rates of accumulation that can be inverted to flux estimates, and for establishing a time framework for the stable and radiogenic isotopic records that are isolated in the calcite deposits. These latter records relate to climatic conditions that existed at the

surface of Yucca Mountain when the parent water of the calcite deposits was introduced by infiltration.

As reported in Paces et al. (1996a), initial uranium-234/uranium-238 ratios of the dated calcite and opal samples vary systematically as a function of stratigraphic position and depth in the ESF. Samples from the Tiva Canyon Tuff, the PTn and the upper part of the Topopah Spring Tuff have uranium-234/uranium-238 ratios generally between 1.5 and 2.0, which are similar to the values of surficial calcite. Samples from the repository horizon have larger initial uranium-234/uranium-238 ratios as great as 9.3. Samples analyzed this fiscal year indicate that this depth-stratigraphic variation will be repeated in the southern part of the ESF main drift and in the south ramp with uranium-234/uranium-238 ratios decreasing through the PTn and the Tiva Canyon Tuff. A provisional conceptual model has been constructed to explain the systematic variation of initial uranium-234/uranium-238 ratios in the calcite and opal deposits. Water infiltrating at the surface acquires the uranium-234/uranium-238 values of surficial materials (calcrete and bedrock coatings) that typically have ratios between 1.4 and 1.8. As small volumes of water percolate downward through the rock mass, uranium-234/uranium-238 ratios will gradually evolve to larger values as a result of alpha recoil and progressive uptake of uranium-234 from decay-damaged sites on pathway surfaces (the bulk rock has uranium-234/uranium-238 ratios of unity reflecting secular equilibrium of the system). Large volumes of percolating water would strip available uranium-234 resulting in uranium-234/uranium-238 ratios similar to those at or near the surface. Therefore, the large uranium-234/uranium-238 values are indicative of relatively small volumes of percolating water. In addition, abundant lithophysal cavities in the crystal-poor upper lithophysal zone of the Topopah Spring Tuff (tptpul) may effectively slow downward percolation, allowing fracture water the opportunity to spread laterally and interact with the upward-mitigating gas phase.

To further understand the relationship between matrix water and fracture water in the unsaturated zone, pore-water salts were extracted from borehole USW SD-7 core from the Tiva Canyon Tuff, the PTn, the Topopah Spring Tuff, and the CHn for strontium-isotope analyses. These soluble salts form when the core dries and the pore water evaporates. The salts are redissolved using high-purity deionized water, and the strontium is then separated from the other cations using ion exchange methods. A systematic but variable increase in delta strontium-87 ($\delta^{87}Sr$) downward from the top of the hole through the crystal poor lower lithophysal zone (Tptpll) of the Topopah Spring Tuff offers important insight into the role of the PTn in percolation through the repository block. Pore water in the upper part of Tiva Canyon Tuff has a $\delta^{87}Sr$ value of +3.5, which increases to +3.8 near the bottom of the unit. Through the PTn, the $\delta^{87}Sr$ values increase monotonically from +3.8 at the top to +4.5 at the bottom. Downward through the crystal-poor middle nonlithophysal zone (Tptpmn) and crystal-poor lower lithophysal zone (Tptpll) of the Topopah Spring Tuff, $\delta^{87}Sr$ values are mostly in the range of +4.5 to +4.8. $\delta^{87}Sr$ then decreases in the basal vitrophyre of the Topopah Spring Tuff and the upper part of the CHn, but the scatter increases substantially. A provisional interpretation suggests that systematic isotopic variation above and below the PTn is caused by two distinct isotopic signatures of infiltrating water. One component infiltrates largely through bedrock surfaces and acquires $\delta^{87}Sr$ values of calcite bedrock coatings (+3.5) whereas the other component infiltrates the thick calcitic soils of alluvial valley fill acquiring a $\delta^{87}Sr$ of +4.5. The systematic variation in $\delta^{87}Sr$

through the PTn can be interpreted as an indication of storage, mixing, and lateral flow that may take place in this unit.

Carbon, oxygen, and strontium isotopic data continue to be collected for calcite fracture- and cavity-filling samples to characterize the changing character of the downward percolating fluids as a function of time. As discussed in Paces et al. (1996a), correlations among $\delta^{13}C$, $\delta^{18}O$, and $\delta^{87}Sr$ data indicate that the variations in isotopic content of the calcite samples do indeed relate to conditions that existed at the surface when the parent waters infiltrated. Using uranium-lead and uranium-series ages to estimate ages of subsamples of calcite for several occurrences reveals a positive correlation between $\delta^{13}C$ and age in the range of 25 ka to 9 Ma (heavier carbon with increasing age). Only the oldest subsample (9 Ma) has a $\delta^{13}C$ value outside the range of possible soil carbon. The other samples record a long-term change in climate and vegetation with a suggestion of a more abrupt change at approximately 3 Ma. The somewhat larger values of $\delta^{13}C$ prior to 3 Ma are compatible with a climate that would support grasslands. This preliminary attempt to use "age calibrated" microstratigraphy in the calcite and opal deposits to establish a correlation of subsurface conditions with surface climate is encouraging.

Forecast: The Ash Meadows area south of Highway 95 appears to be a modern analog of the Stateline area deposit, and will be reexamined to test the interpretation of the field relationships, geochronology, geochemistry, and paleontology of the Stateline sites. Geochronologic analysis will continue of samples from the deposits near Stateline, along the north side of Highway 95 near Lathrop Wells, and from Crater Flat. These records of deposition timing at these sites will be used in conjunction with textural and field observations, ostracode counts, and stable isotope studies to correlate past climates with the chemistry and depositional environments of these localities. Of particular importance will be the collection of strontium-isotope data from the stratigraphic sections near Stateline to determine the relative contributions of the Amargosa-Oasis Valley and Fortymile Wash-Yucca Mountain ground-water systems during deposition of the Stateline sequences.

Samples from the ESF south ramp and from the Northern and Southern Ghost Dance Fault Alcoves will continue to be collected and analyzed. Samples from the south ramp will be used to advance an understanding of the role of the PTn in controlling percolation through the Topopah Spring Tuff. The Northern and Southern Ghost Dance Fault Alcoves will allow direct access to and sampling of the Ghost Dance fault underground. Line surveys continue in the south ramp and the adequacy of the survey data for the main drift will be evaluated. If necessary, the 30-m intervals currently being surveyed every 100 m will be extended to 60-m intervals or full coverage to improve the abundance statistics. Uranium-series, carbon-14, and uranium-lead dating of calcite and opal will continue for samples in the south ramp and in the Northern and Southern Ghost Dance Fault Alcoves. The U-Pb dating will emphasize the determination of accurate ages for opal lenses embedded in calcite-dominated deposits so that the carbon, oxygen, and strontium isotopic records contained therein can be placed in a timeframe for correlation with surficial climate records. Work will continue on the development and application of the thorium-230/radium-226 system to opal and calcite to better constrain the continuous-deposition model. Continued emphasis will be placed on refining a conceptual model(s) of percolation using the ages and distribution of the low-temperature mineral occurrences. Efforts will be made

to construct scenarios for different climate regimes and to develop more quantitative numerical models to simulate the temporal and spatial distribution of percolation flux.

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 unfunded activity.

Activity 8.3.1.5.2.2.2 - Analysis of future unsaturated zone hydrology due to climate changes. The objective statement for this activity has been deleted.

As reported in Revision 9 of the Site Characterization Program Baseline (DOE, 1995a), this activity has been deleted; the scope of work will be performed under Study 8.3.1.2.2.9 (see Section 3.1.13 of this progress report). See also Appendix H for the Site Characterization Program Baseline history.

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.

Progress is reported under Activity 8.3.1.2.1.4.4 (Regional three-dimensional hydrologic modeling) in Section 3.1.4 of this progress report.

Forecast: No activity is planned for this study during FY 1997.

3.5 EROSION (SCP SECTION 8.3.1.6)

The changes to the Erosion Program since the SCP was issued are summarized in Appendix A, Section A.1.5.

The scope of work envisioned for the erosion studies has been completed. As a result of the study plan work scope consolidation effort, no study plans were developed in this program. During the previous reporting period, the NRC provided the DOE with an Issue Resolution Status Report that described the basis for the NRC determination that adequate information existed to close all the open items associated with this issue (NRC, 1996d). [See Progress Report #14 (DOE, 1996g)].

Forecast: No further work is planned for the Erosion Program.

3.6 POSTCLOSURE TECTONICS (SCP SECTION 8.3.1.8)

Changes to the Postclosure Tectonics Program since the SCP was issued are summarized in Appendix A, Section A.1.7.

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.

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

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.

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

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.

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

Activity 8.3.1.8.1.1.4 - Volcanism probability studies. 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.

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

Forecast: No further work is planned for this study.

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.

This study was terminated at the end of FY 1996.

Activity 8.3.1.8.1.2.1 - Eruptive effects. The objective of this activity is to determine the effects of hydrovolcanic, Hawaiian, Strombolian, and violent Strombolian eruptions of basaltic magma on a repository. The results will be available for use in performance assessment calculations of possible radiological releases.

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 the mechanisms of incorporating waste in magma, the geometry of basalt intrusions, and hydrothermal effects on waste isolation of basalt intrusions through or near a repository.

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.

Forecast: No further work is expected for this study.

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, altitude of the water table, local fracture permeability, effective porosity, and rock geochemical properties.

Activity-level progress narratives for this study have been combined into a single discussion because of the close interrelation of the phenomena being considered under credible tectonic scenarios that could affect hydrologic properties and characteristics.

Work continued to advance the analysis of possible credible tectonic scenarios described by G. E. Barr et al. (1996) that could affect hydrologic properties and characteristics, including changes in water-table elevation and accumulation of perched water. Most activity was devoted to assimilating prior results and reviewing ongoing work and interpretations pertinent to scenario development and evaluation. Two major issues were considered: (1) likelihood of the magnitude and recurrence of Quaternary tectonic phenomena, only three of which are significant: basaltic volcanism, local fault displacement and associated fracturing and block tilting, and ground motion or dynamic-stress effects caused by earthquakes; and (2) linkage between seismic activity and volcanism.

The issues of fault displacement and ground motion presently are being assessed through the probabilistic seismic hazard analysis of Yucca Mountain (see Study 8.3.1.17.3.6 in Section 3.13.8 of this progress report). Large faulting events at Yucca Mountain are likely linked to volcanism, but they are related by way of a common crustal-extension mechanism, not through direct cause and effect. Therefore, there is probably a threshold mechanism in effect: below a certain strain threshold faulting occurs without volcanism, and it is probably not distributed and probably involves segmented fault activity (O'Leary, 1996).

With respect to possible effects of tectonic processes and events on the hydrologic system, there are several open issues (G. E. Barr et al., 1996). Among these are perched water, the large hydraulic gradient in the saturated zone, and fault control on flow in the saturated zone. Even though perched water has not as yet been evaluated exhaustively in scenarios, it is important because a tectonic event could alter the connection between perched water and either its source or its drain. Such changes could lead to a diversion of the source pathways or a reduction in the effectiveness of the drain, both of which could result in perched water occurring close to the repository where it could interact with repository heat or participate in the flow pathways responsible for transport. Both the large hydraulic gradient and fault control on saturated zone flow are open issues because of uncertainty about their durability in response to seismic activity.

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.

See discussion under the heading for Study 8.3.1.8.2.1.

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 hydrogeologic unit.

See discussion under the heading for Study 8.3.1.8.2.1.

Activity 8.3.1.8.2.1.3 - Analysis of the effect of tectonic processes and events on 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.

See discussion under the heading for Study 8.3.1.8.2.1.

Activity 8.3.1.8.2.1.4 - Analysis of the effects of tectonic processes and events on 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.

See discussion under the heading for Study 8.3.1.8.2.1.

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.

See discussion under the heading for Study 8.3.1.8.2.1.

Forecast: Work will continue on evaluation of tectonic-scenario logic trees with respect to recent hydrologic modeling results, data acquired from ESF investigations, tectonic models evaluation, and probabalistic seismic hazard analysis results. Scenario evaluation will include describing the processes and ranges of possible consequences under two environments: the ambient environment (present day deformation rates and climate) and a projected anthropogenic environment (present day tectonic and climate conditions plus the full thermal load). A third evaluation factor involves a wet-climate environment.

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

The objective of this study is to produce analysis and assessments of the probability and effects of tectonic initiating events that may result in changes in the average percolation flux rate at the top of TSw2.

This study has been combined with Study 8.3.1.8.2.1 (Section 3.6.3 of this progress report).

Forecast: No further work is planned under Study 8.3.1.8.3.1.

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

The objective of this activity is to provide 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.

This study has been combined with Study 8.3.1.8.2.1 (Section 3.6.3 of this progress report).

Forecast: No further work is planned under Study 8.3.1.8.3.2.

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

The objective of this study is to address possible changes in fractures, or rock mass permeability and effective porosity caused by tectonic events and processes.

This study has been combined with Study 8.3.1.8.2.1 (Section 3.6.3 of this progress report).

Forecast: No further work is planned under Study 8.3.1.8.3.3.

3.6.7 Study 8.3.1.8.4.1 - Analysis of the Effects of Tectonic Processes and Events on Rock Geochemical Properties

The objective of this study is to provide assessments of the initiating events related to local changes in distribution coefficients resulting from tectonic processes and events.

This study has been combined with Study 8.3.1.8.2.1 (Section 3.6.3 of this progress report).

Forecast: No further work is planned under Study 8.3.1.8.4.1.

3.6.8 Study 8.3.1.8.5.1 - Characterization of Volcanic Features

The objective of this study is to provide data on the age, location, eruptive history, 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 refine geophysical models of the Yucca Mountain region, to evaluate the tectonic setting of volcanic centers, and to test concepts of the temporal and geochemical evolution of basalts in the Yucca Mountain 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: (a) the age of the Quaternary volcanic events in the Yucca Mountain region; (b) the age and eruption chronology of the youngest (<0.5 Ma) volcanic event in the Yucca Mountain area; and (c) 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.

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

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.

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

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 volcanic zone. 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 also will be used to correlate basaltic ash in fault trenches with their correct eruptive source.

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

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.

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

Forecast: Further work on this study has been deferred indefinitely; no work is planned for FY 1997.

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.

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

Forecast: No activity is planned for FY 1997.

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 study contains one activity that relies on available data; no unique data are to be acquired. Therefore, no study plan will be developed.

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: No further work is expected in this study.

3.7 HUMAN INTERFERENCE (SCP SECTION 8.3.1.9)

Changes to the Human Interference Program since the SCP was issued are summarized in Appendix A, Section A.1.8.

The studies in this program are intended to assess the survivability of a long-term surface marker system, the natural resource potential, and the impacts of potential human activities in the foreseeable future that could affect the waste isolation capabilities of the site. The natural resource assessment includes metallic resources, water resources, industrial rocks and minerals, and energy resources (such as, oil, gas, coal, tar sands, geothermal energy, and uranium). Studies on the inadvertent human interference issue will evaluate the feasibility of a surface marker system that would warn future generations of a hazard and assess the potential for inadvertent human interference associated with exploration for or exploitation of natural resources.

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. Suitable locations of the monuments for the surface marker system will be determined.

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.

Locations for the surface markers were recommended using information in Fehr et al. (1996). The recommended locations for the markers are on bedrock, at higher elevations, and spaced such that adjacent markers are visible from each location.

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. The available information is being evaluated to identify the optimum locations for the markers.

Suggested locations for the surface markers were indicated on the map included in the feasibility report (Fehr et al., 1996).

Forecast: Additional data evaluation and probability studies will be completed as needed to support design of the permanent marker system.

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 assessment will examine the present and foreseeable future resource potential of the controlled area in comparison with the surrounding area and the general geologic setting. The information and data obtained in this study will provide the basis for probabilistic calculations for evaluating the potential for inadvertent human interference.

The geochemical survey for the metallic resources study and the oil and gas (petroleum) resources study, as well as a water resources study, are in progress. The natural resources synthesis report, discussed in the forecast, will present the results of all the component studies.

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 on the basis of 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.

Laboratory geochemical analyses were completed as part of the metallic resources activity (Activity 8.3.1.9.2.1.5), and a data base compiling all analyses conducted for the project was constructed. These results will be reported in the metallic and mined energy resources report. A summary of this report will be incorporated into the natural resources synthesis report, which is discussed in the forecast.

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.

The results of the geologic and geophysical appraisal of the site and comparison of the site geology with the regional geology will be reported in the metallic and mined energy resources report and summarized in the natural resources synthesis report, which is discussed in the forecast.

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.

This activity was reported as completed in Progress Report #14 (DOE, 1996g, p. 3-111). The findings of this report will be incorporated into the natural resources synthesis report, which is discussed in the forecast.

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.

Information is being compiled on the hydrocarbon potential of Yucca Mountain and the potential compared with other areas having hydrocarbon reserves is in progress. A report is being prepared that will synthesize data on the hydrocarbon resources at the site and assess the oil and gas potential of the site. The potential for undiscovered hydrocarbon resources in the controlled area will be estimated by comparing the site geology and geochemistry with deposit models and with areas in the region that contain known deposits in similar geologic settings. A summary of this report will be incorporated into the natural resources synthesis report, which is discussed in the forecast.

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, hydrocarbon assessment, and the water resources assessment (Study 8.3.1.9.2.2).

Work during the period focused on reviewing drafts of reports from the above activities and compiling data for the natural resources synthesis report, discussed in the forecast.

Forecast: The natural resources synthesis report will be developed as a final assessment of the potential for natural resources, using site-specific data compared with regional geologic data and models of resource deposit genesis. Assessments of the metallic resources, oil and gas resource potential, mined energy resources, and water resources of the site will be combined with previously completed assessments of industrial rocks and minerals and geothermal resources.

This synthesis report will integrate geological, geophysical, and mineralogical information from the literature with data from the site, including new geological and geochemical data from Yucca Mountain and areas of known mineralization in the region. The potential for undiscovered deposits in the controlled area will be evaluated by comparing its geology and geochemistry with mineral deposit models and with areas in the region that contain known metal deposits in similar geologic settings. The completion of the natural resources synthesis report

will conclude the studies planned in the SCP for natural resources. The report is scheduled to be completed in June, 1997 during the next reporting period.

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.

A report is being prepared that describes ground water supply and demand at Yucca Mountain and in the surrounding region, including the Las Vegas Valley. Estimated future demand, value, and probable locations and rates of future exploitation will be included. These findings of the ground-water resources final report will be summarized in the natural resources synthesis report (see forecast for Section 3.7.2 of this progress report).

Forecast: The report on the ground-water resources will be completed. Information from this report will be summarized in the natural resources synthesis report (see Section 3.7.2 of this progress report).

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.

Because no unique data were to be acquired by this study, no study plan was developed. The entire scope of the study was transferred to Study 8.3.1.9.2 (see Appendix A.1.8.2).

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 years) 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.

The scope of this activity was transferred to Study 8.3.1.9.2.1.

Forecast: No further work is planned for this study (see Appendix A.1.8.2).

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.

No unique data are to be acquired by this study; thus, no study plan was developed. The entire scope of this study was transferred to Study 8.3.1.9.2.1 (see Appendix A.1.8.2).

Activity 8.3.1.9.3.2.1 - An analysis of the potential effects of future ground-water withdrawals on the hydrologic system in the vicinity of Yucca Mountain. The objective of this activity is to determine the potential effects of future ground-water withdrawals on the hydrologic system at Yucca Mountain. Effects of the withdrawals will be defined qualitatively and quantitatively.

Work conducted during the reporting period in support of this activity is described under Study 8.3.1.9.2.1 (see Appendix A).

Activity 8.3.1.9.3.2.2 - Assessment of initiating events related to human interference that are considered not to be sufficiently credible or significant to warrant further investigation. The objective of this activity is to demonstrate that those initiating events that have been identified (Table 8.3.1.9-1, SCP) for the human interference issue are not considered sufficiently credible or significant to necessitate additional investigation.

Work conducted during the reporting period in support of this activity is described under Study 8.3.1.9.2.1 (see Appendix A).

Forecast: No work is planned for FY 1997. The inputs to computer modeling for varying water withdrawal assumptions and input bounds will be supplied under Study 8.3.1.9.2.2 and will be reported in the ground-water resources final report, scheduled for next reporting period.

3.8 METEOROLOGY (SCP SECTION 8.3.1.12)

Changes to the Meteorology Program since the SCP was issued are summarized in Appendix A, Section A.1.9.

Four studies and one investigation in the Meteorology Program (8.3.1.12) include work to describe current local and regional meteorological conditions. Three of the studies (8.3.1.12.1.1, 8.3.1.12.1.2, and 8.3.1.12.4.1) and the investigation (8.3.1.12.3) are controlled by the Scientific Investigation Implementation Package for Regional Meteorology (CRWMS M&O, 1995a) and the Nevada Work Instruction: "Acquisition and Analysis of Regional Meteorological Data." The

fourth study, Meteorological Data Collection at the Yucca Mountain Site (8.3.1.12.2.1), is controlled by the corresponding study plan.

3.8.1 Study 8.3.1.12.1.1 - Characterization of the Regional Meteorological Conditions

The major objective of this study is to collect and analyze meteorological data from various locations surrounding Yucca Mountain and to characterize the regional meteorology needed for site characterization performance assessment and design. This characterization will provide a regional overview of wind flow patterns and other parameters (primarily related to atmospheric dispersion and surface facility design) associated with meteorological conditions at Yucca Mountain. For additional descriptions of the objectives, refer to the Scientific Investigation Implementation Package for Regional Meteorology (CRWMS M&O, 1995a).

The climatological analyses and preparation of the Engineering Design Climatology and Regional Meteorological Conditions report continued. Select data identified in the meteorological data synthesis report (CRWMS M&O, 1996j) are being included in the climatological analyses. The analyses included re-evaluating 1985 to 1992 data from the meteorological stations operated by the Project Environmental Field Programs Division.

Forecast: The climatological analyses and reporting phases of this study will be completed.

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 the coordination of meteorological monitoring efforts by various Project participants during site characterization.

The work in this study was combined with other studies in the Scientific Investigation Implementation Package for Regional Meteorology (CRWMS M&O, 1995a) (see Section 3.8 of this progress report).

Forecast: Future work on this study will be controlled through Study 8.3.1.12.1.1 (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 primary objective of this study is to provide site-specific data to resolve design and performance issues associated with preclosure radiological safety, including estimating potential radiological dosage related to repository operations. Data from this study are also used to respond to air quality permit requirements of the State of Nevada covering site characterization activities.

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 sufficient additional locations to characterize the meteorological conditions, including wind flow patterns and atmospheric dispersion characteristics, in the vicinity of Yucca Mountain.

The meteorological monitoring program continued at the nine sites that have been active since 1993. Data were also supplied to the design and environmental groups. Field operations for 17 recording precipitation gauge stations previously operated by the USGS as part of Study 8.3.1.2.1.1 were added to the site meteorological monitoring activities at the beginning of 1997. Data from these stations will be made available to the investigators working in unsaturated zone infiltration studies. The data recording at the original 9 full meteorological stations was modified to include the specific data records requested by the USGS.

Select meteorological data from the monitoring network were included in the two quarterly ambient air monitoring reports submitted to the State of Nevada during the reporting period. These reports fulfill requirements of the State Air Quality Permit (No. AP9611-0573) required for continuing site-disturbing activities. No significant increase in inhalable particulate matter (PM_{10}) concentration was noted during the reporting period.

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.

Data requests were fulfilled for data from the site network formatted to be compatible with atmospheric dispersion models being evaluated for impact assessment purposes.

Forecast: Data collection and reporting will continue at the 9 monitoring stations and the additional 17 recording precipitation stations. The data formatting activity will be performed once the airborne radiological impact assessment method has been determined.

3.8.4 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

The objective of this investigation is to provide data on wind flow patterns in the general region of Yucca Mountain. These patterns are needed to identify areas that could be impacted by airborne radiological material released from surface or underground facilities at Yucca Mountain.

The work in this study was combined with other studies in the Scientific Investigation Implementation Package for Regional Meteorology (CRWMS M&O, 1995a) (see Section 3.8 of this progress report).

Forecast: Future work on this study will be controlled and tracked through Study 8.3.1.12.1.1 (see 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 to determine their recurrence intervals.

This study analyzes existing meteorological data and technical publications to estimate the potential for occurrences and types of extreme weather events that might affect repository operations. The work in this study was combined with other studies in the Scientific Investigation Implementation Package for Regional Meteorology (CRWMS M&O, 1995a) (see Section 3.8 of this progress report).

Forecast: Future work on this study will be controlled and tracked through Study 8.3.1.12.1.1 (see Section 3.8.1 of this progress report).

3.9 OFFSITE INSTALLATIONS AND OPERATIONS (SCP SECTION 8.3.1.13)

Changes to the Offsite Installations and Operations Program since the SCP was issued are summarized in Appendix A, Section A.1.10.

The objective of this program is to provide information required to support resolution of design and performance issues related to offsite radiological safety, including (a) evaluations of offsite accident initiators, their probabilities and potential impacts; (b) assessments of routine releases from nuclear operations; (c) assessments of the onsite impacts of nonrepository-related routine and potential accidental releases of radioactive material; and (d) collection of agricultural and cultural data to support the calculation of the dose to the public from releases at the Yucca Mountain Site.

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

Forecast: Activities are planned to begin in the last half of FY 1997 for completion in FY 1998 to meet objectives described in the SCP. See Appendix A, Section A.1.10.

3.10 SURFACE CHARACTERISTICS (SCP SECTION 8.3.1.14)

Changes to the Surface Characteristics Program since the SCP was issued are summarized in Appendix A, Section A.1.11.

3.10.1 Study 8.3.1.14.2.1 - Exploration Program

The objective of this study is to conduct an exploration program for the characterization of the soil and rock conditions that will influence or be influenced by the construction of the surface facilities and the 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 field reconnaissance to establish a preliminary exploration program to include further topographic and geologic mapping, subsurface drilling, test pits, trenching, and geophysical methods.

The reconnaissance activities identified in the objective statement have been completed. No new activity occurred during the reporting period.

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.

No progress was made during the reporting period because no activity was planned for FY 1997.

Forecast: No additional activity is planned for this study in FY 1997 although future work may be required to support design of waste handling facilities in FY 1999.

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.

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

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 unfunded activity.

Forecast: No additional activity is planned for FY 1997 although future work may be required to support design of waste handling facilities in FY 1999.

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 estimate 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.

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

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 design ESF surface facilities and underground openings.

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

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, to locate discontinuities or other structural features, and to determine the depth, thickness, and lateral extent of soil and rock stratigraphic units.

This activity has been completed. The compilation and analysis of geophysical data are described under Activity 8.3.1.4.1.2 (Integration of Geophysical Activities), discussed in Section 3.3.2 of this progress report.

Forecast: No additional activity is planned for this study in FY 1997 although future work may be required to support design of waste handling facilities in FY 1999.

3.11 THERMAL AND MECHANICAL ROCK PROPERTIES (SCP SECTION 8.3.1.15)

Changes to the Thermal and Mechanical Rock Properties Program since the SCP was issued are summarized in Appendix A, Section A.1.12.

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 provide data to describe the spatial variability of these parameters. To accomplish this, porosity, grain density, and the heat capacity and thermal conductivity of zero-porosity material must also be characterized.

Symbols for the lithostratigraphic units of the Paintbrush Group exposed at Yucca Mountain (e.g., Tptpmn, Tptpln) are found in Buesch et al. (1996a).

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 the spatial variability thereof. Data will contribute to determining in situ thermal properties (porosity and grain density), vertical in situ stress (bulk density), and radiation-shielding properties (bulk density).

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

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 the spatial variability thereof. The data will be used in calculations of the thermal response to the presence of heat-producing waste in unit TSw2 (lithostratigraphic units Tptpmn, Tptpll, and Tptpln, see Geologic/Lithologic Stratigraphy, MO 9510R1B 002.004).

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

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 the spatial variability thereof. The data will be used in calculations of the thermal response to the presence of heat-producing waste in unit TSw2 (lithostratigraphic units Tptpmn, Tptpll, and Tptpln).

Equipment to measure thermal conductivities of geologic specimens has been set up and is being calibrated.

Forecast: Testing is planned for rocks from the Thermal Testing Facility, from the Southern Ghost Dance Fault Alcove, and for rocks from lithostratigraphic units below the repository level sampled in USW SD-7. Characterization of grain densities for units below the repository level are planned for samples recovered from USW SD-7. The data from this study 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 (lithostratigraphic units

Tptpmn, Tptpll, and Tptpln) (see Geologic/Lithologic Stratigraphy, MO 9510R1B00002.004). Samples from the Thermal Testing Facility and the Southern Ghost Dance Fault Alcove of the main drift of the ESF will be tested to determine the lateral variability and anisotropy of thermal conductivity and thermal expansion properties. Thermal conductivity of test specimens from the drift-scale test area of the Thermal Testing Facility will be determined. These results will be reported under SCP Study 8.3.4.2.4.4 (Section 5.2.5 of this progress report).

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. This information will be used to establish the testing frequency at the main test level in the ESF.

Symbols for the lithostratigraphic units of the Paintbrush Group exposed at Yucca Mountain (e.g., Tptpmn, Tptpln) are found in Buesch et al. (1996a).

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 (lithostratigraphic units Tptpmn, Tptpll, and Tptpln).

This activity has been incorporated into Study 8.3.1.15.1.1, discussed in Section 3.11.1 of this progress report.

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, including the spatial variability and the effects of changes in environmental conditions.

Symbols for the lithostratigraphic units of the Paintbrush Group exposed at Yucca Mountain (e.g., Tptpmn, Tptpln) are found in Buesch et al. (1996a).

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 compressive 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 (lithostratigraphic units Tptpmn, Tptpll, and Tptpln) and overlying units and by the presence of heat-producing waste in unit TSw2.

No progress was made during the reporting period. Results from this activity will be reported under SCP Study 8.3.4.2.4.4 (Section 5.2.5 of this progress report).

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. Data will be used in mechanical and thermomechanical calculations of stresses and deformations induced by the presence of heat-producing waste in unit TSw2 (lithostratigraphic units Tptpmn, Tptpll, and Tptpln).

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

Forecast: If funding is provided in the next fiscal year, the main drift of the ESF will be characterized and the spatial variability and effects of anisotropy, pressure, and temperature will be examined. Uniaxial compressive strength and elastic moduli measurements for test specimens from the drift-scale test area of the Thermal Testing Facility will be conducted during the second half of FY 1997.

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, including the spatial variability and the effects of changes in environmental conditions.

Symbols for the lithostratigraphic units of the Paintbrush Group exposed at Yucca Mountain (e.g., Tptpmn, Tptpln) are found in Buesch et al. (1996a).

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 (lithostratigraphic units Tptpmn, Tptpll, and Tptpln) 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 unfunded activity.

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 (lithostratigraphic units Tptpmn, Tptpll, and Tptpln) 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 unfunded activity.

Forecast: If funding is provided in the next fiscal year, the main drift of the ESF will be characterized to assess the lateral variability of mechanical properties of fractures at baseline conditions. Additional potential work includes determining flow properties through fractures as a function of fracture aperture.

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 directly demonstrate performance of repository-scale openings.

Activity 8.3.1.15.1.5.1 - Access convergence experiment. The objective of this activity is to monitor rock-mass deformation around accesses as they are constructed. The intent in the SCP (DOE, 1988) was to measure rock stress changes and deformation of the rock mass as a shaft was progressively constructed to the repository horizon. Since the SCP, changes in the ESF design and testing strategy have lead to a new ESF design where shafts are replaced by a single tunnel. This change made most of this activity unnecessary or a duplication of the efforts being pursued under Study 8.3.1.15.1.8 (Section 3.11.8 of this progress report).

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

Activity 8.3.1.15.1.5.2 - Demonstration breakout room. The objective 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 test was based on data needs related to the ESF design described in the SCP (DOE, 1988) and has been deferred because access to the ESF is by ramps rather than shafts. Test information related to this activity is being collected under Study 8.3.1.15.1.8 (see Section 3.11.8 of this progress report).

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 model evaluation activities, and to demonstrate constructability and stability of repository-sized drifts in lithophysae-poor material. Data will contribute to validating computer models to be used to calculate mechanical responses, as well as empirical evaluations related to nonradiological health and safety.

Detailed planning for this test was completed in FY 1996. The test plan is described in the Thermal Test Design and Layout Report (CRWMS M&O, 1996k). In November 1996, three multipoint borehole extensometers were installed in 27-m-long boreholes extending from the access-observation drift to within 1 m of the rib of the heated drift (when excavated). Installation

occurred before the heated drift was excavated. The access-observation drift, heated drift, and cross drift are parts of the Thermal Testing Facility that will be used in the upcoming drift-scale thermal test discussed in Section 3.11.6, Activity 8.3.1.15.1.6.5. The principal part of the heated drift was excavated between December 1996 and February 1997. Data were recorded as the excavation passed each multipoint borehole extensometer gauge station. These data provide a baseline for rock movement resulting from the excavation of the drift that can be compared with subsequent movement resulting from heating the drift. As excavation proceeded, tape extensometer stations were established inside the heated drift. These measurements of cross-drift closure were monitored as excavation continued. With the exception of the tape extensometer stations, the instrumentation installed for this test will remain in place and also be used for the planned drift-scale thermal test to measure rock response to repository emplacement room heating.

Forecast: Data will continue to be collected from installed instrumentation through the testing period of the heated drift.

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.

Planning, design, and equipment installation continue for testing of the heated drift. During the reporting period, detailed equipment procurement and installation schedules were developed.

Activity 8.3.1.15.1.6.1 - Heater experiment in unit TSw1. The objectives of this activity are 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.

No progress during the reporting period because of the rapid progress of ESF construction.

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 scale in lithophysae-poor tuff (unit TSw2). The data will be used to evaluate thermal and thermomechanical properties of the rock mass and to evaluate the thermal and thermomechanical models.

In early FY 1997, final as-built locations for all the instrumentation and the surveyed geometry of the test block were determined (SNL, 1996a). An initial set of pre-test analyses was performed before the test installation was completed and the single-heater test was initiated (SNL, 1996b). Using the as-built configuration, a second set of pretest analyses was performed (SNL, 1996c). These analyses predict the response of each of the approximately 350 thermal/mechanical sensors.

Approximately six months of data have been recorded from the test thus far. Most sensors appear to be operating properly. Temperatures recorded on the heater package surface and in the surrounding rock were within bounds established by pre-test predictions. As reported in Progress Report #15 (DOE, 1997e), however, the geochemical sensors have not operated correctly since installation. Data through the end of November 1996 has been reduced and reported (SNL, 1997). Data acquired through the end of February 1997 is being reduced and prepared for submittal to the records system. Comparisons of analysis predictions and data collected through the end of November 1996 are under way.

Data reduced and analyzed thus far indicate that the single-heater test is working as designed. Preliminary results indicate that (a) convective heating effects are smaller than predicted from the thermohydrologic-hydrologic analyses, possibly a result of vapor escaping the block or through fracture systems not accounted for in the modeling, (b) at temperatures above boiling, temperature predictions agree quite well with measured values, (c) as expected, rock-mass thermal expansion coefficient appears to be somewhat (10 to 20 percent) less than the thermal expansion coefficient of the intact rock, (d) rock-mass modulus, as measured by a borehole jack, does not yet show any significant effect of temperature, and (e) the rock bolts installed in the heated zone of the test show a greater reduction in tension load than bolts installed on the ambient rock (because the expansion of steel is greater than the rock in this temperature range).

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 models.

The data needs and objectives related to this test have been combined into the ESF tests, under Activities 8.3.1.15.1.6.2 and 8.3.1.15.1.6.5. (Note: The status of Thermal Testing Facility design and construction are described in Sections 7.1.2 and 7.3.3, respectively, of this progress report.)

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 needs and objectives related to these measurements have been incorporated into those of the ESF thermal tests conducted under Activities 8.5.1.13.1.6.2 and 8.3.1.15.1.6.5.

Activity 8.3.1.15.1.6.5 - Heated room experiment. The objectives of this activity are (a) to evaluate the thermomechanical response of welded tuff around repository openings to expected repository conditions during both construction and operation; (b) to develop a data base for evaluating thermal and thermomechanical design analyses and methods applicable for repository considerations; and (c) to use actual site data in predicting drift response and support/rock interactions during construction, operation, retrievability, and postclosure.

Data that will provide a baseline for rock movement were acquired under Activity 8.3.1.15.1.5.3 (see Section 3.11.5 of this progress report) as the drifts for the drift-scale test were excavated. These data are being analyzed.

Final layouts for the instrument arrays have been completed and are being documented. Specifications for each instrument and for the canister and wing heaters have been completed and are being procured. The installation of the first multipoint borehole extensometer parallel to the drift in a 47-m-long borehole began.

Pre-test analyses of the heated drift are under way using site-specific rock property data and planned geometry and gauge locations. These analyses will be completed and documented in June 1997.

Forecast: The single-heater test will continue, and data will be analyzed and compared with pre-test modeling results. Additional modeling will be performed using site-specific data for these comparisons. A design for the drift-scale test will be completed and documented. The instrument boreholes will be drilled and instruments installed in the heated drift.

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. A plate loading test will be conducted as part of the heated drift test. This will allow the measurement of rock-mass modulus under both ambient and heated conditions. The planning for this test is taking place as part of the consolidated thermal test.

The consolidated thermal test consists of two tests: the single-heater test (Activity 8.3.1.15.1.6.2), and the drift-scale test (Activity 8.3.1.15.1.6.5) as described in the In Situ Thermal Testing Program Strategy (DOE, 1995c). A preliminary design of the plate loading test associated with the ESF thermal test was developed and documented in the Thermal Test Design and Layout Report (CRWMS M&O, 1996k).

The niche for the plate loading test in the Thermal Testing Facility has been constructed. Instrumentation is being specified for future procurement, and the reaction frame is being designed. The test will not be conducted until the heaters in the heated drift have been operating for approximately one year so that the rock mass activated by the test will be at elevated temperature.

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 plate loading test design will be finalized. The test equipment will be partially installed in late FY 1997.

3.11.8 Study 8.3.1.15.1.8 - In Situ Design Verification

The objectives of this study are (a) to investigate the effects of the spatial variability of the rock on drift stability, mining activities, and ground supports; (b) 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; (c) to quantify the emanation of radon into repository drifts and observe its dispersion with airflow; and (d) to measure parameters needed to design repository ventilation systems.

Geotechnical design verification activities have been conducted in the ESF to provide data that can be used to confirm adequacy of design, construction, and long-term performance since the 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 a recommendation for mining in the repository by monitoring and evaluating mining activities in the ESF and by conducting mining investigations.

Evaluations of rock mass quality have been keeping pace with ESF excavation. These evaluations were needed for correlation with other studies and to substantiate ground support decisions made by the ESF constructor. Preliminary data were submitted daily and the reviewed data were submitted monthly to the records center.

The blast seismic monitoring and blast damage assessment were performed during construction of the Northern Ghost Dance Fault Alcove and parts of the Thermal Testing Facility, including the access-observation drift, connecting drift, and heated drift. Blast monitoring consists of (a) measuring the near-field and far-field peak particle velocities caused by drill and blast excavation methods, (b) visually inspecting nearby boreholes, and (c) using spectral analysis of the surface wave to estimate blast damage behind the rock surface. Peak particle velocities were measured, and a scaled distance model was developed. Measured velocities have shown considerable variability, and no work to determine the distribution of the particle velocities has been done. Peak particle velocities serve as empirical indicators of the extent of blast damage in the surrounding rock. Blast monitoring in the access-observation drift of the Thermal Testing Facility and Northern Ghost Dance Fault Alcove indicated that damage was generally below the rock damage criteria at 1 m into the rock around the alcove opening. The far-field results obtained on the full-face rounds did not indicate blast anomalies that would result in high peak particle velocity values. Preliminary data were submitted on a daily basis, and the reviewed data were submitted as a Technical Data Information Form package to the Records Processing Center.

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 repository drifts, based on evaluations of the ground-support methodology being used in the ESF and experimentation with other ground-support configurations. Support systems will be recommended, as will methods of selecting appropriate supports for the ground conditions encountered.

Project scientists continued to monitor installed geotechnical instruments and installed new geotechnical instruments closely following the ESF excavation. The geotechnical instrumentation included convergence and strain gauges on steel sets installed as part of the ground support, instrumented rock bolts, and rock bolt load cells. Strain gauges were installed on selected steel sets either before or after installation. For pre-installed strain gauges, installation loads were measured before, during, and after installation. Readings from these instruments have identified no significant concerns regarding the integrity of ground support.

In situ stress measurements were performed in the Thermal Testing Facility at the end of the access-observation drift. The measurements were performed using a mini-fracture method. The results were consistent with previous estimates of horizontal in situ stress (maximum horizontal stress being approximately 50 percent of the vertical overburden stress) (see Section 8.3.1.15 of the SCP).

Activity 8.3.1.15.1.8.3 - Monitoring drift stability. The objectives of this activity are (a) to provide confidence in predictions of usability of the repository underground facilities for their 100-year operational life, (b) to contribute to evaluations of the effectiveness of mining methods and ground supports, (c) to calibrate and refine criteria for determining stability of the openings, and (d) to develop techniques for monitoring stability of the repository drifts.

Project scientists continued to monitor installed geotechnical instruments and installed new geotechnical instruments closely following the ESF excavation. The geotechnical instrumentation included multipoint and single-point extensometers and cross-drift convergence pins. Readings from these instruments have identified no significant concerns related to tunnel stability. Reviewed data were submitted quarterly to the Records Processing Center, with an annual summary report submitted at the end of FY 1996.

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 to design the ventilation systems in the repository underground facility.

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

Forecast: Monitoring of instrumentation in the ESF south ramp will continue until the tunnel boring machine emerges at the south portal. After that, monitoring of installed instrumentation will continue on a quarterly or semiannual basis.

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.

Activity 8.3.1.15.2.1.1 - Anelastic strain recovery experiments in core holes. The objective of these experiments using samples from core holes is to determine the horizontal stresses at Yucca Mountain and especially the spatial variability of these stresses. In situ stress data will contribute to the definition of initial and boundary conditions for mechanical and thermomechanical analyses.

This activity was developed to support the design and operation of the shaft configuration of the ESF and the potential repository. Abandonment of the shaft configuration has eliminated the need for this activity.

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 part 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 the 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 (see Section 3.11.8 of this progress report).

Forecast: No further work is planned for this study.

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 objectives of this activity are to measure the spatial variation of temperature with depth in existing wells; provide baseline temperatures within the repository host rock and surrounding units; measure thermal conductivity (near 25°C) of core samples to check on independent thermal property determinations at various temperatures; and determine heat flow at Yucca Mountain.

Data collection for this activity has been transferred to Study 8.3.1.8.5.2, and pertinent activities are reported under that study (see Section 3.6.9 of this progress report).

Forecast: No additional activity is planned for this study.

3.11.11 Related International Thermal and Mechanical Rock Properties Work

As of November 8, 1995, the subsidiary agreements under which the cooperative work had been conducted were terminated, and all international collaboration was discontinued.

The OCRWM had bilateral agreements with Canada (Atomic Energy of Canada Limited [AECL]), Switzerland (Swiss National Cooperative for the Storage of Radioactive Waste [Nagra]), and Sweden (Swedish Nuclear Fuel and Waste Management Company [SKB]) and has participated in activities of international organizations such as the Organization for Economic Cooperation and Development/Nuclear Energy Agency (OECD/NEA), the European Commission (EC), and the International Atomic Energy Agency (IAEA).

Forecast: No work is planned under the international program.

3.12 PRECLOSURE HYDROLOGY (SCP SECTION 8.3.1.16)

Changes to the Preclosure Hydrology Program since the SCP was issued are summarized in Appendix A, Section A.1.13.

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.

No activities have been funded under this study since FY 1993. Flood potential for the site was described and evaluated in the Technical Basis Report for Surface Characteristics, Preclosure Hydrology, and Erosion (DOE, 1995d).

Forecast: No activities are planned for this study.

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 objective 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 UE-25 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 UE-25 J#13); and (4) identify and evaluate the potential effects of repository-related withdrawals on the ground-water flow system.

This study uses data from other studies; therefore no study plan will be developed. No activities have been funded under this study since FY 1991. Water resource data were reviewed in the Technical Basis Report for Surface Characteristics, Preclosure Hydrology, and Erosion (DOE, 1995d).

Forecast: No activities are planned for this study.

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 for input to Design Issue 4.4.

The purpose of this study was to describe ground-water conditions within and along the potential repository block. Work originally planned for this study has been incorporated into and performed under Study 8.3.1.2.2.9, discussed in Section 3.1.13 of this progress report.

Forecast: No further work is planned under this study.

3.13 PRECLOSURE TECTONICS (SCP SECTION 8.3.1.17)

Changes to the Preclosure Tectonics Program since the SCP was issued are summarized in Appendix A, Section A.1.14.

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.

No study plan will be developed for this activity. The work identified in this section has been completed on the basis of available data and was documented in Perry and Crowe (1987).

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.

This activity has been completed (see Perry and Crowe, 1987).

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-versus-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 years. These hazard estimates will be considered in the design of filters in the mining and surface-facility ventilation systems.

This activity has been completed (see Perry and Crowe, 1987).

Forecast: No further work is planned for this study.

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.

No study plan was developed. The work scope for this study has been combined with that of Study 8.3.1.17.3.6 (see Section 3.13.8 of this progress report).

Forecast: No further work is planned under this study.

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).

The activities composing this study were completed in FY 1996. Results are documented in Whitney (1996). The results form part of the information base supporting the seismic hazard assessment for Yucca Mountain (see Section 3.13.8 of this progress report).

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.

This activity was completed in FY 1996. See Progress Report #15 (DOE, 1997e).

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 by providing 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.

This activity was completed in FY 1996. See Progress Report #15 (DOE, 1997e).

Forecast: No additional work is planned for this Study.

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.

The nuclear test-ban treaty signed by the President in September, 1996 precludes underground testing for the foreseeable future.

Forecast: No work is currently planned for this study.

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.

The activities included in this study were completed in FY 1996. Results are documented in Whitney (1996) and Walck (1996). The results form part of the information base supporting the seismic hazard assessment for Yucca Mountain (see Section 3.13.8 of this progress report).

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.

This activity was completed in FY 1996. See Progress Report #15 (DOE, 1997e).

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. The models will predict ground motion as a function of underground nuclear explosions yield and distance between the underground nuclear explosions and the site.

This work has been completed.

Forecast: No additional work is planned for this study.

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.

The activities composing this study have been completed, and results are documented in Whitney (1996). The results form part of the information base supporting the seismic hazard assessment for Yucca Mountain (see Section 3.13.8 of this progress report).

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.

This activity was completed in FY 1996. See Progress Report #15 (DOE, 1997e).

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.

As part of the probabilistic seismic hazard analyses being conducted in Study 8.3.1.17.3.6 (Section 3.13.8 of this progress report), studies are in progress using resonant-column and dynamic-tensional shear testing to more accurately determine the effects of rock properties on attenuation of ground motion.

Forecast: No additional work is planned for this study.

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 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 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.

A working group was convened to select or develop a method for determining controlling earthquakes. Controlling earthquakes will be determined based on the results of Study 8.3.1.17.8.3.6 (see Section 3.13.8 of this progress report) as well as other available information.

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.

The working group described in Activity 8.3.1.17.3.5.1 will also select or develop an appropriate method for determining seismic design inputs using the identified controlling earthquakes.

Forecast: Project staff will complete the development of the method to determine seismic design inputs and prepare a report describing the method. The method will be implemented in the first quarter of FY 1998.

3.13.8 Study 8.3.1.17.3.6 - Probabilistic Seismic Hazards Analysis

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 that this study combines the objectives originally designated for Studies 8.3.1.17.3.6 and 8.3.1.17.2.1, Section 3.13.2 of this progress report).

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.

See discussion under Activity 8.3.1.17.3.6.2.

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.

The probabilistic seismic hazards assessment process involves using a panel of experts to develop interpretations and assessments of uncertainties required by the hazards calculations. One panel of experts has been characterizing seismic sources and fault displacements, and the other panel has dealt with vibratory ground motion. The development of interpretations is being facilitated through a series of structured workshops to evaluate available data, explore the range of interpretations allowed by the data, examine critically the interpretations proposed by the experts, and provide feedback on the implications of various interpretations for the seismic hazards at the site. The goal of this process is to have differences in interpretations of the experts be true differences in judgment and not differences in access to data, definitions, or understanding other experts' interpretations.

A historical earthquake catalogue for use in the probabilistic seismic hazards assessment was compiled from all available data sources including existing national and regional catalogues and special studies of individual earthquakes. The catalogue covered a region extending to 300 km radius from the site. A substantial effort was made to remove duplicate events and identify and delete all nuclear explosions. Aftershocks induced by the explosions were also removed using a space-time window. All events were converted to moment magnitude using a set of equations derived from existing literature and studies by the University of Nevada at Reno. The catalogue was declustered using two sets of algorithms. The resulting two catalogues were made available to the seismic source experts for their use in characterizing the background earthquake and areal source zones.

The probabilistic seismic hazards assessment for Yucca Mountain resumed. This assessment, which began in FY 1995 and was suspended in FY 1996 because of budget constraints, consists of two parts:

- Seismic source and fault displacement characterization
- Ground motion characterization.

For the seismic source and fault displacement characterization, six teams of three experts each were formed; team individuals provide a range of expertise (paleoseismology, regional geology and tectonics, seismology) needed to develop interpretations and evaluate uncertainties. For the ground-motion characterization, seven individual experts were selected.

During the reporting period, four workshops and a field trip were held:

1. Seismic Source Characterization Hazard Methodologies Workshop

2. Seismic Source Characterization Alternate Models and Interpretations Workshop and Associated Field Trip

3. Seismic Source Characterization Preliminary Interpretations Workshop

4. Methods, Models, and Preliminary Interpretations Workshop on Ground Motions at Yucca Mountain.

The workshop on hazard methodologies was held October 16-18, 1996, in Salt Lake City, Utah. This workshop identified and outlined methods and approaches to characterize seismic sources for ground-motion and fault-displacement hazards assessments.

The Seismic Source Characterization Preliminary Interpretations Workshop was held January 6-8, 1997, in Salt Lake City, Utah. This workshop (a) allowed the expert teams to present and discuss their preliminary interpretations regarding several key issues in seismic-source characterization; (b) trained the teams in the process of elicitation and uncertainty characterization; and (c) presented additional information and recent analyses important to Yucca Mountain seismic-hazards assessments. Presentations were made primarily by the expert panel members, followed by group discussions on promoting interaction and common understanding among the experts.

The Ground Motion Models and Interpretations Workshop was held January 9-10, 1997, in Salt Lake City, Utah. The purpose of this workshop was to identify and outline methods and approaches to characterize numerical and empirical models for assessing ground-motion attenuation, path effects, and site response for Yucca Mountain.

Formal elicitation of experts' interpretations regarding seismic-source characterization started January 21, 1997, at the offices of Geomatrix Consultants, San Francisco, California. The elicitations were a means to collect and assemble the input for calculations of ground-motion and fault-displacement hazards by development of preliminary logic trees characterizing interpretations and assessments of uncertainty. The elicitation meetings facilitated the development of a logic tree structure for each expert or expert team and initiated the process of including weighted interpretations in the tree. Formal elicitations continued into February, at which time preliminary calculations were performed and the results returned to the experts for sensitivity analyses and feedback discussions.

Proceedings of these workshops and the field trip are described in four reports (CRWMS M&O, 1996m and 1996n; CRWMS M&O, 1997b and 1997c).

Forecast: The experts' assessments will be finalized following feedback workshops on the seismic-source and ground-motion characterizations. The final assessments will be used as input to final calculations of the annual probabilities of varying levels of ground motion and fault displacement at Yucca Mountain. The seismic hazard assessment process and its results will be documented in a report that will describe the logic basis and data used by the experts (or expert teams) in developing their assessments. The formal elicitation process, evaluations, probabilities, and calculations of potential ground motions and fault displacements will be completed in the second half of FY 1997. The report on the probabilistic seismic hazards assessment will be prepared, technically reviewed, and submitted to YMSCO in August 1997.

Principal results of the probabilistic seismic hazards assessment also will be summarized in Progress Report #17.

3.13.9 Study 8.3.1.17.4.1 - Historical and Current Seismicity

The objective of this study is to compile information on recorded earthquakes near Yucca Mountain. This information will be used to help identify and characterize potentially relevant 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, under ground nuclear explosion, cavity collapse, or blast. For potentially damaging earthquakes ($M_M \geq 5.5$) in the study region, available information will be compiled on ground-motion intensity, availability of strong-motion records, and extent and style of faulting.

Work on this activity was completed in FY 1996. Preparation of an expanded earthquake catalog to support the probabilistic seismic hazard is discussed in Section 3.13.8 of Progress Report #14 (DOE, 1996g).

Activity 8.3.1.17.4.1.2 - Monitor current seismicity. The objective of this activity is to provide empirical information on the frequency of earthquake occurrence in the southern Great Basin; the orientation, depth, and style of faulting; 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 in the vicinity of Yucca Mountain continued. At the end of the reporting period, the network consisted of 24 3-component stations employing digital acquisition systems in the field. Negotiations are in progress with the National Park Service for approval to install instruments at three remaining sites. The network covers an area with an approximate 50 km radius around Yucca Mountain. More than 800 earthquakes have been located within or near the network during the past 6-month period. The largest event occurred near the northeast corner of the Nevada Test Site on January 17, 1997 and had a local magnitude (M_L) of 3.5.

In November 1996, a significant earthquake swarm occurred to the north of the network, near Saucer Mesa, on the south flank of the Kawich Range 60 km north of the Yucca Mountain site. The largest event in this sequence had a local magnitude (M_L) of 4.1; several other events had magnitudes larger than 3.0. Several hundred aftershocks were recorded at the closest network station. The data from this event will be an important contribution to the determination of site response to seismicity.

Von Seggern and Smith (1997) describe the first full year (FY 1996) of operation of the digital network. This report covers numerous aspects of the network operation and performance, as well as the seismicity for FY 1996. More than 2100 earthquakes were located within or near the network and incorporated into the FY 1996 catalog. Focal mechanisms for more than 100 events were determined (a significantly larger number than in previous years). The detection capability in the immediate vicinity of Yucca Mountain was shown to have a threshold of M_L = -0.3 or less. Since the start of the digital network recording, 16 earthquakes within approximately 10 km of Yucca Mountain have been documented. These earthquakes were described in detail, and they confirm the overall low seismicity rate at Yucca Mountain. Using the high-quality digital network data, a moment-magnitude relation for the Yucca Mountain region was defined, and the rupture plane of the smallest detectable earthquake was determined to be on the order of 3 to 5 m. The smallest M_L observed was -0.9, corresponding to a seismic moment of roughly 3×10^{16} dyne-cm.

Tomography Using Teleseismic P Waves

A study of the Yucca Mountain region using teleseismic tomography was completed (Biasi, 1996). This study used relative teleseismic delay times from 117 earthquakes to invert for crustal and upper mantle velocity structure in the vicinity of Yucca Mountain. Both a regional model and a localized, more detailed model were developed. Results for the regional model show 2 to 3 percent high velocities extending to a depth of 200 km or more beneath the Timber Mountain/Silent Canyon caldera structure and 1 to 3 percent low velocities to the northeast, east, and southeast of Timber Mountain. At shallower depths (greater than about 70 km), 1 to 2 percent high velocities are also imaged to the west-northwest of Timber Mountain. Using the more detailed model, 1 to 3 percent low velocities are shown for crustal depths beneath Little Skull and Skull mountains. These velocities are interpreted to result from a structurally controlled low velocity zone associated with the Rock Valley fault. Shallow high velocities beneath Yucca Mountain connect with the Timber Mountain structure. For the detailed model, at mantle depths, the pattern of low velocities beneath Rock Valley and high velocities beneath Timber Mountain is still present. Although partial melt in small fractions cannot be eliminated because of resolution limitations, there is no large low-velocity zone under Crater Flat or Yucca Mountain that would suggest a major source of magma.

Network Processing Software

Beginning October 1, 1996, the Project converted to the Joint Seismic Project Center Datascope data base and seismic software for the routine processing of seismic events. Parametric data are now routinely stored in the Datascope tables and accessed with Datascope applications. This conversion has improved the efficiency of work and the ability to retrieve and analyze data.

Three major upgrades in software were made in this reporting period. The first was to JSPC 3.2 software, which addresses many previous "bugs" and enhances data processing. The second upgrade was to the Solaris operating system, specifically Solaris 2.5.1, on Project Sun computers. The third upgrade was the installation of the Earthworm system from the University of Alaska. This system was installed in parallel with the current processing scheme. Picking and

associating signals with events is near real time. This new system will produce automatic locations and rapid display of data. Access to external data from other networks is inherent in the system; this capability will be very useful should a large earthquake occur near Yucca Mountain.

The paging system hardware, part of the Earthworm system, was installed and tested. This hardware provides the capability to send text, such as earthquake location and magnitude, to the alpha-numeric pager, providing a much higher level of information than simple beeper signals. The hardware also expedites University of Nevada, Reno, Seismological Laboratory response to major earthquakes, as well as to system problems.

Foam-Rubber Modeling of Normal-Fault Earthquakes

Physical models of faulting, such as foam-rubber models (as distinct from numerical or mathematical models), obey static and dynamic mechanical laws, and thus can be used to gain insight into the physical processes involved. In this study, surface accelerations from normal faults were compared with those from strike-slip geometries. The data show that surface accelerations near the normal fault trace are systematically lower, by an average factor of about 0.10, compared with the accelerations at the side sensors, which represent strike-slip motion. These results suggest that kinematic modeling of ground motion using classic dislocation theory should apply a significant adjustment of the fault slip time function on the shallow part of the fault. The results indicate that estimates of accelerations for normal faults should be scaled down considerably from value bases on current regression curves or simulations.

Physical modeling was performed using a shallow weak layer to verify the physical basis for assuming a long rise time and a reduced high-frequency pulse for the slip on the shallow parts of faults. The results indicate that a 2-km deep, weak zone along strike-slip faults could indeed reduce the high-frequency energy radiated from shallow slip. This effect can best be represented by superimposing a small-amplitude, short rise-time pulse at the onset of a much longer rise-time slip. A weak zone was modeled by inserting weak plastic layers a few inches thick into the foam rubber model. The pulse observed in the model for the 3-in. layer has been reduced by a factor of 0.4 compared with the average value for the case with no weak zone; but, because only one observation was available, this value is quite uncertain. For the 6-in. weak zone, the average pulse is reduced by a factor of 0.46. For the 8-in. case, the reduction factor is 0.11. For the 12-in. case, the reduction factor is 0.045. These results indicated that the thicker the weak layer, the more difficult it is for a short rise-time acceleration pulse to push through the weak layer to the surface. Thus, this is an approximate justification for reducing the high frequency radiation from shallower parts of strike-slip faults.

Precarious Rocks

The distribution of fallen, precarious, and semiprecarious rocks around the Little Skull Mountain earthquake of 1992 has been mapped in more detail. The distribution is consistent with a well-constrained source model of this earthquake. Observations suggest that an earthquake of the magnitude of Little Skull Mountain is statistically unexpected in the time

period of the historical monitoring (about 100 years) and that no events much larger than this earthquake have occurred in the last few thousand years.

Additional surveying of precarious rocks was conducted in northern Nevada, especially in regard to normal-fault regimes. Field measurements of quasi-static toppling accelerations indicate that, for instance, the accelerations of the 1915 Pleasant Valley Earthquake did not exceed 0.25 g in spite of its magnitude of 7.7. This has important implications for future normal-fault style events in the Basin and Range.

Historical Seismicity and History of Network Operations

A draft report has been completed on the historical seismicity of the southern Great Basin for the inclusion in Project Integrated Safety Assessment (in prep.) Section 3.3 (Site and Regional Geologic Description).

The report generally describes the historical seismicity within 300 km of Yucca Mountain, with a focus on significant regional earthquakes, and provides a detailed description of the activity within 100 km. Also included is a comprehensive bibliography of seismological studies and seismicity reports that have been conducted or compiled that are relevant to the 300 km and 100 km regions. A history of seismic network operations and network coverage for the historical period in southern Nevada and eastern California is also included; seismic network operations and data analysis procedures are described in the context of the quality and completeness of the historical record.

Strong Motion Network

Data from the Yucca Mountain strong motion network were downloaded in January. All the stations are operating except for the station at the Field Operations Center. The instrument at the Field Operations Center is being repaired for the second time. A Nevada Work Instruction has been prepared and reviewed to cover operation of this network and the handling of data from it.

Tunnel Monitoring

A three-component strong-motion sensor was installed during October 1996 in the Thermal Testing Facility. The installation is configured with three Kinemetrics FBA-11 1g sensors and a REFTEK 16-bit portable recorder with 528 Megabyte disk drive. Time was established outside of the ESF before the unit was installed, and some clock drift is expected. With clock corrections, however, accurate time should be recoverable. This strong motion station was visited in January, and the data collected up to that time were recovered.

Site Effects

The data from several hundred earthquakes recorded on the regional digital network have been organized and prepared for the analysis of the attenuation and site effect within the network region. Because of the decreased detection threshold and the quality of the recordings, several

thousand seismograms can be used in the inversion. The records have been instrument corrected and the horizontal records have been rotated into the radial and transverse components of ground motion. Body-wave spectra have been calculated for both P and S wave arrivals and for pre-event noise for all three components of ground motion at each station for each event. Spectra have been calculated from 1 to 50 Hz, and these results have been organized in a data base. All information about the source locations has also been compiled into the data base, and the organization of the data has been established for the inversion procedure. This first study is designed to determine a general Q(f) for the region and the frequency-dependent site effects at each site of the regional digital network for weak ground motion. Because of the nature of the data from preliminary analyses, Q(z) and azimuth-dependent site effects may also be resolved with further study. A companion study is under way to calculate the site effects at the Yucca Mountain strong ground motion stations, and portable instruments are currently running in trigger mode at these sites.

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 excavation of the repository.

Seismic monitoring within the ESF and by stations located near Yucca Mountain is providing a data base that will be used to assess the potential for excavation-induced seismicity. This data collection is being performed under Activity 8.3.1.17.4.1.2.

Forecast: When permits can be obtained for three stations in Death Valley National Park, the digital monitoring network will be extended to its full 27 stations. Roughly 1000 events are expected to be located in the last half of FY 1997, and with the full network the locating capabilities will be significantly improved for the Amargosa Desert, Funeral Mountains, and Bullfrog Hills. Within the next six months, location notification capability is expected at near real time for earthquakes within the network using Earthworm software. The site effects will be determined at the sites of the permanent network and the strong-motion network and Q(f) will be determined within the network. The transition of the University of Nevada, Reno, Seismological Laboratory studies to the Management and Operating Contractor should be formally complete, allowing data to be gathered solely under approved quality assurance procedures. Monitoring will continue within the ESF and at borehole UE-25 UZ#16 for unusual seismic activity.

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.

This activity was completed in FY 1996. See Progress Report #15.

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.

This activity was completed in FY 1996. See Progress Report #15 (DOE, 1997e).

Forecast: No further work is planned for this study.

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 primary objectives of this activity are to provide geophysical data and analysis that will (a) help to identify, locate, and characterize potentially significant seismic source zones; (b) characterize the crustal velocity structure and define lateral inhomogeneities in that structure; and (c) assist in determining whether buried magma bodies are present in the Yucca Mountain area.

This activity was completed in FY 1996. See Progress Report #15 (DOE, 1997e).

Activity 8.3.1.17.4.3.2 - Evaluate Quaternary faults within 100 km of Yucca Mountain. The primary objectives of this activity are to establish the abundance, distribution, and geographic orientation of known and suspected Quaternary faults within 100 km of the potential repository site, and to characterize those faults within this area whose apparent length or recurrence rate indicate a potential for future earthquakes of sufficient magnitude to affect design or performance of the waste facility.

This activity was completed in FY 1996. See Progress Report #15 (DOE, 1997e).

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.

This activity was completed in FY 1996. See Progress Report #15 (DOE, 1997e).

Activity 8.3.1.17.4.3.4 - Evaluate the Bare Mountain fault zone. The objectives of this activity are (a) to evaluate the potential for ground shaking associated with future movement along the Bare Mountain fault zone; (b) to estimate the age of the most recent faulting on the Bare Mountain frontal fault; (c) to estimate the recurrence intervals of faulting; (d) to determine the nature and age of faulting within the fault complex east of the frontal zone, (e) to determine the nature of tectonic control of the location and orientation of the main wash in Crater Flat; and (f) to determine the subsurface configuration of fault zones.

This activity was completed in FY 1996. See Progress Report #15 (DOE, 1997e).

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 faults and lineaments; 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 unfunded 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.

This activity was completed in FY 1996. See Progress Report #15 (DOE, 1997e).

Forecast: No further work is planned for this study.

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 objectives of this activity are (a) 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; and (b) to estimate the total displacement, including strike-slip and dip-slip components, of Quaternary datums.

This activity was completed in FY 1996. See Progress Report #15 (DOE, 1997e).

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.

This activity is complete. See Progress Report #15 (DOE, 1997e).

Activity 8.3.1.17.4.4.3 - Evaluate the Stagecoach Road fault zone. The objective of this activity was intentionally deleted.

The objective of this activity has been met under Study 8.3.1.17.4.6 (see Section 3.13.14 of this progress report).

Activity 8.3.1.17.4.4.4 - Evaluate the Cane Spring 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 Cane Spring fault system.

This activity was completed in FY 1996. See Progress Report #15 (DOE, 1997e).

Forecast: No further field work is planned for this study.

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.

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.

This activity is complete. See Progress Report #13 (DOE, 1996f).

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.

This activity was completed in FY 1996. See Progress Report #15 (DOE, 1997e).

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.

This activity was completed in FY 1996. See Progress Report #15 (DOE, 1997e).

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 extensional deformation of the upper plate.

This activity is complete. See Progress Report #13 (DOE, 1996f).

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.

This activity was canceled because active detachment faulting is not present at Yucca Mountain. See Progress Report #15.

Forecast: No additional work is planned for this study.

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.

See the description under the following activity (8.3.1.17.4.6.2).

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 (a) 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 (b) 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.

Nearly all the work for this study was completed in FY 1996. See Progress Report #15 (DOE, 1997e).

Forecast: Any additional work deemed necessary will be performed under activity 8.3.1.17.3.6.2.

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 study and the eight associated activities. Field geophysical surveys and analysis of the subsurface geometry and concealed extensions of Quaternary faults are to be performed under Study 8.3.1.4.2.1 discussed in Section 3.3.3 of this progress report. 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 evaluations associated with Study 8.3.1.17.3.6, discussed in Section 3.13.8 of this progress report.

Forecast: No additional work is planned under this study.

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, but 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 (Section 3.13.20 of this progress report), the scope of this study is now limited to one activity.

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.

Previous hydrofracture stress measurements are described in Stock et al. (1985). Interferences concerning the orientation of the stress field based on earthquake focal mechanisms are summarized in Whitney (1996, Chapter 7) (see Progress Report #15, DOE, 1997e). New hydrofracture stress measurements performed in the ESF as part of the In-Situ Design Verification program are described in Section 3.11.8.

Forecast: Remaining work for this study is contingent upon the drilling of new boreholes.

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.

There will be no study plan developed for this SCP section and no work is being planned. The work scope was transferred to and performed under Studies 8.3.1.5.1.4 and 8.3.1.17.4.12 (Sections 3.3.4 and 3.13.20, respectively, of this progress report). Data to describe the characteristics and parameters of tectonic features were collected under Studies 8.3.1.17.4.3 and 8.3.1.17.4.6 (Sections 3.13.11 and 3.13.14, respectively, of this progress report).

Forecast: No additional work is planned under this study.

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. Secondary objectives are (a) to characterize the historical rate of uplift and subsidence in the Yucca Mountain region and (b) to 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 work involved in these activities is closely interrelated, the activities have been combined.

No progress was made during the reporting period; this was an unfunded study. See Appendix A, Section A.1.14.4 of this progress report for additional information.

Forecast: No work is planned in FY 1997.

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.

No unique data are required by this study. All activities were transferred to Study 8.3.1.17.4.10 (see Section 3.13.18 of this progress report).

Forecast: No further work is planned under this study.

3.13.20 Study 8.3.1.17.4.12 - Tectonic Models and Synthesis

The objectives of this study are (a) to synthesize data relevant to tectonics; (b) 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; (c) 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; (d) to estimate effects of changes on rates and nature of crustal strain at Yucca Mountain and vicinity, and (e) to estimate future rates of tectonic processes at Yucca Mountain.

Activity 8.3.1.17.4.12.1 - Evaluate tectonic processes and tectonic stability at the site. The principal objectives of this activity are to synthesize geologic and geophysical data pertaining to faults (normal, detachment, strike-slip) and other structural and volcanic features in the Yucca Mountain area; and to evaluate these data in terms of the tectonic stability of the potential repository site. For additional information on the objectives, see Study Plan 8.3.1.17.4.12.

See description under Activity 8.3.1.17.4.12.2.

Activity 8.3.1.17.4.12.2 - Evaluate tectonic models. The objectives of this activity are (a) 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; (b) 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)); (c) 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 (d) 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.

Most of the work for this activity was completed in FY 1996. See Progress Report #15 (DOE, 1997e).

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.

Work to accomplish the objective of this activity is being performed under Study 8.3.1.8.2.1 Tectonic Effects: Evaluation of Changes in the Natural and Engineered Barrier Systems Resulting from Tectonic Processes and Events. Progress is discussed in Section 3.6.3.

Forecast: Any additional work deemed necessary for this study will be conducted under Study 8.3.1.8.2.1 (Section 3.6.3 of this progress report).

3.14 STUDY 8.3.1.20.1.1 - ALTERED ZONE CHARACTERIZATION

The Altered Zone Characterization Program was not included in the SCP. However, the changes to the program are summarized in Appendix A, Section A.1.15.

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 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 objective of this activity is to evaluate the impact of chemical, mineralogical, and mechanical change on hydrological properties, particularly on porosity and permeability, and the kinetics of these processes, as functions 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.

Previous plug-flow reactor experiments (a) established the overall protocol for conduct of these experiments, and (b) demonstrated the ability to simulate reactive transport in simple chemical systems (see Progress Report #15, Section 3.14, DOE, 1997e). During this reporting period, plug-flow reactor experiments have been designed to consider reactions in complex geological media similar to that near the repository horizon. One of these experiments has been completed and successfully modeled, using the reactive-transport code GIMRT (Global Implicit Multicomponent Reactive Transport). (See Table 6-1 in Chapter 6 for a description of the code). This work was done to establish reaction kinetics constraints for future simulations that will use more reactive vitric material.

In the first experiment (Johnson et al., 1997), Tsw2 rock was pulverized to 125 to 75 micron size fraction, placed in a titanium cylinder 3.1-cm long with a 0.66-cm effective diameter, and infiltrated by distilled water at a flow rate of 25 mL/day for 36 days at 240°C and 84.1 bar. As reacted fluid exited the plug-flow reactor during progressive dissolution of the crushed tuff, concentrations of the major cations (calcium, sodium, potassium, silicon, aluminum, and magnesium) were systematically monitored; these attained approximately steady-state values within 3 to 4 days. [Note: Although the plug-flow reactor experiment was performed at 240°C and 84.1 bar, the thermodynamic data base used in the GIMRT simulation analog is constructed for $P_{sat}(T)$, which at 240°C is 33.4 bar. This pressure discrepancy, however, is insignificant.]

The solid reaction products were examined using standard x-ray diffraction techniques, and scanning electron microscopy. The results demonstrate clear textural evidence consistent with dissolution of primary cristobalite and feldspars at the inlet of the reactor, which is consistent with the results from the simulations. At the outlet, dissolution of feldspars was apparent as well, although the extent of dissolution was significantly less than that observed in the inlet. It was also evident that cristobalite precipitation had begun, which was consistent with the observation in the water analyses that cristobalite saturation had been reached.

This experiment was used to determine the appropriate dissolution and precipitation kinetics parameters for the phases involved in reactive transport. The crushed tuff was used to evaluate the suitability of existing models of reaction kinetics, where the data was generated over a short time period at laboratory scale. Other experiments using fractured and intact materials are a means to determine the suitability of scaling process models from crushed materials to mountain scale. Primary consideration was given to the dissolution kinetics of the primary feldspar component (K-feldspar, albite, anorthite), and the precipitation kinetics for the possible secondary phases (quartz, cristobalite, muscovite, paragonite, kaolinite, pyrophyllite, gibbsite, diaspore, and boehmite). Varying the reaction rate parameters for these phases, within the

uncertainty limits of the measured values for the rate constants and for the activation energies, allowed the results of the experiments to be accurately reproduced. Rate constants most suitable for modeling evolution of these rocks were obtained.

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 outcomes 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.

Extensive simulation efforts indicate that the OS3D/GIMRT and NUFT code packages provide the most suitable capabilities to model the processes of concern, among the code packages considered. Appendix I describes these codes, which are now in use to evaluate a variety of reactive transport concerns.

During the reporting period, the OS3D/GIMRT code package was further tested by considering specific numerical effects on the calculational results. Preliminary tests were made of different computational modes, using similar initial input. Interest here was on determining whether significant discrepancies appear in the results, if input options are exercised for concentration limits, and if constraints are placed on extent of supersaturation to control precipitation kinetics. Results to date indicate little effect on the results of the calculations.

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 objective of this activity is to determine parameter values, limits, or ranges needed to define the waste package environment.

Simulations were conducted to define the conditions under which dissolution and/or precipitation would impact matrix and fracture porosities and permeabilities. Reactive transport simulations were conducted for flow regimes that may be expected near the boiling front under conditions in which saturation has been achieved. Preliminary results demonstrate that the primary concern for hydrological properties is the formation of cristobalite and/or calcite plugs in fractures in which fluxes exceed approximately 100 mm per year. These preliminary results show that under these conditions, precipitation of solids at the boiling front have the potential to seal fractures in less than 100 years. These results will be refined as further simulations are conducted.

Activity 8.3.1.20.1.1.4 - Performing bounding calculations of the effect of coupled hydrological and reactive transport processes on thermal evolution. The objective of this activity is to determine the response of the altered zone over time using, as initial conditions for simulations, optional designs, and operating configuration of the potential repository.

The effort this year is focused on establishing the location and magnitude of changes in hydrologic properties that could influence heat transfer. The results described for Activity 8.3.1.20.1.1.1 (using the reactive transport simulator GIMRT) were used (a) to establish reaction rates for mineral phases important for changes in hydrological properties that control heat and mass transfer, (b) to predict potentially verifiable porosity and mineralogic evolution during reaction between idealized TSw2 rock and infiltrating fluid compositions, and (c) to model unverifiable, long-term porosity evolution in the post-emplacement altered zone. The results of these models can be provided to thermal-hydrological codes, such as NUFT, to allow iterative updating of flow fields, in order to bound the effects of dissolution and precipitation on repository thermal evolution.

The results of the simulations mapping mineralogical changes are being incorporated into simulations of the thermal evolution of the near-field environment and the altered zone. Preliminary results suggest that fluid movement may be restricted by plugging of fractures at the boiling front, in regions where movement of the boiling front is slow. These results also suggest fluid may drain through pillars between emplacement drifts due to condensation as water enters regions of lower temperatures. Further modeling of fluid transport to regions below the emplacement drifts is in progress, to evaluate the extent to which flow barriers may form because of porosity changes associated with the development of alkaline plumes below emplacement drifts, caused by water interacting with cementitious invert materials.

These initial results are preliminary, and the predictions require considerable refinement.

Forecast: Descriptions of the conditions under which barriers or preferential flow pathways may form will be determined and documented in a format useful for total system performance assessment. Activities will concentrate on conducting detailed reactive transport simulations using repository-relevant properties and geometries. The simulations will be tested using a small suite of experiments to verify the applicability of the simulation results. Activities will focus on establishing realistic reaction rates within the bounds of experimentally measured rates.