Nuclear Waste Policy Act
(Section 113)

Site Characterization Progress Report:
Yucca Mountain, Nevada

October 1, 1993 - March 31, 1994

Number 10

October 1994

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

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Department of Energy
Washington, DC 20585
September 19, 1994

NOTE TO READERS:

In accordance with the requirements of Section 113(b)(3) of the Nuclear Waste Policy Act of 1982, as amended, the U.S. Department of Energy has prepared the tenth in a series of progress reports focused on site characterization at the Yucca Mountain candidate site in Nevada. The document is entitled "Site Characterization Progress Report: Yucca Mountain, Nevada" and covers the period from October 1, 1993, through March 31, 1994.

The Program continued to make significant progress during this reporting period. Delivery of the tunnel boring machine began on March 29 and continued through May 3 with 52 truckloads delivered in all. Progress was also made in the Exploratory Studies Facility design activities that are required to support operation of the tunnel boring machine. In addition, the first test alcove in the Exploratory Studies Facility was excavated for purposes of conducting radial borehole and hydrochemistry tests.

The Director of the Office of Civilian Radioactive Waste Management approved a change to the Civilian Radioactive Waste Management System Program Baseline to incorporate the multipurpose canister concept and to proceed through the design and certification phase. The multipurpose canister, combined with appropriate outer containers or overpacks, will provide a standard package for storage, transportation, and disposal of spent nuclear fuel.

Another major iteration of Total System Performance Assessment was completed. Two reports summarize the results: "Total-System Performance Assessment for Yucca Mountain - SNL Second Iteration (TSPA-1993)" prepared by Sandia National Laboratories and "Total System Performance Assessment - 1993: An Evaluation of the Potential Yucca Mountain Repository," prepared by the Civilian Radioactive Waste Management System Management and Operating Contractor. Results of the total system studies show that aqueous releases for 10,000-year predictions are likely to be well below the remanded Environmental Protection Agency's standards, while gaseous releases (carbon-14) generally exceed the standards.

The Office of Civilian Radioactive Waste Management has initiated changes to the Program that are termed the Proposed Program Approach. This approach was developed to bring the program of work at Yucca Mountain into conformity with the fiscal year 1995 budget request and out-year funding expectations and to develop realistic estimates of schedules and costs.

Sincerely,

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

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FOREWORD

For ease of use of this document, the reader should note that the Executive Summary is intended to provide a summary of major decisions, activities, accomplishments, and issues of interest during the reporting period. Chapter 1, Introduction, provides background information to assist the reader in understanding the current status of the program. Chapter 2 provides specific detailed discussions of activities conducted during the current reporting period and has two major divisions. Section 2.1, Preparatory Activities, provides information on select preparatory activities necessary to conduct site characterization and design activities. Sections 2.2 through 2.8 provide specific details on studies and activities conducted during the reporting period and follow the original structure of the Department's 1988 Site Characterization Plan. Chapter 3 contains the current summary schedule, while Chapter 4 provides a description of the program outreach, including activities during the reporting period, in both the international program and public outreach. Chapter 5 presents an epilogue of significant events that occurred after the end of the reporting period, but prior to printing of this report, and that are believed to be of interest to the reader. Therefore, for general interest a reader may wish to first review the Executive Summary, Introduction and Epilogue prior to turning to more detailed discussion of technical studies and activities of interest in Sections 2.2 through 2.8.

Information in this Progress Report is conveyed in a summary form for convenient information exchange. Additional specific information is available in reference documents identified in Appendix D. Also, while serious effort has been made to minimize the use of acronyms throughout the document, a list of acronyms, abbreviations, and symbols (Appendix E) is included to further assist the reader.

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EXECUTIVE SUMMARY

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), the U.S. Department of Energy has prepared this report on the progress of site characterization activities at Yucca Mountain, Nevada, for the period October 1, 1993, through March 31, 1994. This report is the tenth in a series issued at intervals of approximately six months during site characterization of Yucca Mountain as a possible site for a geologic repository for the permanent disposal of spent nuclear fuel and high-level radioactive waste. Also included in this report are descriptions of activities such as public outreach and international programs that are not formally part of the site characterization process. Information on these activities is provided to report on all aspects of the Yucca Mountain studies.

The Exploratory Studies Facility design and construction activities progressed significantly during this reporting period. The design change for the enhancement to the configuration reported in Progress Report #9 is being implemented. This change reduces the grades in the initial loop formed by the North Ramp, main drift, and South Ramp and reorients the main drift to be parallel and adjacent to the Ghost Dance fault along much of its length. Advantages of this change include increased repository design flexibility and accommodation of conventional rail haulage as a future option. Given the changes in the configuration of the Exploratory Studies Facility, the previous seismic design basis has been reevaluated and found to be inappropriate. New seismic design inputs are under development and will be based on annual exceedance probabilities. Development of revised repository layout concepts continued during the reporting period and a draft set of drawings was prepared showing the interfaces between the Exploratory Studies Facility and the proposed repository.

Delivery of the tunnel boring machine began during the reporting period. Significant progress was made in the Exploratory Studies Facility design activities that are required to support operation of the tunnel boring machine. Design packages for the tunnel boring machine launch chamber were completed and the design packages associated with the North Ramp progressed to support the schedule. After approximately six months of shakedown, full tunnel boring machine operations are scheduled to begin in the second quarter of fiscal year 1995. Cost savings were realized by relocating the muck storage area for the Exploratory Studies Facility to the east of the North Portal access road and expanding the existing North Portal pad to the southeast for additional storage of equipment and material. These changes are currently being incorporated into the appropriate design packages.

The first test alcove in the Exploratory Studies Facility was excavated during the reporting period for purposes of conducting radial borehole and hydrochemistry tests. Both of these tests are aimed at detecting vertical movement of water in the liquid or vapor phase. The radial borehole test will also provide information on the effects of excavation on hydrologic properties. The face of the test alcove is at a distance of 34.5 meters from the centerline of the Starter Tunnel. Equipment for the radial borehole tests has been designed and will consist of multiple packers, each 2 meters in length with a 0.4-meter sampling and

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monitoring port. In related studies, the effects of shotcreting on hydrochemistry test results were investigated by collecting testing samples of the shotcrete for carbon dioxide adsorption studies. Also under investigation is the time interval that should be allowed to elapse after blasting to avoid contamination of gas chemistry samples.

Important surface-based and laboratory studies continued during this reporting period. The maximum depth of seasonal influences on shallow infiltration was estimated based on records of water content versus depth at 97 boreholes. This information was used in conjunction with measured material properties, water content, and assumptions about fracture flow to create a map of the near-surface potential moisture flux at Yucca Mountain. The map identifies potential areas of relatively high net-infiltration rates and serves as important input to site-scale unsaturated flow models. Gas samples were obtained and air permeability measurements were made in the Tiva Canyon, Topopah Spring, Calico Hills, and Prow Pass rock units at UE-25 UZ-16. Performance of field equipment has exceeded expectations and more than 200 air-injection tests have been completed. Drilling continued at USW UZ-14 during this period to a depth of 465 meters on March 21, 1994. Chemical and isotopic data collected to date do not allow quantification of the amount of drilling fluid present in the fluid encountered above the basal vitrophyre of the Topopah Spring Member in USW UZ-14.

The planning documents needed to proceed with the Large Block Test were prepared and issued. The objective of this test is to develop and refine methods for characterizing environmental responses to the emplacement of waste and understanding the processes involved. An appropriate rock volume was located and the sides were cut by a belt saw. The top was mapped and vertical boreholes were completed to allow permeability testing, geophysical measurements of moisture conditions, and core logging. Preliminary test results indicate that the permeability is on the order of 5 to 10 millidarcy, which should be adequate to allow the rock to dry out and develop a condensate reflux zone for geochemical testing.

Another area of notable progress is in the geochemistry program. With regard to the validity of experimental data, concerns had been raised about whether the grinding of rock samples during preparation for batch sorption studies could increase surface sites for sorption. A comprehensive laboratory study has been completed that addresses this concern and confidence is high that no significant increase in sorption sites occurs due to grinding. The methodology used over the past decade for empirical batch sorption data collection and sample size selection has been shown to be valid. Similarly, data on the solubility limits of plutonium, americium, and neptunium at variable temperatures and pH indicates that previous work has been carried out below the solubility limits. This increases confidence that previous sorption data are not biased by the occurrence of precipitation.

A one-dimensional simulation of water movement beneath Pagany Wash was completed using best estimates of hydrologic properties. The simulation reproduced observed saturation and water potential profiles in boreholes in the area reasonably well. Simulations indicated that contact zones between nonwelded and welded tuffs provide a significant capillary barrier; this observation suggests that potentially greater infiltration associated with future climate change will be prevented from penetrating into the densely welded intervals of the Topopah Spring Member for long periods of time. Two-dimensional simulations were used to examine

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the importance of lateral subsurface flow as a spreading mechanism for focused surface infiltration. Results suggest that spatially variable surface infiltration may be more evenly distributed at repository depth; thus, the flux entering the upper densely welded Topopah Spring Member may be uniform and less than one millimeter per year.

During the reporting period, the Director of the Office of Civilian Radioactive Waste Management approved a change to the Civilian Radioactive Waste Management System Program Baseline to incorporate the multipurpose canister concept and to proceed through the design and certification phase. The multipurpose canister, combined with appropriate outer containers or overpacks, provides a standard package for storage, transportation, and disposal of spent nuclear fuel. It is designed to reduce the number of spent-fuel-handling operations and associated occupational exposures, standardize storage technologies, reduce total Program costs, and simplify repository operations. Potential impacts on repository and waste package design include the use of larger waste packages, horizontal in-drift emplacement, nuclear criticality control, and thermal loading. These impacts are currently being addressed in Advanced Conceptual Design.

Advanced Conceptual Design for the repository and waste package continued during the reporting period. A new approach called focused Advanced Conceptual Design was initiated late in the reporting period to focus and integrate design activities and avoid unnecessary duplication of efforts. This approach to Advanced Conceptual Design relies on identifying assumptions to be verified as site characterization progresses. Key assumptions identified during the reporting period include horizontal in-drift emplacement of multipurpose canister-based waste packages, integrated rail transport for subsurface transport of waste packages, use of burnup credit and partial neutron absorber for nuclear criticality control, 100-year retrievability period, and a subsurface standoff distance of 60 meters from the main trace of a fault at the repository level.

Work has continued on establishing limits on thermal loading with large multipurpose canisters and on determining the effect of fuel age and waste package spacing on the timing of the spent fuel peak temperature. As predicted, studies confirmed that early thermal behavior is identical for vastly different thermal loads. Areal mass loading and fuel aging were found to have a significant effect on peak temperature but little effect on long-term temperature. To support the waste package and thermal studies work, two design-basis fuels have been chosen to provide a set of parameters for shielding, thermal, and criticality studies.

Another major iteration of Total System Performance Assessment was completed during this reporting period. Two reports summarize the results: "Total-System Performance Assessment for Yucca Mountain - SNL Second Iteration (TSPA-1993)" prepared by Sandia National Laboratories and "Total System Performance Assessment - 1993: An Evaluation of the Potential Yucca Mountain Repository," prepared by the Civilian Radioactive Waste Management System Management and Operating Contractor. Results of the total system studies show that aqueous releases for 10,000-year predictions are likely to be well below the remanded Environmental Protection Agency's standards, while gaseous releases (carbon-14) generally exceed the standards. As has been the case in previous studies, results show high sensitivity to percolation flux and the conceptual model used for fracture-matrix interaction.

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Calculations were also completed for longer time periods and show that for 100,000 years, the dominant aqueous species contributing to peak doses is technetium-99, whereas for one million years, peak doses are attributable to neptunium-237. For the longer time frames, peak doses are sensitive to saturated zone mixing depths and dose conversion factors. The Department is in the process of consolidating the two reports into a single document and results will be incorporated into the License Application Annotated Outline for transmittal to the U.S. Nuclear Regulatory Commission in fiscal year 1995.

During the reporting period, Revision 3 of the "Mined Geologic Disposal System (MGDS) Annotated Outline Skeleton Text for the Preparation of a License Application" was transmitted to the U.S. Nuclear Regulatory Commission. This revision developed information on the geologic setting into an updated description of the site for use in a potential license application and summarized the report, "Evaluation of the Potentially Adverse Condition 'Evidence of Extreme Erosion During the Quaternary Period' at Yucca Mountain."

The Department and the Office of Civilian Radioactive Waste Management have initiated changes to the Program that are termed the Proposed Program Approach. This approach was developed to bring the program of work at Yucca Mountain into conformity with the fiscal year 1995 budget request and out-year funding expectations and to develop realistic estimates of schedules and costs. The approach also confronts the issues of waste acceptance, interim storage, and transportation, although these topics are not covered in this Progress Report. Clearer lines of responsibility and accountability are being established by reorganizations at both U.S. Department of Energy Headquarters and the Yucca Mountain Site Characterization Office. The intent is to place authority at the organizational levels at which the actual work is to be done. The proposal also was formulated to ensure efficient, rapid progress toward determining the suitability of the Yucca Mountain site for a permanent repository; and, if the site is suitable, to proceed with the Environmental Impact Statement, site recommendation, License Application, and construction of a repository. The Proposed Program Approach will provide a Technical Site Suitability Determination in 1998 that is accompanied by a Draft Environmental Impact Statement. The scoping period required prior to preparation of the Draft Environmental Impact Statement will be initiated in 1995. The Final Environmental Impact Statement will be completed in 2000 and a Site Recommendation Report will be provided to the President of the United States later that year.

Under the Proposed Program Approach, repository licensing is viewed as an incremental process beginning with submittal of the License Application for construction authorization in 2001, an updated application for a license to receive and possess spent nuclear fuel and high-level waste in 2008, and a final application for a license amendment to close the repository during or before 2110. The Safety Analysis Report supporting the License Application for construction authorization will be based on a Title I (preliminary) design for the repository and a Title II (final pre-fabrication) design for the waste package. The focus will be on ensuring the safety of repository operations and providing high confidence in waste package containment. Predictions about the long-term ability of the engineered and natural barriers to contain and isolate spent nuclear fuel and high-level waste will be based on bounding analyses and models. After submittal of the initial License Application, scientific studies and engineering activities will continue as required by

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Subpart F of 10 CFR Part 60 (Performance Confirmation) to confirm the basis for the long-term predictions of repository performance made in the License Application and to acquire data needed for more detailed design. The repository will be designed to permit retrieval for up to 100 years from the date of first emplacement to ensure the opportunity to obtain confirmatory data over an extended Performance Confirmation period, should that be necessary.

The restructured Program requires no changes to the Nuclear Waste Policy Act but does anticipate a new U.S. Environmental Protection Agency standard for a repository at Yucca Mountain that is based on acceptable health risks to individuals and conforming changes to the U.S. Nuclear Regulatory Commission regulation, 10 CFR Part 60, as required by the Energy Policy Act of 1992. Revisions to the U.S. Department of Energy standard contract for spent fuel acceptance, 10 CFR Part 961, may also be required. The Proposed Program Approach is still undergoing development and stakeholder input will be sought and addressed before the final version is prepared.

CHAPTER 1 - INTRODUCTION

1.1 PURPOSE AND SCOPE

In accordance with Section 113(b)(3) of the Nuclear Waste Policy Act of 1982 (NWPAA, 1983), as amended (NWPAA, 1987) and 10 CFR 60.18(g), the U.S. Department of Energy (DOE) has prepared this report for the U.S. Nuclear Regulatory Commission (NRC) on the progress of site characterization activities at Yucca Mountain, Nevada, for the period October 1, 1993, through March 31, 1994. This report is the tenth in a series issued at intervals of approximately six months during site characterization activities undertaken to evaluate Yucca Mountain as a possible geologic repository for the permanent isolation of spent nuclear fuel and high-level radioactive waste.

Section 113(b)(3) of the Nuclear Waste Policy Act states:

"During the conduct of site characterization activities at the Yucca Mountain site, the [DOE] Secretary shall report not less than once every 6 months to the Commission and to the Governor and legislature of the State of Nevada, on the nature and extent of such activities and the information developed from such activities."

In conjunction with these requirements, 10 CFR 60.18(g) states:

"During the conduct of site characterization activities, DOE shall report not less than once every six months to the Commission on the nature and extent of such activities and the information that has been developed, and on the progress of waste form and waste package research and development. The semiannual reports shall include the results of site characterization studies, the identification of new issues, plans for additional studies to resolve new issues, elimination of planned studies no longer necessary, identification of decision points reached and modifications to schedules where appropriate. DOE shall also report its progress in developing the design of a geologic repository operations area appropriate for the area being characterized, noting when key design parameters or features which depend upon the results of site characterization will be established. Other topics related to site characterization shall also be covered if requested by the Director."

This Site Characterization Progress Report presents summaries of the status of site characterization activities and cites technical reports and research products that provide more detailed information on such activities. The report highlights work started, work in progress, and work completed during the reporting period. In addition, this report documents and discusses changes to the Office of Civilian Radioactive Waste Management (OCRWM) Site Characterization Program resulting from ongoing collection and evaluation of site information, systems analyses, development of repository and waste package designs, and results of performance assessment activities.

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Documents cited in the text are available for inspection at DOE public reading rooms in Washington, D.C. and Nevada. They can also be obtained through the DOE Office of Scientific and Technical Information at Oak Ridge, Tennessee.

1.2 BACKGROUND INFORMATION

Yucca Mountain has not been selected as a site for a repository. Rather, it has been designated by the U.S. Congress as the only candidate repository site to be characterized. In accordance with Section 113 of the Nuclear Waste Policy Act, OCRWM is conducting a program of detailed site-specific investigations and evaluations to assess whether Yucca Mountain is suitable for development as a geologic repository. The plans, activities, and results of the site characterization program are reviewed by the State of Nevada, NRC, the Nuclear Waste Technical Review Board, and other external organizations and interested parties.

If Yucca Mountain is found to be suitable for development as a repository and is recommended for such development by the President and approved by Congress, then OCRWM will be required to demonstrate to NRC that the potential repository system will meet applicable regulations. If, during the course of scientific investigations, information supports a finding that the Yucca Mountain site is unsuitable for development as a repository, OCRWM will terminate all characterization activities at the site. Should that occur, OCRWM will, in accordance with Nuclear Waste Policy Act provisions, notify Congress and the Governor and legislature of the State of Nevada of its action and the reason for such action.

The OCRWM plans for site characterization are described in the Site Characterization Plan (DOE, 1988a). More detailed information is presented in study plans for the various site characterization studies and their component activities. The Site Characterization Plan was submitted to NRC in December 1988, and the "NRC Staff Site Characterization Analysis of the U.S. Department of Energy's Site Characterization Plan, Yucca Mountain, Nevada" (NRC, 1989) (hereinafter referred to as the "Site Characterization Analysis") was issued in July 1989. Responses to over 5000 comments from NRC, State of Nevada, affected units of local government, other interested parties and agencies, and the public were sent by OCRWM and the Yucca Mountain Site Characterization Project. Changes to the statutory Site Characterization Plan are documented in Project technical baseline documents, primarily the Site Characterization Program Baseline (DOE, 1993a).

Activities planned for site characterization consist of surface-based studies, underground studies conducted in an Exploratory Studies Facility, laboratory tests, modeling, and analyses. Performance assessment will assist in evaluating (1) whether a repository can be constructed and operated at the site while adequately protecting the health and safety of the public and workers, and (2) whether nuclear waste emplaced in a repository will remain isolated from the accessible environment.

According to the current Program schedule (see Chapter 3), all site characterization activities are to be completed by the end of the year 2001. The baseline schedule which was

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last published in September 1992, and upon which this date is based, is currently under review and will be revised upon completion of the Secretary's review of the Program and the issuance of any new Program guidance. During site characterization, a performance confirmation program, as required by 10 CFR 60.140, will be initiated. As part of this program, if the site is found to be suitable for a geologic repository, selected surface-based and underground tests will continue beyond the site characterization phase. Appropriate new tests and monitoring will also be initiated and continued while OCRWM is constructing the repository and during waste emplacement, until there is adequate confidence that the repository is performing as expected, and NRC issues a license amendment to permanently close the repository.

Studies have been conducted at Yucca Mountain since the late 1970s to support programmatic site screening and provide information for the Environmental Assessment (DOE, 1986). Surface-based studies at Yucca Mountain have been in progress since May 1986. Initially, these studies consisted of non-surface-disturbing testing in existing exploratory boreholes and wells; analyses of, and experiments with rock and water samples; geophysical surveys; meteorological, hydrologic, and seismic monitoring; geologic mapping, and sampling of surficial materials. New surface-disturbing work began in July 1991 when the State of Nevada granted necessary permits, with expanded surface-based activities started in November 1992, to support construction of the Exploratory Studies Facility North Portal.

1.3 MAJOR PROGRAMMATIC CHANGES

1.3.1 Office of Civilian Radioactive Waste Management Proposed Program Approach

During the past several months, the DOE conducted preliminary evaluations of ways to restructure the OCRWM Program. This led to the development of the Proposed Program Approach, which is still in the early stage of development. The proposed approach differs from the previous Program approach in several ways. In the waste acceptance, storage, and transportation areas, the DOE will continue to support the efforts of the Nuclear Waste Negotiator to identify potential volunteer hosts for development of a Monitored Retrievable Storage facility. Funding for development of this facility will not be requested until a host site is identified. Development of a system to provide standardization and simplification of storage technologies, based on the multipurpose canister concept, and the option for providing multipurpose canisters to utilities, are included in the Program.

Regarding differences in the Repository Program, emphasis is placed initially on those investigations and engineering activities deemed necessary and sufficient to support a technical site suitability determination of Yucca Mountain in 1998. The evaluation will be based on available data supported with calculations and models intended to bound the range of site conditions and system performance characteristics. Additional tests will be conducted wherever needed to support preparation of the Environmental Impact Statement and License Application. The repository will be designed to permit waste retrieval for up to 100 years from the start of waste emplacement, rather than the 50-year retrieval period required by the NRC (10 CFR 60.111(b)). This design goal will provide assurance that the performance

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confirmation program required by the NRC (10 CFR Part 60, Subpart F) could be conducted, if necessary, to acquire longer-term information from monitoring changes to the site caused by excavation, thermal-mechanical, and radiation effects. Longer-term monitoring may enhance confidence in the basis for the long-term predictions of compliance with the U.S. Environmental Protection Agency (EPA) standard.

With respect to the repository element of the OCRWM Program, the underlying technical basis for the decisions that led to development of the Proposed Program Approach was the realization on the part of DOE that the expectations that have been built up over the years cannot be satisfied solely by science. Therefore, the Proposed Program Approach is an attempt to bring the Program back to the original intent of the legislative and regulatory framework. The underlying rationale for the Proposed Program Approach is also consistent with some of the recommendations of the National Academy of Sciences, contained in their 1990 report, "Rethinking High-Level Waste" (National Research Council, 1990). That report stressed the point that it is not practical to assume that all information would be available prior to constructing the repository.

The restructured Program under the Proposed Program Approach requires no changes to the Nuclear Waste Policy Act but does anticipate a new EPA standard for a repository at Yucca Mountain, and conforming changes to the NRC regulation, 10 CFR Part 60, as required by the Energy Policy Act of 1992 (U.S. Congress, 1992). Revisions to the DOE standard contract for spent fuel acceptance, 10 CFR Part 961, may also be required.

CHAPTER 2 - STATUS OF SITE CHARACTERIZATION

Specific details regarding site characterization activities during this reporting period are presented throughout Chapter 2.

SECTION 2.1 - PREPARATORY ACTIVITIES

This section reviews interactions with NRC and other overview bodies, and discusses activities that are necessary to plan and implement site characterization and design studies.

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

2.1.1.1 Interactions with the U.S. Nuclear Regulatory Commission

During the reporting period the following interactions took place between DOE and NRC:

October 4-5, 1993 A Technical Exchange was held in Las Vegas, Nevada, to discuss status of the Exploratory Studies Facility design and construction activities, and selected design issues. This interaction was originally scheduled to update NRC staff on the above activities; however, prior to the interaction, NRC issued a letter dated August 20, 1993, that expressed NRC concerns about the controls the Civilian Radioactive Waste Management System Management and Operating Contractor (CRWMS M&O or M&O) has in place for design of the Exploratory Studies Facility. This topic was also discussed. Following the discussions, NRC staff stated that it greatly benefitted from the information provided; however, they requested bimonthly meetings with DOE to continue discussions about Exploratory Studies Facility design and construction until they had a higher level of confidence in the processes controlling design and construction. Subsequently, bimonthly meetings were established at the Interactions Scheduling Meeting on November 18, 1993.

October 13, 1993 A Technical Exchange was held in Los Alamos, New Mexico, to discuss studies pertaining to migration of radionuclides in the unsaturated zone. The objective of the Technical Exchange was to provide NRC staff with information they had requested on the progress of DOE studies relative to radionuclide migration. All of the information requested by NRC was provided during the course of the Technical Exchange.

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- October 14, 1993 A Technical Exchange was held in Los Alamos, New Mexico, to discuss near-field phenomena related to radionuclide releases from the Engineered Barrier System, and to provide NRC staff with information they had requested on the progress of those studies. All of the information requested by NRC was provided during the course of the Technical Exchange.
- October 15, 1993 A site visit to Los Alamos National Laboratory was conducted to provide NRC staff an opportunity to observe the laboratory areas relevant to subjects of the October 13-14, 1993, Technical Exchange.
- November 9, 1993 A Technical Exchange was held in Bethesda, Maryland, to discuss results from the Multi-purpose Canister (MPC) Implementation Program Conceptual Design Phase Report (CRWMS M&O, 1993a) and associated studies.
- November 16, 1993 A Quality Assurance (QA) Meeting was held in Rockville, Maryland, to discuss status of implementation of the new Quality Assurance Requirements and Description document (DOE, 1992), the MGDS Design Control Improvement Plan (CRWMS M&O, 1993b), quality control inspection activities on the Exploratory Studies Facility, status of QA open items, NRC observation of recent DOE audits, corrective actions from previous audits, fiscal year (FY) 1994 audit schedules, Yucca Mountain Site Characterization Project (Project) issues hierarchy and controls for their resolution, QA overview of site characterization field activities, DOE progress in graded QA and Q-List, root cause actions for Reynolds Electrical & Engineering Co., Inc. survey problem, and an update on software QA (audits, surveillances, findings).
- November 17, 1993 A Technical Exchange was held in Washington, D.C., to discuss the technical basis for a future topical report on seismic hazards assessment methodology and to solicit comments. The DOE provided NRC with an overview of the topical report and plans for its completion and submittal. The NRC provided feedback on the topical report.
- November 18, 1993 A Management Meeting was held in Washington, D.C., to discuss and agree to the interactions to be held between DOE and NRC during the period of December 1993 to June 1994. The focus of NRC-DOE interactions is related to Issue Resolution, NRC open items, or events/processes of concern to NRC.
- November 30 -
December 1, 1993 A Technical Exchange was held in Bethesda, Maryland, to discuss technical issues associated with relying on burnup credit in the criticality analysis for spent fuel casks and containers. The DOE considers burnup credit to be one of the most significant technical issues for the proposed multipurpose canister system.

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- December 8, 1993 A Technical Meeting was held in Washington, D.C., to provide and discuss the status of Exploratory Studies Facility design, construction activities and related topics from the October 4-5, 1993, Technical Exchange on the Exploratory Studies Facility, provide a design/construction update, discuss design changes, and discuss the DOE process for acceptance of completed Exploratory Shaft Facility construction. Selected items from the NRC October 1, 1993, letter regarding Determination of Importance evaluations were also discussed. The NRC staff stated that their level of confidence in DOE design processes has increased as a result of the interactions on the Exploratory Studies Facility. Topics for upcoming meetings on the Exploratory Studies Facility were discussed and were factored into the next meeting.
- February 1-2, 1994 A site visit to Yucca Mountain, Nevada, was conducted to provide NRC an opportunity to observe items in the field pertaining to the topical report entitled "Evaluation of the Potentially Adverse Condition 'Evidence of Extreme Erosion During the Quaternary Period' at Yucca Mountain" (DOE, 1993b) (hereinafter referred to as "Erosion Topical Report"), and to discuss any questions resulting from the NRC review of the report. The NRC staff appears to be taking a broader interpretation of 10 CFR Part 60.122(c)(16). The NRC staff indicated they believe the evaluation of the potentially adverse condition should also consider the characteristics of the geologic setting within 50 km of Yucca Mountain, such as an evaluation of soil aging studies, stream incision, uplift, erosion rates from least to worst case within the setting, and the 1986 erosion event at Jake's Ridge to further corroborate DOE conclusions in the topical report.
- February 3, 1994 A Technical Meeting was held in Las Vegas, Nevada, to provide NRC with presentations on the Exploratory Studies Facility design review process, document hierarchy, rationale for the enhanced Exploratory Studies Facility layout, Exploratory Studies Facility seismic design basis, strategy of the drilling program, and other related Exploratory Studies Facility topics.
- February 10, 1994 A Technical Exchange was held in Bethesda, Maryland, for NRC to provide comments, observations, and questions for discussion concerning the information DOE presented at the previous burnup credit Technical Exchange held November 30 - December 1, 1993.
- February 23, 1994 A QA Meeting was held in Rockville, Maryland, to discuss the status of implementation of the revised Quality Assurance Requirements and Description document, QA open items, observation of recent DOE audits, graded QA and Q-List (DOE, 1990a), tunnel boring machine overview, DOE/Nye County cooperative drilling program, status of corrective action requests, FY 1994 audit schedule, M&O design

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improvement efforts, QA overview of site characterization field activities, and the Determination of Importance Evaluation process.

March 30-31, 1994 A Technical Exchange was held in Bethesda, Maryland, to discuss DOE activities related to investigating burnup credit for spent fuel casks and multipurpose canisters and questions raised by NRC in the previous burnup credit Technical Exchange held November 30 - December 1, 1993.

2.1.1.2 Resolution of U.S. Nuclear Regulatory Commission Open Items

Resolving NRC open items is a bilateral process that consists of (1) OCRWM providing documentation or other basis to NRC to claim resolution of specific items, and (2) NRC accepting (or not accepting) the basis for resolution, and informing OCRWM. Both steps are needed to remove open items from further consideration.

Site Characterization Analysis

The Project continues to work toward resolving the open items from the Site Characterization Analysis (NRC, 1989). During this reporting period, NRC staff agreed, in letters dated December 30, 1993 (NRC, 1993) and February 18, 1994 (NRC, 1994a), that OCRWM has provided the technical basis to resolve Comment 75 and Questions 1, 14, and 15. In addition, OCRWM provided supplemental responses to Question 58 (DOE, 1994a), Comment 80 (DOE, 1994b), Comment 122, and Question 22 (DOE, 1994c). As of the end of this reporting period, 82 open items have been closed (including 2 objections) and 116 remain open. The majority of the remaining open items await data to be acquired through site characterization activities for their resolution. Of the 116 remaining open items, 23 were being reviewed by NRC staff.

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

Progress Report Comments and Questions

During this reporting period the Project received comments and questions from NRC staff on Progress Report #8 (NRC, 1994b). In the same letter, NRC staff also provided their evaluation of DOE responses to the comments and questions on Progress Reports #6 and #7.

As of the end of this reporting period, 19 observations, 2 comments, and 3 questions have been closed; 2 comments and 5 questions remain open. Of the open items, five from Progress Report #8 and two from Progress Reports #6 and #7 (Comment 3 and Question 1), were awaiting NRC staff verification of corrective action.

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2.1.1.3 Interactions with the Advisory Committee on Nuclear Waste

- December 13, 1993 The 59th Advisory Committee on Nuclear Waste (ACNW) meeting was held in Las Vegas, Nevada. The meeting included briefings by Project staff on overall Project status, Exploratory Studies Facility progress and test plans, and issue resolution.
- December 14, 1993 The ACNW held a working group meeting on unsaturated zone hydrology in Las Vegas. Project staff made presentations on a number of topics related to the unsaturated zone, including testing, data analysis, modeling, and the regulatory focus of the work. Briefings were also given by NRC staff and the State of Nevada.
- December 15, 1993 The ACNW toured the Yucca Mountain site. Tour stops included the Exploratory Studies Facility, the Hydrological Research Facility, and the Fran Ridge Large Block Test. Inclement weather prevented the group from visiting the Ghost Dance fault pavement study area, as intended.
- December 20, 1993 The 60th ACNW meeting was held in Bethesda, Maryland. The purpose of the meeting was to prepare for the upcoming ACNW briefing of the NRC Commissioners.
- December 21, 1993 The ACNW briefed the NRC Commissioners in Rockville, Maryland. Discussions centered on the mission and future plans of ACNW, as described in their Program Plan. The NRC emphasized the need for ACNW to prioritize its work and focus on the key issues identified by NRC.
- January 31, 1994 Two ACNW members visited the Yucca Mountain site. This tour was a follow-up to the December 15, 1993, Site Visit. It included stops at a pavement exposing the Ghost Dance fault, the Sundance fault, and several trenches on the Solitario Canyon fault.
- February 23-24, 1994 The 61st ACNW meeting was held in Bethesda, Maryland. The main topics covered at the meeting were the NRC's review plan for DOE topical reports and the status of NRC volcanism studies.
- March 23-24, 1994 The 62nd ACNW meeting was held in Bethesda, Maryland. The main topics covered at the meeting were the NRC overview of the NRC high-level waste research on natural analogs and its application to Yucca Mountain regulatory requirements and performance assessment, the current NRC Office of Nuclear Material Safety and Safeguards division and the proposed division reorganization, and an NRC presentation on "What is the Societal Pledge?"

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2.1.1.4 Interactions with the Nuclear Waste Technical Review Board

During the reporting period the following interactions took place between DOE and the Nuclear Waste Technical Review Board (NWTRB):

- October 19-20, 1993 A Full Board meeting was held in Las Vegas, Nevada. The NWTRB was briefed on the drilling program and the role of study plans. The meeting focused on the DOE site characterization surface-based and underground testing program. Specifically, DOE discussed Exploratory Studies Facility design, excavation, testing and coordination; accelerated Surface-Based Testing; the systematic drilling program; thermal testing activities; and testing integration planning.
- November 1-2, 1993 A joint Engineered Barrier System Panel/Transportation and Systems Panel workshop was held in Dallas, Texas. The topic of the meeting was "Technical Challenges of Interim Storage of Spent Fuel." The meeting was held included a plenary and two focused sessions. The purpose of the meeting was to review the OCRWM strategy and plans for the interim storage of spent fuel and to hear comments on these plans from the utilities and other interested groups.
- November 22, 1993 An Environmental and Public Health Panel meeting was held in Las Vegas, Nevada. Presentations that focused on DOE studies of terrestrial ecosystems and provided an overview of Project environmental activities were made. Presentations were also made on the results of environmental monitoring activities obtained during the past few years, including statistical analyses of monitoring data. The purpose of the meeting was to focus on current studies of terrestrial ecosystems, results of environmental monitoring activities, the decision-making process used to determine the environmental significance of monitoring results, and DOE plans for future activities to document baseline environmental conditions and to project the potential long-term environmental effects of a potential repository.
- March 8-9, 1994 A Structural Geology and Geoengineering Panel meeting was held in San Francisco, California. The topic of the meeting was "Probabilistic Seismic and Volcanic Hazard Estimation," and NWTRB was briefed on this issue. The meeting focused on issues of future use of seismic probabilistic analysis and its validity in the Yucca Mountain Program. Volcanic issues focused on the validity of the assumption that probabilistic estimates won't change much in the future.

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March 10-11, 1994 An Engineered Barrier System Panel meeting was held in Pleasanton, California. Presentations were made on current and planned research on the engineered barriers including DOE strategy and timing for determining the long-term corrosion performance for materials. There was a tour of Lawrence Livermore National Laboratory facilities on the following day.

2.1.1.5 Interactions with the National Academy of Sciences

The Energy Policy Act of 1992 (U.S. Congress, 1992) directed EPA to contract with the National Academy of Sciences (NAS) to conduct a study to provide findings and recommendations on reasonable standards for protection of the public health and safety from releases of radioactive materials stored or disposed of in a repository at the Yucca Mountain site. The 1992 law also directed EPA, based on the recommendations of NAS, to promulgate public health and safety standards for a repository at the Yucca Mountain site. Furthermore, NRC was directed to modify its requirements to be consistent with EPA standards and the recommendations of NAS.

The NAS formed the Committee on Technical Bases for Yucca Mountain Standards to prepare its recommendations to EPA. Committee activities began in May 1993. Public meetings were held November 9-10, 1993 and December 16-17, 1993, with the last public meeting scheduled for April 28-29, 1994. A committee report, containing recommendations to the EPA, is expected by the end of 1994.

At the request of NAS, OCRWM designated a technical liaison representative to the NAS committee. In addition, a task force was formed to monitor activities associated with developing a standard for Yucca Mountain, and to provide input to the NAS committee. Several scientists associated with the Project made presentations to NAS at the November 1993 and December 1993 meetings. The OCRWM formulated its recommendations to NAS on a standard for Yucca Mountain and anticipates providing this input to the NAS committee in April 1994.

2.1.2 Issue Resolution

The OCRWM has continued an Issue Resolution process to aid in the identification, clarification, and resolution of technical and regulatory issues raised during site characterization. This process was developed based upon the "Issues-Based Approach to Planning Site Characterization" contained in the Site Characterization Plan (DOE, 1988a) (p. 8.1-1). Issue Resolution is directed toward receiving guidance and comments from NRC staff regarding the definition and interpretation of regulatory terms, acceptability of site characterization methodologies, adequacy of site characterization planning, and acquired data and analyses as required by 10 CFR Part 60. Although an issue is not considered "closed" during the precicensing period, and any issue can be revisited based on new information, it is important for DOE to seek clarification and early resolution with NRC staff on as many areas of

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uncertainty as possible. This clarification will be accomplished by frequent interactions and communications with NRC. These interactions may include reports sent to NRC staff for review and comment (e.g., topical or technical reports), letters, submittals of the "Mined Geologic Disposal System (MGDS) Annotated Outline Skeleton Text for the Preparation of a License Application" (CRWMS M&O, 1993c) (hereinafter referred to as the "Annotated Outline") (see Section 2.1.3), or meetings between DOE and NRC. In addition, resolution of the Site Characterization Analysis open items (see Section 2.1.1.2) is being coordinated within the Issue Resolution process. Issue Resolution activities during the reporting period included the following:

Volcanism

The DOE provided responses to NRC staff comments and questions resulting from NRC staff review of the draft technical report, "Status of Volcanic Hazard Studies for the Yucca Mountain Site Characterization Project" (Crowe et al.). Study Plan 8.3.1.8.1.2, "Physical Processes of Magnetism and Effects on Potential Repository," and Study Plan 8.3.1.8.5.1, "Characterization of Igneous Intrusion Features," were submitted to NRC for review.

Seismic Hazards

Development of the topical report, "Methodology to Assess Fault Displacement and Vibratory Ground Motion Hazards at Yucca Mountain" (CRWMS M&O), continued during the reporting period. The report was being developed by a group of experts with broad experience in seismic hazard assessment. The group includes representatives from both Project participants and outside organizations. Preliminary results were presented at a DOE-NRC Technical Exchange held on November 17, 1993. In preparation for this interaction, the annotated outline for the topical report was submitted to NRC on August 18, 1993. It is anticipated that the topical report will be submitted to NRC for review during the third quarter of FY 1994.

The updated state-of-the-practice methodology described in the report is probabilistic in nature and thus explicitly incorporates information on the frequency of earthquake occurrence and uncertainties in input values. The seismic hazard assessment methodology provides results in the form of annual probabilities that various levels of ground motion or surface fault displacement will be exceeded. This information is required by designers to implement a seismic design process based on seismic safety performance categories and by investigators assessing the performance of a potential repository with respect to waste containment and isolation. The updated methodology no longer employs a 10,000-year cumulative slip earthquake or a deterministic approach as described in the Site Characterization Plan. Study plans that address the various components of seismic hazard assessment will be developed or revised for consistency with the updated methodology.

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Substantially Complete Containment

The DOE is proposing a qualitative interpretation for compliance with the substantially complete containment provisions in 10 CFR Part 60. This methodology is being documented as part of DOE efforts associated with closure of Site Characterization Analysis open items and will be submitted to NRC for review and resolution. A supplemental response to Site Characterization Analysis Comment 80 (DOE, 1994b) was submitted to NRC in March 1994.

Absence of Extreme Erosion

The DOE conducted a site visit to Yucca Mountain and the Nevada Test Site for NRC staff and affected units of government to discuss field locations supporting conclusions in the Erosion Topical Report (DOE, 1993b). This site visit provided NRC staff with additional insight into studies and sampling techniques used to support the conclusion that there is an absence of extreme erosion at Yucca Mountain. Additional information to support the topical report was also provided to NRC staff in letters dated November 30, 1993 (DOE, 1993c), January 26, 1994 (DOE, 1994d), and January 26, 1994 (DOE, 1994e).

Engineered Barrier System

The DOE completed an acceptance review and finalized a paper entitled "Boundary of the Engineered Barrier System (EBS)" to be issued early in the next reporting period. This paper documents the DOE position on the definition of the Engineered Barrier System boundary. The DOE agrees with the NRC definition that the Engineered Barrier System does not extend into the host rock.

Forecast: During the second half of FY 1994, DOE intends to accomplish the following through the Issue Resolution process:

1. Resolve any comments and questions from the NRC review of the Erosion Topical Report (DOE, 1993b).
2. Issue a final report on the status of volcanic hazards investigations.
3. Issue a topical report entitled "Methodology to Assess Fault Displacement and Vibratory Ground Motion Hazards at Yucca Mountain."
4. Issue an annotated outline for a second topical report on seismic design.
5. Continue to resolve additional Site Characterization Analysis open items.
6. Distribute a letter enclosing the paper, "Boundary of the Engineered Barrier System (EBS)" documenting the DOE position on the Engineered Barrier System boundary (see Epilogue).

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2.1.3 License Application Annotated Outline

The process of developing the Annotated Outline is a product-oriented management tool that has a key role in the Project program management and licensing strategies. Specifically, the Annotated Outline process: (1) integrates site characterization, performance assessment, design, and regulatory activities; (2) provides feedback to the site characterization program; (3) implements guidance provided by NRC in their draft regulatory guide, entitled "Format and Content for the License Application for the High-Level Waste Repository" (NRC, 1990); (4) facilitates focused interactions with NRC; and (5) provides an instrument for the resolution of technical and regulatory issues. The Annotated Outline is an iterative process that contributes to the development of shared interpretation and understanding of regulations.

Revision 3 of the Annotated Outline was submitted to NRC on November 23, 1993. This revision developed information on the geologic setting into an updated description of the site for use in a potential license application and summarized and referenced the Erosion Topical Report. Over 100 information needs were identified during the Annotated Outline Revision 3 development. These were incorporated into a report entitled "Feedback to Site Characterization Program" (CRWMS M&O, 1994a) and will be incorporated into the annual and long-range planning processes. This is a significant development that sets the precedent for focusing site characterization, design, and performance assessment activities on the acquisition of information needed to demonstrate regulatory compliance.

Forecast: Revisions to the Annotated Outline are planned to be issued on an annual basis. The next revision will consist of extensive changes to Chapter 3 and the results of the 1993 Total System Performance Assessments will be incorporated into Chapters 3, 5, and 6; this revision is scheduled to be completed in November 1994. The letter report providing feedback to the site characterization program based on that revision will be completed in January 1995.

2.1.4 Permits

2.1.4.1 Compliance with Federal Environmental Requirements

Consultations continued with Native American tribes and organizations as specified in the Programmatic Agreement with the Advisory Council on Historic Preservation.

Quarterly reports on water levels and spring-flow measurements continue to be sent to the National Park Service and the Nevada State Engineer as stipulated in the water appropriation permits.

Forecast: There is still a potential need for another Free-Use permit for the excavation of sand and gravel for use in conjunction with the Exploratory Studies Facility concrete batch plant that may require various types of gravel. Other sources of gravel will be explored and,

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based on the results and potential sources, a new site for a gravel pit may be selected. This decision is expected to be made by December 1994.

Within the next six months, two additional site visits will be conducted for the Consolidated Group of 17 Yucca Mountain-involved Native American tribes and organizations. The site visits will involve cultural resources and selected current activities.

2.1.4.2 Compliance with State Environmental Requirements

Water Quality

A request for approval to use a portable bathroom/holding tank facility was submitted to the State. Additional information was provided to the Nevada Department of Health on January 4, 1994. The Nevada Department of Health requested several modifications to the design. These changes will be made and the design drawings will be updated. Approval is expected by September 1994.

Air Quality

Air Quality Permits to Construct and/or modifications to those permits were received for the Concrete Batch Plant (February 1994), Exploratory Studies Facility Surface Rock Conveyer system (October 1993), two radial stacker belts (October 1993 and December 1993), Cone (screening) Plant (October 1993), and the following drill rig/dust collector systems (December 1993): LM-300, Joy-1, Stratmaster, Failing-1500S, CME-850, and CME-550.

Drilling and Tracers

A waiver to drill and a request for the use of tracers was requested for USW SD-9. The waiver was submitted in March 1994 and is expected in May. The tracer request was submitted in December 1993 and approval was received in the same month. Approvals for the use of tracers was received for the Exploratory Studies Facility (tunnel and alcoves) and Boreholes USW NRG-8A, 8B, and 8C.

Forecast: The Project permit applications projected over the next six months include: four tracer injection approvals under the Underground Injection Control Permit, a sewage disposal permit, a mine wastewater permit, and one temporary water appropriation permit changing the place of use for trenching activities.

2.1.5 Land Acquisition

The primary land acquisition task during this reporting period has been the processing of participant requests to initiate site characterization activities. A participant request to initiate site activity is a prerequisite requirement for the activity.

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Several applications for rights-of-way have been filed with the Bureau of Land Management (BLM) for site characterization activities and an extension application has been filed for N-48602, the large right-of-way on the Nellis Air Force Range, which expires June 30, 1994.

Thirteen participant requests to initiate site characterization activities were processed during the period. Eleven of these requests have been completed and access authorization granted. Of the remaining two requests, one is awaiting the receipt of a right-of-way reservation from the BLM and one is awaiting an operations permit from the Nevada Test Site Office. Six requests from the last reporting period are awaiting the results of the following actions: one right-of-way application to the Barstow Resource Area BLM office for a surface water monitoring station; two rights-of-way applications to the Barstow Resource Area BLM office for seismic stations; a right-of-way application to the Stateline Resource Area BLM office for a seismic reflection program; a casual access determination from both the Barstow and Stateline Resource Area BLM offices for pump tests in 42 existing wells; and two rights-of-way reservations from the Caliente Resource Area BLM office for volcanism studies at both Sleeping Butte and Crater Flat.

2.1.6 Quality Assurance Program

Section 2.1.6.1 of this report is a revision of Site Characterization Plan, Chapter 8.6, Quality Assurance, and reflects current OCRWM policies and philosophy; it supersedes that chapter in its entirety.

2.1.6.1 Program Activity

Quality Assurance

The OCRWM has established the minimum requirements for the Civilian Radioactive Waste Management Program Quality Assurance Program in the Quality Assurance Requirements and Description document. The Quality Assurance Requirements and Description, which contains regulatory requirements and Civilian Radioactive Waste Management Program commitments necessary for the development of an effective quality assurance program, applies to the following Civilian Radioactive Waste Management Program elements:

1. Acceptance of spent nuclear fuel and high-level radioactive waste.
2. Transportation of spent nuclear fuel and high-level nuclear waste.
3. Monitored retrievable storage facility through application for an operating license.

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4. Mined Geologic Disposal System, including site characterization activities (Exploratory Studies Facility and Surface-Based Testing), through application for an operating license.
5. High-level waste form from production through acceptance.

The Quality Assurance Requirements and Description is organized into 18 sections plus supplements, appendices, and a glossary. The sections specify requirements that are common to all Civilian Radioactive Waste Management Program elements. Each supplement delineates the requirements that are applicable to a specialized activity. The appendices contain requirements that are specific to an individual Civilian Radioactive Waste Management Program element. The glossary establishes a common vocabulary for the Civilian Radioactive Waste Management Program QA Program.

The Quality Assurance Requirements and Description provides for both the achievement and the verification of quality. The line organizations within each Affected Organization (i.e., OCRWM, other DOE offices, other government agencies, national laboratories, and suppliers responsible for applying the Quality Assurance Requirements and Description to the performance of assigned work) have total responsibility for the achievement of quality with each individual in the Affected Organization being responsible for the quality of his/her work. As such, each line organization is responsible for implementation of the quality assurance program applicable to its scope of work. The line organizations and the quality assurance organization within an Affected Organization share responsibility for the verification of quality.

The Director of the Civilian Radioactive Waste Management Program retains overall responsibility for the QA Program; ensures its development, implementation, and verification; and retains ultimate review and acceptance/approval authority on matters pertaining to the implementation of the QA Program requirements.

The Civilian Radioactive Waste Management Program QA Program comprises the applicable requirements of the Quality Assurance Requirements and Description and the QA implementing documents of all Affected Organizations. Prior to initiating activities that must be performed in accordance with the applicable requirements of the Quality Assurance Requirements and Description, each Affected Organization establishes QA implementing documents (e.g., procedures, instructions, etc.) appropriate to its assigned scope of work that translate these requirements into work processes; and, in addition, trains affected personnel in the purpose, scope, and implementation of such documents.

Each Affected Organization develops and maintains a current matrix that correlates the Quality Assurance Requirements and Description requirements applicable to its assigned scope of work and to associated Affected Organization's QA implementing documents that translates the specific requirements into work processes.

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Audits and Surveillances

During this reporting period, the DOE/Office of Quality Assurance Yucca Mountain Quality Assurance Division conducted audits of Raytheon Services Nevada and Reynolds Electrical & Engineering Co., Inc. to verify compliance with the applicable requirements of the OCRWM QA Program and to determine the effectiveness of those portions of the OCRWM QA Program being implemented by these Affected Organizations.

The DOE/Office of Quality Assurance Yucca Mountain Quality Assurance Division also conducted 40 surveillances to evaluate specific site characterization related activities including the adequacy and effectiveness of corrective actions taken to resolve previously reported deficient conditions.

2.1.6.2 Determination of Importance Evaluations

A Determination of Importance Evaluation is the mechanism for QA classification and grading. This evaluation is conducted as an engineering analysis using the methodology described in the "M&O Plan for Evaluating Items and Activities in the MGDS Program for Importance to Safety and Waste Isolation" (CRWMS M&O, 1992). The Determination of Importance Evaluation establishes the importance of a given item or activity relative to radiological safety, waste isolation, or any other QA classification as discussed in Quality Assurance Requirements and Description, Section 2.2.3A. For permanent items (i.e., those items that may become part of a licensed pre- or postclosure repository), the Determination of Importance evaluation is used as the supporting analysis for classification of the item if it has a function that falls within one of seven categories:

- QA-1 Important to Radiological Safety
- QA-2 Important to Waste Isolation
- QA-3 Important to Radioactive Waste Control
- QA-4 Important to Fire Protection (i.e., of QA-1 or -2 items)
- QA-5 Important to Potential Interaction (i.e., function not required, but failure could impact QA-1 or -2 items)
- QA-6 Important to Physical Protection of Facility and Materials
- QA-7 Important to Occupational Radiological Exposure

Note that the classification numbers do not imply an order of importance. Classification is controlled under a new procedure for classification of permanent items, which was accepted by the DOE Office of Quality Assurance during this reporting period. Where an item is identified as permanent and as falling within one of the above classifications, that item will also be recommended for placement on the Q-List (DOE, 1990a) (see Section 2.1.6.3).

For activities that include the use of temporary items, the Determination of Importance Evaluation is used to evaluate potential adverse impacts of the activities on permanent, important items (i.e., items on the Q-List, including the natural barrier). Based on these potential impacts, appropriate controls are established for the associated activities.

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As part of the planning process for testing and construction activities, Test Interference Evaluations and Waste Isolation Evaluations are carried out. These evaluations address the potential of site characterization activities to interfere with ongoing or planned tests, and to affect the ability of the site to isolate waste. Potential test interference or waste isolation concerns are addressed through imposition of controls on testing, design, construction, or operations activities.

Waste Isolation Evaluations and Test Interference Evaluations have historically been inputs into Determination of Importance Evaluations for Exploratory Studies Facility design packages, and directly into Job Packages or Test Planning Packages for non-Exploratory Studies Facility activities. During this reporting period, an effort was begun to consolidate these inputs through the Determination of Importance Evaluation process for Surface-Based Testing activities as well as for Exploratory Studies Facility activities. This consolidation allows for consistent presentation of control requirements and allows for better integration of evaluations on a common schedule. The Determination of Importance Evaluation organization receives requests for evaluations of specific activities from all participants. Based on the Waste Isolation Evaluation and Test Interference Evaluation input associated with these activities, a Determination of Importance Evaluation is prepared which establishes the minimum controls on the activities, including on the use of associated tracers, fluids, and materials. This information is transmitted to the Job Package or Test Planning Package coordinator (for Surface-Based Testing) or to the design organization (for Exploratory Studies Facility) for incorporation into appropriate packages, specifications, or drawings. The information is also used to update the tracers, fluids, and materials data base. As-built information on the actual use of tracers, fluids, and materials is provided by the constructor or tester. Evaluation of Yucca Mountain Site Characterization Office (YMSCO) procedures is currently under way to provide additional guidance in this area.

Waste Isolation Evaluations provide guidance for avoiding, to the extent practical, any effects from conducting site characterization activities that may impair performance of the site if used as a high-level radioactive waste repository. Given that site characterization is not complete, these evaluations use the best available information and conservative bounding assumptions to provide recommended controls used in design, construction, testing, and operational activities. During this reporting period, 29 Waste Isolation Evaluations were completed in support of the following Exploratory Studies Facility and Surface-Based Testing site characterization activities:

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Item/Activity	Number of Waste Isolation Evaluations
Exploratory Studies Facility	
North Portal Pad/Starter Tunnel	2
Exploratory Studies Facility Surface Utilities	8
North Ramp Excavation	1
Surface-Based Testing	
Boreholes/Drill Pads/Access Roads	8
Testing	4
Other	6

Examples of recommended controls are limits on discharge of water during Exploratory Studies Facility construction and operation of the water supply system, water use for surface infiltration testing, and discharge of organics during underground construction. In addition to these formal evaluations, considerable preliminary work was performed to address the potential waste isolation impact of diesel exhaust generated by diesel powered transportation, excavation, and other support equipment that may be used during construction of the Exploratory Studies Facility North Ramp.

Test Interference Evaluations are intended to identify and mitigate the potential for site characterization data to be biased due to interference from construction or other testing activities. When a potential interference is identified, controls on design, construction, testing, or operational activities are recommended to avoid the interference condition or to provide a means for identification and correction of data. Test Interference Evaluations are conducted using conservative bounding assumptions and the best available information on the proposed activity and site conditions. During this reporting period, 30 Test Interference Evaluations were completed in support of the following Exploratory Studies Facility and Surface-Based Testing site characterization activities:

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Item/Activity	Number of Test Interference Evaluations
Exploratory Studies Facility	
North Portal Pad/Starter Tunnel	3
Exploratory Studies Facility Surface Utilities	11
North Ramp Excavation	2
Surface-Based Testing	
Boreholes/Drill Pads/Access Roads	6
Testing	5
Other	3

Recommended controls are very similar to those discussed for waste isolation evaluations above. In addition, Test Interference Evaluations have recommended limits on the use of specific materials for potential test impact reasons (e.g., prohibition on use of sodium chloride for electrical grounding).

Input documentation for Determination of Importance Evaluations is also used for Test Interference Evaluations, Waste Isolation Evaluations, and design configuration packages. Determination of Importance Evaluations use Test Interference Evaluations and Waste Isolation Evaluations as design inputs, and these inputs are transmitted in accordance with QA procedures for transmittal of design input. The Determination of Importance Evaluations resolve any potentially conflicting control requirements from Waste Isolation Evaluations and Test Interference Evaluations, consider permanence of design items for possible classification, and impose controls on the evaluated items and activities. Completed Determination of Importance Evaluations are transmitted to the design organization for inclusion of these controls within the Basis for Design document. From the Basis for Design, these controls flow down into design outputs (specifications and drawings) for implementation by the construction contractor.

As discussed above, an effort is under way to provide Determination of Importance Evaluations as a consolidation mechanism for non-Exploratory Studies Facility activities. Although the consolidation effort is well under way, no consolidated non-Exploratory Studies Facility Determination of Importance Evaluations were scheduled during this reporting period. The following Exploratory Studies Facility items or activities were evaluated or their Determination of Importance Evaluations were revised during this period:

- Change House/Shop Building
- H-Road Improvement (Widening, Grading, and Paving)

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- 69 kV Power Supply System (including Site Lighting, Grounding, and Lightning Protection)
- Subsurface Wastewater System (Surface Portion) and Sanitary Sewer Collection
- Procurement of Temporary Items
- Compressed Air System
- Standby Generators
- North Portal Pad (revision for on-pad construction of tunnel boring machine, pad extension, and drainage revisions)
- Starter Tunnel Drill-and-Blast Section (revision to address test alcove and launch chamber)
- Exploratory Studies Facility North Ramp (Starter Tunnel to Topopah Spring - preliminary for Exploratory Studies Facility Package 2C 90% Design Review)

Forecast: A draft line procedure for performing Determination of Importance Evaluations is to be distributed for review prior to the end of this reporting period; implementation of this procedure is anticipated shortly thereafter. Revisions to the respective line procedures for performing Waste Isolation Evaluations and Test Interference Evaluations are also in progress to facilitate the consolidation process discussed above.

2.1.6.3 Q-List and Management Control-List

The Project Q-List and Management Control-List (DOE, 1993d) are used to tabulate items which may become part of a licensed pre- or postclosure repository. The Q-List describes those 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. The Management Control-List describes those items determined not to be subject to these Quality Assurance Requirements and Description requirements, and are subject to normal management and design controls.

Both documents reflect conclusions of Determination of Importance Evaluations; the Q-List also contains items originally placed thereon by direct inclusion using a conservative assumed basis. Items on the Q-List by direct inclusion require documented analysis to warrant their removal. The YMSCO evaluates recommended changes to the Q-List, based on a procedural review and an assessment team consisting of representatives from several Project participants.

No changes were made to the Q-List during this reporting period. Revision 2, discussed in Progress Report Number #9, was formalized in November 1993. Revision 3 is

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in review, and includes proposed clarifications to the Exploratory Studies Facility Starter Tunnel, Waste Ramp, Tuff Ramp, and underground excavations (see Forecast below).

No changes were made to the Management Control-List during this reporting period. Discussion is under way concerning a proposal to delete the Management Control-List and incorporate the information into an appendix to the Q-List.

Forecast: Revision 3 of the Q-List is expected to be issued in the second half of FY 1994. Review of the Management Control-List is under way for consideration of its deletion and incorporation of basic information into a Q-List appendix. A Technical Document Preparation Plan for the Q-List is being prepared and will replace procedures currently defining the classification process.

2.1.6.4 Design Control Improvement Plan

The purpose of the "M&O MGDS Design Control Improvement Plan" (CRWMS M&O, 1993b) was to coordinate the implementation of corrective actions to provide immediate response to open Corrective Action Reports, ensure that conditions adverse to quality (if any) were identified and corrected, and provide for the development of a series of improvements to the design control process to preclude recurrence. The plan was initially issued July 30, 1993. It was revised (Revision 1, September 15, 1993) to incorporate comments from Project and QA representatives as well as other informal comments.

The problems and action items identified in this plan were divided into three areas: (1) near-term or immediate actions; (2) longer-term, broader process improvement actions; and (3) improvement verification or confirmation actions. It was the intent of these action items to provide a broad view of the entire design control process to identify weaknesses and resolve them in order to prevent future problems. During the reporting period, there were two additional action items added to the process improvement area. The status of the action items associated with the improvement plan follows:

	Identified	Complete	Open
Immediate actions	33	32	1
Process improvement actions	18	14	4
Confirmation actions	5	4	1

The open immediate action item will be complete on April 15, 1994 and the open confirmation action item will be complete on April 1, 1994. Of the remaining four open process improvement actions two items will be complete in July 1994 and two items will be carried over to be completed in FY 1995.

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Forecast: The Mined Geologic Disposal System Design Control Improvement Plan will be closed out in early May 1994. The remaining open action items will be tracked on the Mined Geologic Disposal System development tracking system.

2.1.7 Document Hierarchy and Program Baseline

The DOE is developing the Civilian Radioactive Waste Management System facilities using a systems engineering approach. As a result of this approach, the various technical requirements and regulatory constraints are allocated to the different system elements. This allocation is represented in the baseline documents shown in Figure 2.1-1, OCRWM Document Hierarchy.

As reported in Progress Report #9, an improved document hierarchy was implemented for the program. For the Project, those technical and programmatic requirements specifically allocated to the Mined Geologic Disposal System are important.

The requirements pertinent to Mined Geologic Disposal System development are captured in the Mined Geologic Disposal System Requirements (DOE, 1993e). As the Mined Geologic Disposal System is developed in more detail, the requirements are developed further in the lower tier documents. Traceability of the more detailed requirements to the source requirements is maintained.

2.1.7.1 Regulatory Controls

The Mined Geologic Disposal System comprises the Exploratory Studies Facility, the Surface-Based Testing Facility, the Repository, and the Engineered Barrier System. Interface requirements between these elements are documented in the interface sections of the Repository Design Requirements Document (DOE, 1993f), Engineered Barrier Design Requirements Document (DOE, 1993g), Site Design and Test Requirements Document (DOE, 1993h), Exploratory Studies Facility Design Requirements Document (DOE, 1993i), and Surface-Based Testing Facilities Requirements Document (DOE 1993j) (see Figure 2.1-1). Changes to the relevant baseline requirements documents during the reporting period are summarized below.

Mined Geologic Disposal System Requirements

The Mined Geologic Disposal System Requirements was modified to reflect the implementation of the multipurpose canister as a waste form in the system. This change is important to the Project as it brings focus and clarity to several fundamental concepts regarding the conduct of operations for the repository and Engineered Barrier System (e.g., large waste packages and in-drift emplacement).

Figure 2.1-1. OCRWM Document Hierarchy

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Repository Design Requirements Document

No changes were made to this document during this reporting period. The multi-purpose canister and early results from Advanced Conceptual Design will be incorporated in FY 1995.

Engineered Barrier Design Requirements Document

No changes were made to this document during this reporting period. The multi-purpose canister and early results from Advanced Conceptual Design will be incorporated in FY 1995.

Site Design and Test Requirements Document

No changes were made to this document during this reporting period. A revision will be prepared during the next reporting period to resolve unqualified requirements needed for continued Exploratory Studies Facility development.

Exploratory Studies Facility Design Requirements

No changes were made to this document during this reporting period. Changes will be incorporated during the next reporting period to resolve unqualified requirements needed for continued Exploratory Studies Facility development.

Surface-Based Testing Facilities Requirements Document

No changes were made to this document during this reporting period.

2.1.7.2 Management Controls

No changes were made to the Yucca Mountain Management Control Documents during this reporting period.

2.1.7.3 Site Characterization Program Baseline

As presented in DOE's letter to NRC (DOE, 1993k), the Site Characterization Program Baseline (DOE, 1993a) is currently the primary document used by the Project to convey information on the integration of the Exploratory Studies Facility with the Geologic Repository Operations Area and to present high-level description of the test program and the physical relationship of the test facilities to the potential repository.

The Site Characterization Program Baseline identifies the baselined site characterization program and provides a means to demonstrate traceability of changes in the objectives of site

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characterization studies. All revisions to the Site Characterization Program Baseline are reviewed, approved, and controlled in accordance with approved change control procedures.

Site Characterization Program Baseline Revision History

Revision 0, Issued February 22, 1991

Revision 1, Issued April 5, 1991: Updated information related to the Exploratory Studies Facility in preparation for start of Title II design studies. Incorporated changes to program planning resulting from the "Exploratory Studies Facility Alternatives Study: Final Report" (Dennis, 1991).

Revision 2, Issued October 2, 1991: Documented revised plans for testing in Site Characterization Plan Section 8.3.1.14. Consolidated all of the anticipated studies under Investigation 8.3.1.14 into one Study Plan (8.3.1.14.2, "Soils and Rock Properties").

Revision 3, Issued February 7, 1992: Documented changes to the objectives of Activities 1 and 4 in Study Plan 8.3.1.2.1.4, "Regional Hydraulic Synthesis and Modeling" and Activity 4 in Study Plan 8.3.1.2.3.2, "Characterization of the Saturated-Zone Hydrochemistry." Added three drillholes to Study Plan 8.3.1.2.3.1, "Regional Ground-Water Flow System." Deleted requirement for tagging surface dust suppression water with chemical tracer. Various editorial changes.

Revision 4, Issued March 13, 1992: Incorporated changes in the objectives of Activities 1 and 3 in Study Plan 8.3.1.2.3.2, "Characterization of the Upper Saturated-Zone Hydrochemistry."

Revision 5, Issued July 15, 1992: Corrected references to integration of geophysical activities.

Revision 6, Issued July 15, 1992: Updated Section 8.4 to be consistent with current Exploratory Studies Facility concept.

Revision 7, Issued July 15, 1992: Deleted Activity 8.3.1.4.2.1.6, "Integration of geophysical activities." Scope was redundant with 8.3.1.4.1.2.

Revision 8, Issued September 24, 1992: Reorganized waste package near-field environment program (Section 8.3.4.2.4) to separate the tests addressing the effects of man-made materials from testing in the near-field environment.

Revision 9, Issued October 2, 1992: Changed scope of the Site Characterization Program Baseline to delete activity descriptions that are controlled in study plans; place parameter tables in separate controlled document; and remove hypothesis testing tables and analyses supporting test control from the Site Characterization Program Baseline. Documented changes made to Activities 8.3.1.2.2.4.6, 8.3.1.5.2.1.2, 8.3.1.5.2.2.1, 8.3.1.5.2.2.2,

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8.3.1.5.2.2.3; changes made to Studies 8.3.1.3.7.2, 8.3.1.8.1.1, 8.3.1.8.1.2, 1.10.4.3; and changes made to Investigation 8.3.1.7.1.

Revision 10, Issued January 14, 1993: Documented changes made to Study 8.3.1.2.2.4; Activities 8.3.1.8.5.2.2, 8.3.1.15.2.2, 8.3.1.17.4.3.2, 8.3.1.17.4.4.3; and Section 8.3.5.13.

During this reporting period no revisions to the Site Characterization Program Baseline were issued.

Forecast: The Site Characterization Program Baseline currently contains information about the site characterization test objectives and activities that is redundant to information contained in the Site Design and Test Requirements Document. Therefore, an activity to evaluate and improve the role of the Site Characterization Program Baseline has been under way at YMSCO.

During FY 1995, it is expected that a revision to the Site Characterization Program Baseline will be prepared to improve its utility. Redundant test information will be eliminated and a presentation of the Exploratory Studies Facility, Surface-Based Testing Facilities, Repository, and Engineered Barrier System concepts will be included. The Site Characterization Program Baseline will provide an accurate source for reviewing top-level integration of the physical layout for Exploratory Studies Facility, Surface-Based Testing Facilities, and potential repository facilities. As an interface control document, the Site Characterization Program Baseline will then be revised to describe how the Exploratory Studies Facility and Surface-Based Testing Facilities are incorporated into the potential Geologic Repository Operations Area.

2.1.7.4 Change Control Board Actions

The table in Appendix B summarizes the Project Change Control Board actions that occurred during this reporting period that affected baseline documents or activities regarding the Exploratory Studies Facility and Surface-Based Testing. The key change requests during this period pertained to: (1) pulling the casing in boreholes UE-25 NRG-2A, UE-25 NRG-2B and UE-25 NRG-4 to allow geophysical logging (Change Requests 94/013 and 94/049); (2) baselining Design Package 1B that included design documents for the H-Road, shop building, subsurface wastewater system, explosive storage area at North Portal Utility into the Exploratory Studies Facility Technical Baseline (Change Request 94-071); (3) baselining Design Package 2A that included design documents for the mechanical and electrical systems to support tunnel boring machine operations into the Exploratory Studies Facility Technical Baseline (CR 94/077); and (4) providing flatter gradients in the North Ramp and Topopah Spring level drift (CR 94/085) for the enhanced Exploratory Studies Facility layout (as discussed in Progress Report #9).

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2.1.8 Environmental Audit Program

2.1.8.1 Audits

Environmental compliance activities during this reporting period consisted of environmental audits of two Project participants, EG&G Energy Measurements, Inc. and Technical and Management Support Services, in accordance with the Environmental Regulatory Compliance Plan (DOE, 1988b). Additionally, one special interest audit of a Project waste accumulation area was completed.

Forecast: An environmental audit of the CRWMS M&O contractor is the next scheduled audit. One other audit will be completed in FY 1994, for which there is currently no designated auditee.

2.1.8.2 Surveillances

During this period, approximately 178 environmental surveillances were conducted at the Yucca Mountain site to ensure compliance with environmental, programmatic, and permit requirements. Corrective action and follow-up work was required on 30 percent (53) of the surveillances; and 33 percent (18) of those follow-up activities were completed. In addition, health and safety surveillances were conducted as part of the environmental audit program.

Forecast: The number of surveillances projected over the remainder of FY 1994 is 180.

2.1.8.3 Preactivity Surveys

During the reporting period, 22 land access and environmental compliance activity reviews were completed. This effort involved a total of 66 radiological, archaeological, and biological preactivity surveys. An additional 14 requests to initiate site activity have been received this period. There are currently 12 "open/active" field activities, for which environmental preactivity surveys are being, or will be, conducted.

Forecast: It is anticipated that approximately 35 land access and environmental compliance activity reviews will be completed in the next six months. This effort will involve an estimated 105 radiological, archaeological, and biological preactivity surveys.

2.1.9 Project Planning

2.1.9.1 Technical Implementation Plan

Technical Implementation Plans for FY 1994 have been substantially completed and forwarded to NRC and NWTRB for most Work Breakdown Structure elements. In FY 1994,

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the Project developed Technical Implementation Plans for the majority of the Project's Work Breakdown Structure elements for the first time. Draft Technical Implementation Plans are developed early in the planning process for a given fiscal year to provide information for planning early in the budgeting process. The final Technical Implementation Plans document the budget, scope, and schedule for planned activities, along with the rationale for the planned work.

For FY 1994, the process for budget allocation among third-level Work Breakdown Structure elements began with the development of guidance on the Program and Project priorities for the fiscal year. For each Work Breakdown Structure element, individual studies were assigned to these priorities to assist in deciding which studies would be funded for the fiscal year. In some Work Breakdown Structure element areas, the technical rationale for the assignment of studies to priorities was reviewed with participant Technical Project Officers. As actual funding levels became known, DOE and the participants adjusted individual study funding proposals. Each DOE Division Director presented the Work Breakdown Structure element priorities and proposed activities fulfilling the priorities to Program and Project management. Requests for additional funding in specific areas were made and justified based on requirements to support Project priorities. After evaluating all requests in terms of overall Project goals, Program and Project management determined the final budget providing a well-balanced plan for FY 1994.

Preliminary drafts of the FY 1995 Technical Implementation Plans were completed in early calendar year 1994 and were in review as the planning process continued for FY 1995. Activities proposed in the drafts are aligned in light of the Proposed Program Approach. The suite of proposed activities will be reviewed for current Project goals and long-range planning.

Forecast: The final drafts of the FY 1995 Technical Implementation Plans are expected to be issued after budgets are finalized, currently scheduled for September 1994.

2.1.9.2 Integrated Test Evaluation

The Integrated Test Evaluation-1992 task was initiated to produce a management tool for prioritizing site characterization testing. This decision framework tool was produced to develop a systematic and defensible approach to adjust to the relative priorities of tests/experiments as new site data are available or as programmatic influences change. The Integrated Test Evaluation-1993 task follows the Integrated Test Evaluation-1992 task. Previous tasks had considered the suitability of the site as the only motivation for prioritizing the testing program. While determination of site suitability is an important reason for conducting tests, there are many reasons for conducting tests. The Integrated Test Evaluation-1992 and 1993 efforts considered multiple reasons for prioritizing tests.

The Integrated Test Evaluation reports made recommendations for the prioritization of the testing program for FY 1993 and FY 1994 according to a set of criteria that reflect the major reasons for testing. These criteria include factors for prioritizing tests based on their

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ability to aid in determining the suitability of the site (detect unsuitable site conditions), their ability in supporting a license application to the NRC from a DOE perspective (i.e., demonstrating regulatory compliance), their ability to provide scientific confidence within the many scientific oversight groups and the scientific community (build scientific confidence), and the costs of the testing program. The 1993 effort added the criterion of design support (provide design information) to the decision framework and provided a basis for allocating drilling costs and underground alcove construction costs to the tests that require these support functions.

The test prioritization was based upon a set of trade-off weights that can be adjusted to reflect alternate judgments or perform sensitivity analysis on the relative importance of the prioritization criteria. The integrated test evaluation model and decision framework were based on expert judgment using available information, including the results of previous prioritization task forces and the results of performance assessment studies. The results of the 1993 effort will be useful to DOE in making FY 1994 and out-year planning decisions.

Examples of the results and recommendations of the 1993 effort include:

1. Scientific confidence has the largest effect on the results of the 1992 and 1993 efforts.
2. Regulatory compliance makes the second-largest contribution to the recommended priority ranking.
3. Design information and site suitability have very little impact on the proposed ranking.
4. Two tests, 8.3.1.2.2.3, "Characterization of Percolation in the Unsaturated Zone, Surface-Based Study," and 8.3.1.2.2.4, "Characterization of the Yucca Mountain Unsaturated Zone in the Exploratory Studies Facility," occur as top ranked tests under all criteria even with wide ranges of adjustment of the trade-off weights
5. Three other tests, 8.3.1.2.3.1, "Site Saturated Zone Flow System," 8.3.1.2.2.1, "Characterization of Unsaturated Zone Infiltration," and 8.3.4.2.4.2, "Hydrologic Properties of the Waste Package Environment" will rank highly under most conditions of sensitivity analysis.

The draft executive summary documenting the Integrated Test Evaluation methodology and the 1993 assessment results were received by YMSCO in September 1993. The 1993 notebook revisions were received by YMSCO on February 14, 1994. The draft notebook contains an executive summary, technical summary, supporting briefing materials, and background appendices developed by the integrated test evaluation task group.

Forecast: The Integrated Test Evaluation methodology may be reapplied in the future as more information is gained through site characterization.

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2.1.10 Technical Data Parameter Dictionary

The Technical Data Parameter Dictionary (DOE, 1993m), which identifies data necessary to support the site suitability determination and the license application development, was issued in October, 1993.

Forecast: It is anticipated this section will not appear in future Progress Reports.

2.1.11 Energy Policy Act of 1992, Section 803 Report

A draft report to Congress entitled "Adequacy of Management Plans for the Future Generation of Spent Nuclear Fuel and High-Level Radioactive Waste" (DOE, 1993n) was prepared in accordance with Section 803 of the Energy Policy Act of 1992 (U.S. Congress, 1992). This Act requires that DOE review its current programs and plans to manage nuclear waste as mandated by the Nuclear Waste Policy Act of 1982, as amended, and to assess the adequacy of these programs and plans to manage additional waste that may be generated by nuclear power plants constructed and licensed after October 1992.

The draft report was released for public comment in June 1993. The DOE concluded that current waste-management programs and plans are adequate for any additional volumes and categories of nuclear waste produced by new nuclear power plants. The draft report contained these findings:

1. Radioactive material from new nuclear power plants, and most other radioactive materials not managed as part of the current waste-management system, will not be generated until well into the future.
2. Flexibility has been built into the current programs and plans.
3. Development of the waste management system is at an early stage, allowing ample opportunity to accommodate changing needs.

The draft report was discussed in two public meetings, one held in Las Vegas, Nevada, on July 20, 1993, and a second held in Washington, D.C., on July 29, 1993.

The final report was originally slated for delivery to Congress and the President by October 25, 1993, in accordance with the Energy Policy Act. However, due to the large number and complexity of comments received from numerous public stakeholder groups on the draft report, delivery of the final report has been delayed. The additional time will be used to more fully respond to these public stakeholder comments and to revise the report as appropriate.

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SECTION 2.2 SITE PROGRAMS

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

- Geohydrology (Section 2.2.1) - investigates surface and subsurface hydrology on both site and regional scales, with ground-water flow system characterization and modeling for both the unsaturated zone and saturated zone (Site Characterization Plan (SCP) Section 8.3.1.2).
- Geochemistry (Section 2.2.2) - investigates and models rock chemistry and mineralogy, ground-water chemistry, and geochemical behavior of materials along potential radionuclide transport pathways (SCP Section 8.3.1.3).
- Rock Characteristics (Section 2.2.3) - characterizes and models rock stratigraphic and structural features and distributions within the site area, and integrates geophysical and drilling activities to obtain subsurface stratigraphic and structural data (SCP Section 8.3.1.4).
- Climate (Section 2.2.4) - analyzes paleoclimate, paleohydrology, and paleo-environment, and characterizes modern climate, future climate, and future hydrology (SCP Section 8.3.1.5).
- Erosion (Section 2.2.5) - characterizes modern and past erosion and evaluates the potential effects of future climate and tectonics on erosion (SCP Section 8.3.1.6).
- Postclosure Tectonics (Section 2.2.6) - characterizes tectonic features such as igneous activity and fault and fold deformation in the Yucca Mountain vicinity, with emphasis on volcanic activity, and analyzes the potential effects of tectonic processes on a potential repository and the site ground-water system (SCP Section 8.3.1.8).
- Human Interference (Section 2.2.7) - evaluates the known and potential natural resources in the site area, and the potential for future human intrusion into the site area in search of such resources (SCP Section 8.3.1.9).
- Meteorology (Section 2.2.8) - characterizes the site and regional meteorological conditions of the Yucca Mountain vicinity (SCP Section 8.3.1.12).
- Offsite Installations and Operations (Section 2.2.9) - determines the presence, and potential impacts on the site area, of offsite industrial, transportation, and military installations and operations in the Yucca Mountain vicinity (SCP Section 8.3.1.13).

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- Surface and Subsurface Access Characteristics (Section 2.2.10) - characterizes the properties of surficial soil and rock materials and topographic characteristics in the site area (SCP Section 8.3.1.14).
- Thermal and Mechanical Rock Properties (Section 2.2.11) - determines rock thermal and mechanical properties from laboratory and in situ investigations and characterizes thermal and mechanical stress conditions at the site (SCP Section 8.3.1.15).
- Preclosure Hydrology (Section 2.2.12) - characterizes the potential for flooding and determines location of an adequate water supply for repository construction and operation and preclosure hydrologic conditions in the unsaturated zone at Yucca Mountain (SCP Section 8.3.1.16).
- Preclosure Tectonics (Section 2.2.13) - characterizes faults, seismicity and tectonic stress field, and evaluates the potential for faulting, ground motion, and volcanic ash fall in the site vicinity (SCP Section 8.3.1.17).
- Altered Zone Characterization (Section 2.2.14) - a new activity that was not addressed in the Site Characterization Plan, has been created to develop techniques for characterizing the altered zone, particularly focusing on thermal effects of integrated radionuclide release testing and modeling and establishing a thermodynamic data base (SCP Section - N/A).

These programs are discussed in detail in the referenced sections. In these sections are many references to study plans. The status of the study plans is summarized in Appendix C. A map showing surface features in the vicinity of Yucca Mountain is included as Figure 2.2-1.

2.2.1 Geohydrology (SCP Section 8.3.1.2)

2.2.1.1 Study 8.3.1.2.1.1 - Characterization of the Meteorology for Regional Hydrology

Activity 8.3.1.2.1.1.1 - Precipitation and meteorological monitoring. Data collection continued during the reporting period. Site meteorology data from five weather stations plus four remote tipping-bucket rain gauge locations were downloaded, reviewed, and archived.

Additional precipitation data were collected from the network of nonrecording (storage) rain gauges deployed on and around Yucca Mountain. This network expands upon the automated network and fills in gaps. Three types of storage gauges were deployed: (1) plastic wedges, (2) 0.1-m-diameter plastic canisters, and (3) 0.2-m-diameter National Weather Service gauges. During the reporting period there was an effort to replace most of the wedge-shaped rain gauges. It was found that the accuracies of the wedge-shaped gauges were unsatisfactory due to the square shape of the orifice. The 0.1-m-diameter round canister

Figure 2.2-1 Map of Surface Features

FIGXX1.123.FH3/6-27-94

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gauges were used as replacements. The network now consists of 132 nonrecording gauges. During the reporting period, there were ten precipitation events affecting Yucca Mountain.

Isohyetal maps and numerical models for simulating precipitation are needed to help characterize natural infiltration at Yucca Mountain. A geostatistical analysis of measured precipitation was conducted to determine the spatial variability of precipitation accumulated from storm periods. Results are presented in a paper, "A Preliminary Analysis of the Spatial Variability of Precipitation at Yucca Mountain," (Hevesi), prepared for the 5th Annual International High-Level Radioactive Waste Management Conference & Exposition, in Las Vegas, Nevada, May 22-26, 1994 (hereinafter referred to as the 1994 High-Level Waste Conference). A U.S. Geological Survey (USGS) open-file report entitled "Precipitation Measurements from a Network of Non-Recording Gages at Yucca Mountain, Nevada" (Ambos) summarized the data and was in technical review.

Meteoric water samples were taken from the storage gauge network for stable isotope analysis. Collection and archiving of satellite and lightning data continued. Synoptic weather charts were also received and analyzed daily. The daily synoptic weather patterns were cataloged according to the five major weather types. Time-lapse video data of Yucca Mountain weather continued to be collected.

Forecast: Collection and analyses of data from the precipitation networks will continue. The 1992-93 data reports will be completed.

2.2.1.2 Study 8.3.1.2.1.2 - Characterization of Runoff and Streamflow

Activity 8.3.1.2.1.2.1 - Surface-water runoff monitoring. Monitoring activities continued at 14 continuous-recording stream gauges, 12 peak-flow sites, and 26 storage-type precipitation gauges. Sites for three additional continuous-recording stream gauges planned for selected washes along the eastern slope of Yucca Mountain were investigated and flagged. Data collected from these sites will be used to support studies associated with the Unsaturated Zone Infiltration Study (8.3.1.2.2.1) and other hydrologic activities.

Streamflow and precipitation data collected at and near Yucca Mountain will be used to support flood frequency and infiltration studies in the unsaturated zone and Fortymile Wash. Two reports summarize and analyze data collected through 1990. A report entitled "Streamflow and Selected Precipitation Data for Yucca Mountain and Vicinity, Nye County, Nevada, Water Years 1983-85" (Pabst et al., 1993) was published. A report entitled "Streamflow and Selected Precipitation Data for Yucca Mountain Region, Southern Nevada, and Eastern California, Water Years 1986-90" (Kane et al.) was drafted. Work continued on processing streamflow, water-quality, and precipitation data collected during water years 1991-93 for inclusion into the Nevada District's Annual Water Resources publication.

Activity 8.3.1.2.1.2.2 - Transport of debris by severe runoff. No progress during the reporting period; this was an unfunded activity.

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Forecast: Data collection and analyses from the streamflow-precipitation networks will continue. Three additional continuous-recording gauges will be installed at selected drainages along the eastern slope of Yucca Mountain to support the Unsaturated Zone Infiltration Study. Peak-flow gauges will also be installed to supplement data collected at these and other selected continuous-recording sites. Reports documenting runoff and precipitation data for Yucca Mountain and its vicinity for 1986-90 and 1991-93 will be completed.

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

Activity 8.3.1.2.1.3.1 - Assessment of regional hydrologic data needs in the saturated zone. An evaluation of this activity was made in which a prioritization of project data needs was largely completed. It was determined that as new project data become available, data needs may change based on previously unrecognized hydrologic conditions. The current data uncertainty was used to prioritize data collection needs, as documented in the study plan.

Activity 8.3.1.2.1.3.2 - Regional potentiometric-level distribution and hydrogeologic framework studies. Chemical data from water samples obtained from the hydraulic testing of borehole USW UZ-14 were examined for representativeness. Results of this testing are summarized in a poster session entitled, "Spreadsheets for Field Analyses of Hydrochemical Samples" (Czarnecki et al., 1993) presented at the Fall Meeting of the American Geophysical Union in San Francisco, California, December 6-10, 1993. A map showing the location of boreholes in the vicinity of the proposed repository is included as Figure 2.2-2.

Water levels were monitored at several wells in the southern Amargosa Desert using a well sounder to add to the available data set of regional potentiometric levels.

A plan was prepared for testing the dissolution of Sr from various rock types in the vicinity of Yucca Mountain to gain a better understanding of dissolution rates and mechanisms. Isotopes of Sr are being evaluated from rock and ground-water samples obtained from Yucca Mountain and vicinity to identify possible ground-water flow paths within the saturated and unsaturated zones.

Activity 8.3.1.2.1.3.3 - Fortymile Wash recharge study. Soil-moisture and depth-to-water measurements were made in upper Fortymile Wash on a regular basis. Ground-water levels and unsaturated zone soil moisture continued to decline following a period of recharge in January-March, 1993. Precipitation, streamflow, unsaturated zone, and saturated zone data for Water Year 1993 were compiled.

Precipitation, streamflow, and unsaturated zone and saturated zone data were compiled to document ground-water recharge in Fortymile Canyon during 1992. The data are summarized in a draft report entitled "Selected Hydrological Data from Fortymile Wash in the Yucca Mountain Area, Nevada, Water Year 1992" (Savard) which was submitted for technical review. Streamflow, unsaturated zone, and saturated zone data were compiled and discussed in the paper entitled "Ground-Water Recharge in Fortymile Wash near Yucca Mountain,

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Nevada, 1992-93" (Savard). The paper documents ground-water recharge in Fortymile Canyon during 1992-93 and was scheduled to be presented at the 1994 High-Level Waste Conference.

Activity 8.3.1.2.1.3.4 - Evapotranspiration studies. Hydrochemical data from water samples from Franklin Lake were organized in a spreadsheet and various plots of the data generated. In addition, field alkalinities were recalculated using a computer spreadsheet for water samples collected at Franklin Lake Playa. These sample data were plotted on a Piper diagram along with data from Ash Meadows and other wells in the Amargosa Desert. These data should yield a better understanding of ground water sources that discharge at Franklin Lake Playa.

Forecast: Testing of a Campbell Scientific Bowen radio station for obtaining continuous evapotranspiration estimates at Franklin Lake Playa will begin. Hydraulic and hydrochemical testing of drillhole USW G-2 will occur. Monitoring of water levels in the subregional ground-water flow system will continue. Hydrochemical sampling of at least one deep piezometer nest in the Amargosa Desert will be conducted and automated monitoring of pH and specific conductance of the discharge water performed. Monitoring of water levels, soil moisture, and precipitation will continue at Fortymile Wash. Long-term hydrographs of water levels from wells in the subregional ground-water flow system will be constructed to document long-term water-table fluctuations.

2.2.1.4 Study 8.3.1.2.1.4 - Regional Hydrologic System Synthesis and Modeling

Activity 8.3.1.2.1.4.1 - Conceptualization of regional hydrologic flow models. No progress during the reporting period; this was an unfunded activity.

Activity 8.3.1.2.1.4.2 - Subregional two-dimensional areal hydrologic modeling. Estimates of ground-water velocities near Wells UE-25 J-12 and UE-25 J-13 were calculated based on vectors from Plate 2 of the finite-element model presented in "Finite-Element Simulation of Ground-Water Flow in the Vicinity of Yucca Mountain, Nevada-California" (Czarnecki and Waddell, 1984) for use in estimating order-of-magnitude ground-water velocities using uranium isotopic ratios. Sections for a report on conceptual models of ground-water flow at Yucca Mountain were finalized and submitted for colleague review.

Various tests of a finite-element mesh generator were performed. Several styles of meshes were developed and used in conjunction with different well densities. An upgrade version of the mesh generation software was installed and preliminary tests conducted.

Activity 8.3.1.2.1.4.3 - Subregional two-dimensional cross-sectional hydrologic modeling. No progress during the reporting period; this was an out-year activity.

Activity 8.3.1.2.1.4.4 - Regional three-dimensional hydrologic modeling. Development of a three-dimensional hydrogeologic framework model of the Death Valley regional ground-water flow system, which includes the Yucca Mountain site, was completed. The

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model, which is continually being modified and improved, was developed using Stratamodel's Stratigraphic Geocellular Modeling System. The solid representation was then queried to develop numerical ground-water flow model input arrays for the regional numerical ground-water flow model. Hypotheses about the effects of faults and hydrogeologic geometries were also evaluated using the model.

The role of faults and other structural discontinuities on regional ground-water flow are discussed in a paper entitled "Hydrogeologic Characterization of Structural Discontinuities in the Death Valley Region, Nevada and California" (Faunt). Data used to construct the hydrogeologic map and hydrogeologic framework model are summarized in a report entitled "Digital Geologic Maps of the Mariposa, Kingman, Trona, and Death Valley Sheets, California" (D'Agnese et al.). Both reports were in the technical review process.

Hydrologic analysis of the regional flow system continued. Estimates of ground-water discharge and recharge were modified from earlier investigations. A method to refine the Maxey and Eakin first-approximation recharge method was developed utilizing comparative data. These comparative data included the vegetation-landform map also developed as part of this study.

Preliminary numerical ground-water flow simulations of a 190 row, 155 column, and four-layer model were conducted utilizing the hydrogeologic framework model and hydrologic analyses. The data, which are contained in a Geographic Information System data base, were modified for input to the MODFLOW numerical modeling code. Initial runs showed reasonable agreement with observed conditions. As a result of these runs, the model design was modified to a three-layer model.

Reports describing development of the hydrogeologic framework model, interpretation of regional hydrologic analysis, and preliminary regional ground-water model were begun.

Forecast: The hydrogeologic framework model will continue to be modified and improved. The three-dimensional numerical model will be modified based on initial, preliminary runs. Calibration of a steady-state model will continue. The digital geologic maps report (D'Agnese et al.) will be submitted for approval.

Construction of finite-element model simulations of the revised subregional model domain with dense mesh refinement at Yucca Mountain will be continued.

2.2.1.5 Study 8.3.1.2.2.1 - Characterization of Unsaturated-Zone Infiltration

Activity 8.3.1.2.2.1.1 - Characterization of hydrologic properties of surficial materials. Work was conducted to optimize tool configurations and performance of the geophysical tools. Various tool stacks were run in UE-25 UZN-85, USW UZN-55, and USW UZN-54. These holes are being used for calibration of the various tools and for the development of data transfer techniques. Various selections of wireline geophysical tools were used in

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boreholes in the Yucca Mountain area. Neutron Holes UE-25 UZN-1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 13, 85; Neutron Holes USW UZN-54, 55, and 63; Boreholes UE-25 NRG-2A, 2B, UE-25 UZ-4; and Well USW WT-2 were logged.

The effect of gamma-gamma detector spacing on the diameter variation behind casings was investigated. A 45.7-meter-long surface transect was logged repeatedly to establish a baseline density measurement. The gamma-gamma tool was then dragged repeatedly through a uniformly dense 4.5-meter section of drillhole casing. Following each run, different size holes were excavated beneath the casing. In one area, a lead brick was placed under the casing. The gamma-gamma tool was able to detect the different treatments. The results of this study will be applied to detecting washout zones behind a section of casing in a borehole.

Particle size analysis was used to investigate the range in particle size separates found in the less than 2 mm fraction of the surficial materials. The effect of surface carbonate and clay coatings on the physical and hydrologic properties of rock fragments (>2 mm fraction) was studied. The depth to bedrock data gathered for this activity are to be used in the refinement of maps and map units being produced by Activity 8.3.1.5.1.4.2, Surficial Deposit Mapping. Various coverages of different Yucca Mountain features have been received from EG&G in digital format for incorporation into the ARC/INFO data base, including the Busted Butte and Topopah Spring NW 7.5" Quadrangle Digital Elevation Maps.

The infiltration rate of a soil is an important parameter for understanding other physical and hydrologic properties of that soil. An automated, constant head, double-ring infiltrometer system was developed and used for continuous, long-term, ponded, field infiltration studies in skeletal, arid soils at Yucca Mountain. The description of this system is detailed in a paper entitled "A Large-scale, Automated, Constant Head, Double-Ring Infiltrator" (Hofmann et al., 1993) presented at the Annual Soil Science Society of America Meeting in Cincinnati, Ohio, November 7-12, 1993. Prior to conducting the double-ring infiltrometer test, profile description and sampling, borehole geophysics, and laboratory analysis were used to determine the physical and hydrologic properties of the soil. Soil development and the existence of distinctive stratigraphic layers were identified, and bulk density, porosity, grain density, and water retention were measured in the laboratory. The detailed characterization of the soils was reported in a paper entitled, "Characterization of the Physical and Hydrologic Properties of Desert Alluvium used in a Large Scale Ponding Experiment at Yucca Mountain, Nevada" (Flint et al., 1993a) presented at the Annual Soil Science Society of America Meeting.

Field soil-retention data were collected from surface soils on ridgetops, sideslopes, and washes at Yucca Mountain. The field range of water retention data during both wet and dry periods were measured. Data and methodology are detailed in a paper entitled "Field Water Retention of Skeletal Desert Soils, Yucca Mountain, Nevada" (Hudson and Flint, 1993) presented at the Annual Soil Science of America Meeting.

Water-retention characteristics of a skeletal soil are a function of both the soil fraction (<2 mm) and the rock fragments (>2 mm). The water-retention relation can be estimated from laboratory measurements of the separate water-retention properties of the soil and rock

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fragments. Preliminary results indicate that combining the separate water-retention properties of the components of a skeletal soil produces a good description of the water-retention characteristics of that skeletal soil. This study is summarized in a paper entitled "Determination of Water Retention Characteristics of a Skeletal Soil at Yucca Mountain, Nevada" (Nash and Flint, 1993) presented at the Annual Soil Science of America Meeting.

Activity 8.3.1.2.2.1.2 - Evaluation of natural infiltration. Monthly logging of borehole UE-25 UZN-85 was discontinued because it no longer represented natural conditions—it was used for a ponding experiment and had been flooded. Logging at borehole USW UZN-83 was also discontinued because it is now being utilized by the seismic studies group and is not available for logging.

Water content profiles from 97 unsaturated zone neutron access boreholes were measured at monthly intervals by using neutron soil-moisture probes. All data collected through February 1994 were validated and entered into the data base. Laboratory analysis of core samples from the neutron calibration boreholes was completed (Activity 8.3.1.2.2.3.1), and measured values of volumetric water content and material properties were being used to define calibration equations for the neutron probes. Preliminary neutron-probe calibration equations were developed, but have not been finalized. An analysis comparing the logs obtained from the hand-held neutron soil-moisture probes with the larger dual-detector neutron tool, the gamma-gamma tool, and the lithologic logs was in progress and will be used to finalize the calibrations.

A one-dimensional numerical model of shallow infiltration in alluvium was developed, calibrated, and verified by matching simulated water-content profiles with the measured profiles obtained at UE-25 UZN-7, 8, and 9 in Pagany Wash. The model performs a continuous simulation of shallow vertical infiltration and redistribution in alluvium using precipitation data and evapotranspiration data as input. The results of this work were presented in a paper entitled "Developing and Verifying a Numerical Model of Water Content Profiles in Alluvium at Yucca Mt., Nevada" (Hevesi and Flint, 1993). Measured water-content profiles obtained from January 1990 to October 1993 for a total of 36 boreholes in both WT-2 Wash and Pagany Wash were analyzed and compared with lithology, thickness of alluvial cover, topography, measured precipitation, and estimated runoff. This study was conducted to test and possibly modify the conceptual model of natural infiltration. A paper entitled "Shallow Infiltration Processes in Arid Watersheds at Yucca Mountain, Nevada" (Flint et al., 1993b) summarized this work. An analysis of the influence of soil texture, modeled solar radiation, measured precipitation, and topographic position on measured water contents and water potentials at 15 and 30 cm below the surface along three transects in WT-2 Wash was completed and summarized in a paper entitled "Properties Controlling the Seasonal Variability of Soil Surface Water Content in an Arid Watershed at Yucca Mountain, Nevada" (Nash et al., 1993). All three of these papers were presented at the Annual Soil Science Society of America Meeting.

The standard deviation of water content vs. borehole depth using the 1990 to 1993 record at each borehole site for all 97 boreholes was used to estimate the maximum depth of seasonal influences on shallow infiltration as a function of both geology and

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location. This information was used in conjunction with measured material properties, measured water contents, an assumed unit gradient, and assumptions concerning fracture flow to create a map of the near-surface potential moisture flux at Yucca Mountain. The map identifies potential areas of relatively high net-infiltration rates and defines a spatially variable, surface boundary condition for the three-dimensional, site-scale unsaturated flow model. This preliminary map and paper entitled "Spatial Distribution of Potential Moisture Flux at Yucca Mountain" (Flint and Flint) will be presented at the 1994 High-Level Waste Conference. A characterization of net infiltration rates is needed for site-scale evaluation of ground-water flow at Yucca Mountain. Shallow infiltration caused by precipitation may be a potential source of net infiltration. A one-dimensional finite difference model of shallow infiltration with a moisture-dependent evapotranspiration function and a hypothetical root-zone was calibrated and verified using measured water-content profiles, measured precipitation, and estimated potential evapotranspiration. The results of this study are presented in a paper prepared for the 1994 High-Level Waste Conference entitled "Verification of a 1-Dimensional Model for Predicting Shallow Infiltration at Yucca Mountain, Nevada" (Hevesi et al.).

An analysis of potential evapotranspiration using measurements from a Class A evaporation pan in Jackass Flats, a Bowen ratio station in Pagany Wash, and five full Penman weather stations continued. These results are being used to develop and calibrate the evapotranspiration component of watershed (water balance) models for Yucca Mountain.

Activity 8.3.1.2.2.1.3 - Evaluation of artificial infiltration. A ponded infiltrometer was used to study infiltration into a layered skeletal desert alluvial soil sequence. Fifty thousand liters of water infiltrated into the soil under a constant 10 cm head during a 14-day period. Vertical water movement was monitored with a neutron probe. The results of the large plot infiltration test were summarized in a paper entitled "Large Plot Ponded Infiltration on a Skeletal Desert Alluvial Soil Sequence" (Guertal et al., 1993), which was presented at the Annual Soil Science Society of America Meeting.

A ponding study site was established at UE-25 UZN-7. This will be the site of the next ponding experiment. A design for a tension infiltrometer was completed. A prototype design of a sprinkle infiltrometer was developed.

Morphological descriptions, borehole geophysics, hydraulic properties from samples, and a ponding experiment were used to characterize a layered, heterogeneous, desert soil sequence at UE-25 UZN-85. The borehole geophysical logging data correlated well with the observed horizons from the exposure and/or the corresponding washout zones. In addition, the geophysical logs provided a quantitative estimation of the porosity for the horizons. Specific results of this experiment are described in a paper entitled "Characterization of Desert Soil Sequence at Yucca Mountain, Nevada" (Guertal et al.) prepared for presentation at the 1994 High-Level Waste Conference.

One-dimensional and two-dimensional radial flow numerical models were used to evaluate the results for a 60.5-hour ponded infiltration experiment conducted at UE-25 UZN-85. The numerical modeling of the infiltration experiment indicated a possible washout zone around the borehole existed, significant lateral flow away from the borehole

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occurred, measured permeabilities were too large to simulate infiltration, layering in the profile affected infiltration, and permeabilities were anisotropic. Specific results of this experiment are described in a paper entitled "Modeling a Poned Infiltration Experiment at Yucca Mountain, Nevada" (Hudson et al.) prepared for the 1994 High-Level Waste Conference.

An automated double-ring infiltrometer was developed to determine saturated hydraulic conductivity and sorptivity, encompassing a wide range in rocky desert soils. The infiltrometer was tested in two washes. The cumulative infiltration data were fit with the two term Philip infiltration equation in order to estimate infiltration rates at different initial saturations so that the two soils could be compared with each other and with hypothetical rainfall rates expected to occur at Yucca Mountain. Results of this research are presented in a paper entitled "Field Determination of Hydrologic Parameters of Yucca Mountain Surficial Materials" (Hofmann et al.), which is currently in review.

Forecast: Surficial Deposit Mapping will be developed. These properties will be used to create the geohydrological surficial-infiltration and runoff. An experiment that focuses on the interaction between various types and sizes of rock fragments and surface coating will be performed. Hydraulic characterization of the map units will be initiated.

A study site in Split Wash has been identified for a detailed analysis of evapotranspiration. The study will incorporate instrumentation for the continuous monitoring of near-surface water content, soil temperature, and water potential in conjunction with estimates of evaporation and potential evaporation using a Bowen ratio station, a Penman weather station, and continuous measurements of vertical water-content changes and water potentials using two fully instrumented boreholes. Measurements of monthly water content profiles at the 97 neutron access boreholes will continue. Calibration equations for the neutron probes will be completed and an open-file report of the historical neutron log record will be prepared. Calibration of water balance models for developing a three-dimensional watershed scale model will continue using measurements of potential evapotranspiration, precipitation, water content profiles, and material properties.

The double-ring infiltrometer will be used in various locations in conjunction with the hydrologic characterization of map units. A tension infiltrometer unit will be built and used. A prototype sprinkler infiltrometer will be constructed.

2.2.1.6 Study 8.3.1.2.2.2 - Water Movement Test

Chlorine-36 analyses were completed on 24 samples of drill cuttings from USW UZN-11, 37, 53, 54 and UE-25 UZ-16, plus a perched water sample from USW UZ-14. Results of some of these analyses were reported by J. Fabryka-Martin at various Project meetings, including the Project Technical Program Review in Las Vegas, Nevada, February 14-18, 1994. A paper entitled "Distribution of Chlorine-36 in the Unsaturated Zone at Yucca Mountain: An Indicator of Fast Transport" (J. Fabryka-Martin), which discussed the

results of numerical modeling studies under way to evaluate possible moisture migration pathways that are consistent with the observed ^{36}Cl distributions, was being prepared.

Forecast: Surface soil samples, soil profiles from pits, and cuttings from neutron access boreholes and the Exploratory Studies Facility will be obtained and examined to (1) determine the prebomb meteoric $^{36}\text{Cl}/^{35}\text{Cl}$ ratio, (2) assess the variability in meteoric Cl/Br and $^{37}\text{Cl}/^{35}\text{Cl}$ ratios, and (3) estimate present-day shallow infiltration. Cuttings from deep surface-based holes in the unsaturated zone at Yucca Mountain will be collected and analyzed to (1) determine the depth to which bomb-pulse ^{36}Cl has penetrated and correlate such distribution with lithology and structural features, and (2) estimate the average residence time of infiltrating water as a function of depth.

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

Activity 8.3.1.2.2.3.1. - Matrix hydrologic properties testing. Matrix property data from outcrop transect data sets were re-analyzed, and statistical analyses were completed on the distributions of physical and hydrologic properties of the different lithologic units. Good relationships between porosity and flow measurements were developed for two transects for predictive purposes, as very low flow permeabilities cannot yet be measured. These analyses resulted in estimates of parameters for modeling of all lithologic units exposed at the surface within the boundaries of the site scale model. This information, along with estimates of present-day surface rock water contents from Activity 8.3.1.2.2.1.2, was used to develop an approach for estimating potential and present-day surface fluxes at Yucca Mountain.

A study is being conducted to investigate the determination of porosity using helium pycnometry on rocks of various lithologies. This is showing where the water is held in the rock at different degrees of dryness and what pore space constitutes an "effective" porosity that contributes to the flow processes. This study has investigated a series of samples from the nonwelded base of the Tiva Canyon Member that range in porosity from 11 to 36 percent, samples of zeolitized tuff from the tuffaceous beds of the Calico Hills, as well as samples from the nonlithophysal zone of the welded Topopah Spring Member.

All preserved samples from the 23 neutron holes drilled into tuff (as opposed to alluvium) have been processed to determine bulk density, porosity, particle density, and water content. Water potential measurements have also been completed. About 305 m of the samples preserved in LEXAN from UE-25 UZ-16 have had plugs cut from them for permeability and moisture retention measurements. The permeability procedure is in place and samples are being run. The high pressure permeameter for use on very low permeability samples has been built but has not yet been installed in the laboratory and tested.

It was determined, using simple one-dimensional models, that the water potential values obtained using the CX-2 chilled-mirror psychrometer were very good for rock saturations less than about 99.5 percent and less reliable closer to full saturation when developing moisture retention relationships. Relatively quick methods for measuring moisture retention close to

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saturation is by use of pressure pots and hanging water columns, which are currently being tried with rock core with only partial success. The Submerged Pressure Outflow Cell system, which is rather time consuming, has been shown to work well and it can measure moisture retention at the wet end as well as provide hysteresis measurements. This method will be used on rock cores that have had moisture retention curves measured using the chilled-mirror psychrometer.

Activity 8.3.1.2.2.3.2 - Site vertical borehole studies. Several planning and design meetings were held to review and finalize design requirements for instrumenting small diameter (less than 0.15 m) boreholes and the UE-25 UZ-16 borehole. Siting studies for locating USW UZ-7A in the Ghost Dance fault zone were completed and the location of this borehole was staked in the field in late March. Drilling of USW UZ-7A is scheduled to begin after completion of USW SD-12.

The fabrication of two additional insulated instrument shelters for the in situ borehole instrumentation and monitoring program was started. Refurbishing of two existing instrument shelters that were built in 1989-90 was completed.

Sensors for instrumenting USW NRG-6 were calibrated, and calibrations of sensors for use in instrumenting USW UZ-7A were initiated. A design for an aluminum sliding screen unit for use in instrumenting large-diameter boreholes (30.5 cm) was completed and a prototype was built and tested. Work continued on fabrication of a second gas-sampling apparatus for use in sampling deep formation rock gases without condensing water vapor in the sampling tubes.

Two 12-meter deep, dry-augured boreholes, located adjacent to the Hydrologic Research Facility in Area 25, were instrumented in October 1991, and a third in February 1992. Four instrument stations located at depths of 3.0, 6.1, 9.1, and 12.2 m were established in each borehole in order to evaluate instrumentation that will be used in the deep unsaturated zone borehole instrumentation program. Results of the prototype borehole instrumentation program indicate that the stability and operational reliability of the sensors selected for use at Yucca Mountain will be adequate to sustain a long-term, in situ monitoring program of three to five years duration. Sensor accuracy and precision are sufficient to measure the state variables (pneumatic pressure, temperature, vapor pressure and water potential) needed to quantify water, water vapor, gas, and heat flux in the unsaturated zone at Yucca Mountain. This information is summarized in a paper entitled "Results of Prototype Borehole Instrumentation at the Hydrologic Research Facility, Area 25" (Rousseau et al.) to be presented at the 1994 High-Level Waste Conference.

A gas sampling system was designed to withdraw nearly vapor-saturated gases (93 to 100 percent relative humidity) from deep, unsaturated zone boreholes. Using this sampling system, nearly vapor-saturated formation rock-gases can be withdrawn from deep boreholes without condensing water vapor in the sampling tubes, and fractionating heavy isotopes of oxygen, hydrogen, and carbon. This sampling system is described in a paper entitled "A Gas Sampling System for Withdrawing Humid Gases from Deep Boreholes" (Rousseau et al.) to be presented at the 1994 High-Level Waste Conference.

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The borehole instrumentation and monitoring program provides a means of defining the unsaturated zone fluid flow (liquid and gas) potential. Data will include in situ temperature, pneumatic pressure, and water potential. In addition, the instrumentation program provides facilities for gas-sampling, gas-tracer diffusion testing, water-injection testing, water-level monitoring, neutron moisture-meter monitoring, temperature profiling, and in situ recalibration of the downhole sensors. This program is presented in some detail in a paper entitled "A Borehole Instrumentation Program for Characterization of Unsaturated-Zone Percolation" (Kume and Rousseau) to be presented at the 1994 High-Level Waste Conference.

A 6-wire, Peltier-type thermocouple psychrometer was designed for monitoring in situ water potentials in dry-drilled boreholes in the unsaturated zone and consists of a wet-bulb, chromel-constantan, sensing junction and a separate dry-bulb, copper-constantan, reference junction. The new design has resulted in a psychrometer that has an expanded range and greater reliability, sensitivity, and accuracy compared to the standard model. Results of the testing of this new design were scheduled to be presented in a paper entitled "Evaluation of a 6-Wire Thermocouple Psychrometer for Determination of *In-Situ* Water Potentials" (Loskot et al.) at the 1994 High-Level Waste Conference.

Geologic and hydrologic data from borehole USW UZ-6S including those from drilling operations, lithology, coring, and laboratory analyses of hydrologic properties, which include gravimetric water content, water potential, and bulk-and grain-density values are presented in a report entitled "Geohydrologic Data from Test Hole USW UZ-6s, Yucca Mountain, Nye County, Nevada" (Loskot, 1993).

Vertical Seismic Profiling

The seismic cross-borehole experiment in the Experimental Mine at Idaho Springs, Colorado, was completed. Over 5000 three-component source-receiver combinations were recorded, processed, and analyzed to produce a two-dimensional cross hole image of the subsurface. A final report entitled "The Use of the Cross-Borehole Seismic Technique in Geological Investigations at the Near Surface" (Balch and Karazincir) was in review.

A multiple offset, "9-component" vertical seismic profile has been designed to obtain subsurface hydrogeologic information at Yucca Mountain. Physical elastic models were used to demonstrate the viability of the concept and to develop imaging computer software. These models were also used to locate the optimum position of UE-25 UZ-16 in order to image the Ghost Dance fault in the center of Yucca Mountain, yet retain the capability to image the imbricate fault structures along the eastern flank. A preliminary vertical seismic profile, using a single 3-component, wall-locking seismometer, was run in August 1993, to establish that coherent seismic signals can be obtained at depth, and at large offset distances, in the volcanic rocks present at Yucca Mountain. This survey was run in the UE-25 UZ-16 borehole. A summary paper entitled "Applications of Multi-Mode Imaging to Multiple Offset VSP Data" (Balch et al.) was accepted for presentation at the 1994 High-Level Waste Conference.

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Additional processing done on the UE-25 UZ-16 vertical seismic profile data included Minivibe data recorrelation and analysis, three-dimensional polarization analysis on Omnipulse and Minivibe recordings, and enhancement of reflections and diffractions. Based on the UE-25 UZ-16 vertical seismic profile, velocity-depth plots were made for inclusion in the UE-25 UZ-16 well data base, and observed Omnipulse seismic source wave forms were extracted for use in generating realistic synthetic seismograms. A preliminary status on evaluation of the UE-25 UZ-16 vertical seismic profile data was completed and presented at the Integrated Geophysics Meeting in Las Vegas, Nevada, December 13, 1993. The report verified that all objectives of the survey were fulfilled, and a production vertical seismic profile is feasible.

Hydrologic Data Acquisition System

The automated data-collection programs were tested and improved. Code was added to monitor a precision resistor as an ongoing check on the current generator and voltmeter. An automated transfer of files from the instrument shelter at the Hydrologic Research Facility (used as a test facility) was developed using radio modems and an implementation of a communications protocol TCP/IP. Work was also begun on monitoring the electronic keyed entry system. Additional work was done on the IDISPLAY program which is used to display and evaluate the sensor data. All major functions have been implemented. The DISATEST program was developed and tested. This program tests the proper operation of sensors and valves once they are assembled in the Downhole Instrumentation Station Apparatus.

Evaluation of data from the Hydrologic Research Facility boreholes continued throughout the reporting period. Sensors in these boreholes have been in operation for 29 months and continue to provide reliable data. Sensors in the second borehole were retrieved and are in the process of being recalibrated.

Surface-Based Air-Permeability Testing

The surface-based air-permeability testing packer system was assembled and installed in UE-25 UZ-16. Initial testing of the packer system and support equipment was conducted on an interval of the Tiva Canyon Member 21.3 - 25.3 m below ground surface. The equipment was successfully tested and the packer system was lowered to 470.3 m, isolating an interval of the Prow Pass at 475.8 - 479.7 m. The packers were inflated and stabilized, the test interval was pumped with a vacuum pump, and gas samples were extracted for use in the geochemistry program. Air permeability testing was conducted after completing the gas sampling. Surface-based air-permeability testing in UE-25 UZ-16 was successfully conducted in the Tiva Canyon and Topopah Spring members of the Paintbrush Tuff and in the Calico Hills and Prow Pass units. The performance of the field equipment exceeded expectations, and more than 200 air-injection tests have been conducted in UE-25 UZ-16. Air-injection testing data to determine air permeabilities in Borehole UE-25 UZ-16 were analyzed and included in a paper entitled "Results of Air Permeability Testing in a Vertical Borehole at Yucca Mountain, Nevada" (LeCain and Walker) to be presented at the 1994 High-Level Waste Conference.

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Work began on the packer assembly to be used for air-permeability testing in the NRG and SRG boreholes. The ramp boreholes will have a nominal diameter of 15.9 cm and will require a different size packer assembly than that used in the larger diameter (31.1 cm) unsaturated zone boreholes. The new packer assembly is 80 percent complete.

USW UZ-14 Support

Drilling at USW UZ-14 was temporarily suspended in October. The LM-300 drill rig was moved to USW SD-12 and another rig was moved to USW UZ-14 in February. PQ-size core drilling was restarted in March. High pH water, presumably derived from the micro-fine cement grout used to seal the perched water zone above the basal vitrophyre, has delayed continuation of drilling. The present plan is to remove borehole residue, monitor for a drop in pH, and continue drilling this borehole to a depth of 9.1 m below the water table. Reaming of this borehole is contingent upon the results of matrix property testing of the core. Fracture logging of USW UZ-14 core continued throughout the reporting period.

Activity 8.3.1.2.2.3.3 - Solitario Canyon horizontal borehole study. No progress during the reporting period; this was an out-year activity.

Forecast: An open-file report on the current understanding of matrix hydrologic and physical properties based on data from outcrop transects will be reviewed. A report will be prepared presenting all laboratory data from the neutron borehole core samples. Samples from the unsaturated zone boreholes, the systematic drilling boreholes, NRG and SRG boreholes, as well as samples from boreholes drilled in the Exploratory Studies Facility and artificial infiltration plot boreholes, will be processed for physical properties and water content. Many of the samples will be processed for flow properties. As the core processing continues and the data base expands, the analysis will continue to narrow down the representative property values for various rock types to provide all parameters necessary for modeling with an error as small possible. A focused effort will be made to understand and quantify the unsaturated flow characteristics of the rocks at Yucca Mountain.

Boreholes UE-25 UZ-16, USW UZ-7, and USW NRG-6 will be instrumented for collection of hydrologic data and monitoring will begin. Calibration of sensors for boreholes USW UZ-14 and USW SD-12 will begin. The UE-25 UZ-16 borehole completion report will be submitted for review and approval. Vertical seismic profiles at UE-25 UZ-16 will be conducted. Monitoring of the sensors in the Hydrologic Research Facility boreholes will continue. Surface-based air-permeability testing will be conducted. Coring and fracture logging will be completed at USW UZ-14. Water from USW UZ-14 will be analyzed for cation, anion, and isotopic composition. Testing and calibrating of new logging tools will begin during the next reporting period.

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

Activity 8.3.1.2.2.4.1 - Intact-fracture test in the Exploratory Studies Facility. The linear variable differential transducers were received and preliminary testing of the PC-based data acquisition was completed. However, the linear variable differential transducers calibration stand used in the laboratory developed some hysteresis problems and could not be repaired. The stand was replaced and calibration of the linear variable differential transducers will be completed in late-March or early-April 1994. Testing began on the isothermal bath for thermocouple psychrometer calibrations to check thermal stability.

A PC-based software data base was established for the calibrations and instruments/transducers for the Intact Fracture Test, Percolation Test, and the Excavation Effects Test using Paradox for Windows. Activity staff continued to provide support for prototype testing of the Percolation Test in the Exploratory Studies Facility, Activity 8.3.1.2.2.4.2.

Activity 8.3.1.2.2.4.2 - Percolation tests in the Exploratory Studies Facility. The ponding test continues on a large, fractured, welded tuff block from the Tiva Canyon columnar unit. The block dimensions are 54.3 cm long x 47.5 cm wide x 80.6 cm high. Measurements are being made of water flow rate at different upper boundary pressures. The upper boundary pressure will be decreased until water flow stops. Then, pressure will be increased until flow is re-established. This plan will allow testing for hysteresis and air blockage effects on unsaturated flow through fractures. These results will provide input to the unsaturated zone fracture model. A paper entitled "Observations of Water Movement in a Block of Fractured Welded Tuff" (Thamir et al.) summarizes the current work and was prepared for the 1994 High-Level Waste Conference.

Activity 8.3.1.2.2.4.3 - Bulk-permeability test in the Exploratory Studies Facility. No progress 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 packer assemblies were redesigned to eliminate problems identified in the prototype equipment. The redesigned single-hole packer assembly, data acquisition system, power system, and mass flow control unit are being assembled.

The design of the radial borehole three-dimensional anisotropy testing packer system has been finalized. The system will consist of multiple packers each 2 m in length. The 2 m packers will consist of a 0.4-meter sampling and monitoring port and 1.6-m-long packer. Up to 15 of these packers can be joined together, thereby converting a 30-m-long borehole into 15 observation points.

The radial borehole locations in Exploratory Studies Facility Alcove 1 and their preferred orientation were determined after meeting with the Exploratory Studies Facility fracture mappers. Some modifications of the locations were required to accommodate the drilling rig.

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Activity 8.3.1.2.2.4.5 - Excavation effects test in the Exploratory Studies Facility.

Several preliminary locations were identified in the Exploratory Studies Facility to conduct this test. The locations were chosen to minimize excavation delay without jeopardizing test objectives. Instruments that will be used in the Exploratory Studies Facility test have been identified. Packer air-injection strings will be used to measure air permeability changes around the excavated areas. Borehole pressure cells will be used to measure changes in rock stress around the first test location, and possibly around successive locations. Borehole extensometers may be used to measure fracture deformation. Borehole pressure cells and extensometers will be used around successive test locations if measurements are shown to be meaningful during the first test.

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

Activity 8.3.1.2.2.4.7 - Perched-water test in the Exploratory Studies Facility. Monitoring for perched water in the Exploratory Studies Facility Starter Tunnel and the first Alcove was conducted during the reporting period without detecting any perched-water.

Activity 8.3.1.2.2.4.8 - Hydrochemistry tests in the Exploratory Studies Facility. The effects of shotcreting on Exploratory Studies Facility hydrochemistry test results were investigated by collecting and testing samples of the shotcrete for CO₂ adsorption. Gas samples for hydrochemical analysis (¹⁴C and ¹³C) were collected from short boreholes (shotholes) drilled as the first alcove was constructed. These samples are being prepared for analysis. One of the shotholes (A1SB3) was drilled the day after blasting; this shothole was packed off and sampled for CO₂, ^{12/13}C, and ¹⁴C, and CH₄. Another shothole (A1SB4) was drilled the same day after blasting, and similar sampling was conducted. Results from these two shothole tests will be compared to determine the necessary time interval after blasting to ensure uncontaminated samples are obtained. Core samples for unsaturated zone hydrochemical analysis were collected from the radial boreholes in the first alcove. Core samples from the radial boreholes were collected and packaged using different methods to compare different sealing methods for moisture retention.

Activity 8.3.1.2.2.4.9 - Multipurpose-borehole testing. This activity was deleted from the study plan in Revision 9 of the Site Characterization Program Baseline. In the current Exploratory Studies Facility design with two ramps, testing is no longer planned in a scientific shaft. 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.

Activity 8.3.1.2.2.4.10 - Hydrologic properties of major faults encountered in main test level of the Exploratory Studies Facility. Meetings were conducted to develop and discuss possible equipment and materials that might be used to construct the major faults packer

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system. Additional meetings were conducted to assign priorities for the Exploratory Studies Facility alcove testing program.

Forecast: Intact fracture activity will continue to develop testing methods and procedures. After final testing of the confining vessel with synthetic fractured material, experiments should begin within a few months. Subsequently, experiments will begin with fractured tuff from Yucca Mountain.

The prototype Percolation Test will continue to finalize boundary conditions and flux rates in the fractured tuff block. Plans for Exploratory Studies Facility testing will be finalized. Study plan modification for sections on Percolation Tests will be reviewed by YMSCO.

Radial borehole single-hole air-injection testing in Exploratory Studies Facility Alcove 1 is scheduled to begin in late-May or early-June. Testing is expected to take about two months. After the single-hole testing is complete, a three-dimensional anisotropy packer system will be installed into the boreholes and cross-hole testing will start. This testing will take about three months.

The Excavation Effects Test will continue to evaluate essential equipment and testing procedures and locations. The Perched Water test will continue to refine and develop testing methods and strategies. The Hydrochemistry Test activity will continue to analyze samples taken from the Exploratory Studies Facility Starter Tunnel and Alcove 1. Different sample preparation and sealing methods that were performed in the Starter Tunnel will be evaluated.

2.2.1.9 Study 8.3.1.2.2.5 - Diffusion tests in the Exploratory Studies Facility

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

Forecast: No activity is planned for FY 1994.

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

Activity 8.3.1.2.2.6.1 - Gaseous-phase circulation study. A gas sampling tubing string was prepared for sampling from 152-, 213-, 305-, and 381-m depths in deep NRG boreholes. Equipment was obtained to construct a vertical deep air flow instrument for future borehole testing. Dryer vents were placed on UE-25 NRG-2B, 4, 5, and USW NRG-6 in anticipation of gas chemistry sampling in those boreholes. The dryer vents prevent atmospheric air from flowing into the boreholes.

Gas sampling for gas chromatographic analysis (CO_2 , CH_4 , SF_6) and for isotopic analysis (^{14}C , $^{13/12}\text{C}$, ^3H , $^{18/16}\text{O}$) was conducted in boreholes USW UZ-6S, 13, UE-25 NRG-5, the Hilti holes (small diameter, shallow boreholes near the crest of Yucca Mountain), and

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selected neutron-access boreholes. CO_2 , CH_4 and $^{13/12}\text{C}$ samples were collected from UE-25 NRG-2B, 4, and USW NRG-6 at the surface and selected depths. Staff conducted a $^{13/12}\text{C}$ sampling methods comparison test by sampling one depth at USW UZ-6S and the atmosphere using tedlar bags, aluminum cylinders, glass flow through cylinders, and mylar balloons. Comparison tests of the carbon dioxide gas analyzer and the gas chromatograph for CO_2 analysis were conducted.

Divergent tracer tests at USW UZ-6S and the Hilti holes were conducted. Chromatograph results from all divergent tracer tests are being analyzed. Air-flow, temperature, and barometric pressure data were collected from USW UZ-6S, 13, UE-25 A-4, and USW NRG-6. Physical data tabulation and analysis continued, including pressure, temperature, and air-flow data from USW UZ-6S, 6, and UE-25 UZ-16. Shut-in pressure tests were conducted at UE-25 UZ-16 using the air-permeability packer system.

Tritium, CO_2 , and CH_4 samples were collected at several pumping rates from USW UZN-94 to determine the effect of pumping rate on sample concentration. Gas concentrations for CO_2 and CH_4 were not affected by pumping rates. Radial boreholes in the first alcove in the Exploratory Studies Facility were instrumented with pressure transducers to conduct pressure shut-in tests.

Forecast: Periodic testing, sampling, and monitoring activities at boreholes USW UZ-6, 6S, selected NRG boreholes, and selected neutron-access boreholes will continue. Selected boreholes will be instrumented and monitored to establish baseline conditions for gaseous-phase circulation in the unsaturated zone. Boreholes along the alignment of the North Ramp, Main Test Level tunnel, and South Ramp will be tested as part of this study. Gaseous-phase circulation testing will be conducted in the Exploratory Studies Facility.

2.2.1.11 Study 8.3.1.2.2.7- Hydrochemical Characterization of the Unsaturated Zone

Activity 8.3.1.2.2.7.1 - Gaseous-phase chemical investigations. Annual USW UZ-1 gas sampling was conducted in December. Samples collected from 15 zones were analyzed for CO_2 concentrations and carbon isotopic compositions. Results were similar to those obtained during the past several years. Calculations were made with assumed CO_2 total diffusivities ranging from 10^{-6} to $10^{-6.7}$ m^2/sec to test whether the theoretical diffusion curve will fit the observed ^{14}C curve. The results indicated that the observed ^{14}C (with depth) curve fit the calculated diffusion curve, but different boundary conditions and assumptions were required above and below 6 m. The shallow $^{14}\text{CO}_2$ is consistent with downward diffusive transport in response to recent near-surface perturbation. The deeper data are consistent with steady-state diffusion and decay. In the absence of reactions, the uncorrected ^{14}C age estimates would represent minimum "ages" of the $^{14}\text{CO}_2$.

Batch tests were conducted to determine the sorption equilibrium constants and retention equations for SF_6 in contact with volcanic tuffs, gypsum cement, and clinoptilolite. The results indicated that particle sizes of different fractions had the same adsorption properties. High equilibrium adsorption constants were observed for samples of bedded tuffs,

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Topopah Spring Member tuff, and clinoptilolite; low adsorption constants were observed for Tiva Canyon Member tuff, Pah Canyon Member tuff, and gypsum cement. The primary control of the amount of SF_6 adsorbed onto different materials is the percentage of zeolite in the sample.

Activity 8.3.1.2.2.7.2 - Aqueous-phase chemical investigations. Core samples from Borehole USW UZ-14 were being analyzed. Pore-water extractions by vacuum distillation are nearly complete, and pore-water extractions by one-dimensional compression were completed on most of the nonwelded units. The Topopah Spring unit was extremely dry and attempts to squeeze out any water have been only partially successful. Future attempts will be concentrated on selected cores whose moisture-content and degree of saturation are larger. Preliminary results for USW UZ-14 core water indicate that tritium concentrations were below 11 tritium units for most samples measured. The results of chemical and isotopic compositions of USW UZ-14 have not yet determined the relative amounts of drilling fluids and naturally occurring perched water.

The triaxial compression method can successfully extract representative pore water from Yucca Mountain nonwelded tuffs having initial moisture contents as low as 8 percent by weight. The one-dimensional compression method can successfully extract representative pore water from Yucca Mountain nonwelded tuffs with initial moisture contents as low as 7.6 percent and welded tuffs with initial moisture contents as low as 6.5 percent by weight. Pore-water chemistry of samples obtained by both triaxial compression and high-speed centrifugation are comparable, indicating that representative pore-water chemistry can be obtained by compression methods. These results will be presented in a paper entitled "Pore-water Extraction from Unsaturated Tuff Using Triaxial and One-Dimensional Compression Methods" (Yang et al.) that has been accepted for the Proceedings of the Nuclear Energy Workshop in Nottingham, United Kingdom, June 7-9, 1994. Triaxial and one-dimensional compression system development and validation of test methodology are reported in the papers entitled "Pore-water Extraction from Unsaturated Tuff by Triaxial and One-Dimensional Compression Methods, Nevada Test Site, Nevada" (Mower et al., 1993) and "Development of the One-Dimensional Compression Method for Extraction of Pore Water from Unsaturated Tuffs" (Higgins et al.), which were in technical review.

Forecast: Core samples from UE-25 UZ-16 will be compressed and distilled for pore-water samples. Extracted water will be analyzed for cations, anions, and isotopic compositions. Two manuscripts, "Interpretations of Gaseous-Phase Isotopic and Chemical Composition Data from Test Hole USW UZ-1" (Yang et al.) and "Development of the One-Dimensional Compression Method for Extraction of Pore Water from Unsaturated Tuff" (Higgins et al.), will be reviewed. Two other papers on pore-water chemistry and on tracer gas sorptions on Yucca Mountain tuffs and borehole stemming materials will be written.

2.2.1.12 Study 8.3.1.2.2.8 - Fluid Flow 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. Activity for the period focused on two areas: compiling

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fracture data from 16 boreholes, and building computer files of the data for input into developing the fracture network conceptual model. Files for eight of the sixteen boreholes have been completed. A draft report relating fracture permeability to aperture and roughness measurements entitled "Permeability of Rough-Walled Fractures" (Zimmerman and Bodvarsson) has been written and was in review.

Methods were developed for calculating the equivalent radius of irregularly shaped matrix blocks, and for calculating the equivalent radius of a collection of matrix blocks of different sizes for use in simulations of water flow and radionuclide transport. These methods are presented in a draft report entitled "Approximating the Imbibition and Absorption Behavior of a Distribution of Matrix Blocks by an Equivalent Spherical Block" (Zimmerman and Bodvarsson), prepared for presentation at the 1994 High-Level Waste Conference.

Activity 8.3.1.2.2.8.2 - Validation of conceptual and numerical models of fluid flow through unsaturated, fractured rock. No progress during the reporting period; this was an out-year activity.

Forecast: Compilation of borehole fracture data and development of files will continue as input to fracture network models. Fracture data mapped from outcrops (pavements, scan lines, and area surveys) will be compiled into computer files as input to develop fracture network models.

2.2.1.13 Study 8.3.1.2.2.9 - Site Unsaturated-Zone Modeling and Synthesis

Activity 8.3.1.2.2.9.1 - Conceptualization of the unsaturated-zone hydrogeologic system. Rock hydrologic properties were estimated from correlations previously derived between unsaturated zone hydrologic parameters and porosity. One-dimensional numerical simulations of water movement beneath Pagany Wash, based on the stratigraphy observed in boreholes UE-25 UZ-4 and 5 were prepared for presentation at the 1994 High-Level Waste Conference in a paper entitled "Simulation of Flow in the Unsaturated Zone Beneath Pagany Wash, Yucca Mountain" (Kwicklis et al.).

The simulations reproduced the observed saturation and water potential profiles at UE-25 UZ-4 and 5 reasonably well using a time-varying infiltration rate. The observed saturation and water potential profiles appear to have evolved in response to relatively wetter recent conditions rather than drainage from a past pluvial period. The exact time scales over which wetting occurred could not be reliably determined from the one-dimensional model, which could not capture the effects of lateral flow. Nonetheless, the simulations indicated that capillary barrier effects at the contact between nonwelded, unfractured tuffs and underlying fractured, welded tuffs are very significant. Potential increases in infiltration associated with future climate change will be prevented from penetrating the densely welded intervals of the Topopah Spring Member for several hundreds, and possibly thousands, of years until water potentials at the contact become large enough to initiate fracture flow. Similarly, because of capillary barrier effects, drainage of water from the nonwelded and

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bedded tuffs overlying the vitric caprock of the Topopah Spring Member requires tens of thousands of years.

The one-dimensional simulations were done as prelude to two-dimensional simulations that examined the importance of lateral subsurface flow in dissipating focussed surface infiltration, which in this case was assumed to occur through Pagany Wash. Similar stratigraphy, rock properties, and boundary and initial conditions were used as for the simulations described above. Several horizons important to promoting lateral flow were identified from plots of the flux vectors. Capillary barrier effects at the contact between the nonwelded, unfractured tuffs and the underlying fractured welded tuffs of the Topopah Spring Member were particularly important in promoting lateral water movement in the nonwelded and bedded zones immediately above the vitric caprock. An important conclusion of this work is that although simulated surface infiltration rates may be spatially variable and locally as high as 20 mm/yr, water fluxes into the upper, densely welded part of the proposed repository horizon are uniform and less than 1 mm/yr.

Activity 8.3.1.2.2.9.2 - Selection, development, and testing of hydrologic-modeling computer codes. No progress during the reporting period; this was an out-year activity.

Activity 8.3.1.2.2.9.3 - Simulation of the natural hydrogeologic system. The development of the three-dimensional site-scale model of Yucca Mountain continued. New data were received, including new estimates for infiltration patterns and amounts, hydrologic properties data, and a map of various Calico Hills zones including zeolitic, vitric, and glassy rocks. New reports were received from other participants and these were reviewed with respect to relevance to the site-scale model. Much of the new information was integrated into the site-scale model. Various simulation studies were performed using the three-dimensional model. Uniform infiltration rates ranging from 0.001 to 0.5 mm/year were used and simulations of the moisture flow to steady-state were conducted.

Various nonuniform infiltration distributions were also simulated. The results of the simulations showed large amounts of lateral flow and concentrated vertical percolation even when uniform infiltration rates are assumed. This is due to the complex stratigraphy of the site and major fault offsets. The three-dimensional moisture flow distribution within Yucca Mountain depends strongly on assumptions made about hydrological behavior of major faults. Careful measurements of saturation and capillary pressure conditions in the rock adjacent to major faults may yield as much information about the hydrological behavior of faults as direct measurements within the faults themselves. Results from nonuniform infiltration distributions show large areas within Yucca Mountain where mostly one-dimensional vertical flow occurs. Complex three-dimensional moisture flow patterns are found in areas north of the potential repository region, where most concentrated infiltration is believed to occur.

Gas flow and the geothermal gradient have been incorporated into the site-scale model, and calibration of these components against known gas and thermal conditions are under way. Internal reviews were completed on the report on grid effects and it was found that additional simulations needed to be conducted in order to complete the report. These simulations are

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under way. Work has commenced on incorporation of the Exploratory Studies Facility into the three-dimensional site-scale model.

Activity 8.3.1.2.2.9.4 - Stochastic modeling and uncertainty analysis. No progress during the reporting period; this was an out-year activity.

Activity 8.3.1.2.2.9.5 - Site unsaturated zone integration and synthesis. No progress during the reporting period; this was an out-year activity.

Forecast: An analysis report summarizing the results and implications of the two-dimensional modeling of subsurface flow beneath Pagany Wash will be prepared.

A three-dimensional model of gas movement will be created for Yucca Crest, based on measured air flows from Boreholes USW UZ-6 and 6S. The purpose will be to calibrate the air permeabilities for various stratigraphic intervals and subsequently predict the extent of air movement within Yucca Mountain due to wind, barometric, and topographic effects, in the absence of open boreholes.

The development of the three-dimensional site-scale model will continue. New geological, hydrological, and geochemical data will be incorporated into the model as they become available. Three-dimensional moisture flow within Yucca Mountain will be evaluated using the site-scale model. Areas of Yucca Mountain with different flow complexity will be identified. The initial moisture flow report describing the initial development of the three-dimensional site-scale model will be completed and published. Data on spatial and temporal distributions of infiltration will be incorporated into the model as they become available and the results evaluated. Gas effects will be further evaluated using submodels, and then incorporated into the site-scale model. Effects of the Exploratory Studies Facility on moisture and gas flow in the nearby rock masses will be evaluated using the site-scale model.

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

Activity 8.3.1.2.3.1.1 - Solitario Canyon fault study in the saturated zone. No progress during the reporting period; this was an out-year activity.

Activity 8.3.1.2.3.1.2 - Site potentiometric-level evaluation. Monitoring of water levels in the saturated zone at Yucca Mountain continued. Monthly water-level measurements were made in 18 wells. Hourly water-level data were collected from 17 zones in 12 wells, and continuous data were obtained in 4 zones in 2 wells. Thirty-four transducer calibrations were performed in support of the hourly monitored wells. Additional water-level measurements were made in support of other activities at the C-Well complex, USW NRG-7, and USW UZ-14. Water levels have essentially remained stable during the reporting period. Evaluation of the 1992 water-level data was completed and a draft report, "Water Levels in the Yucca Mountain Area, Nevada, 1992" (O'Brien et al.), documenting water levels for that period was completed. The water level data for 1989 and 1990-91 were also documented in

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similar reports being prepared by Luckey et al. and Tucci et al., respectively. Reduction and evaluation of the 1993 monthly water-level data were completed, and work began on reduction and evaluation of the 1993 hourly water-level data.

Four zones in two wells were monitored continuously to detect water-level fluctuations caused by earthquakes and underground nuclear testing. The region remains seismically active. Water-level fluctuations associated with the January 17, 1994, earthquake near Los Angeles, California, were detected. Water-level fluctuations associated with that earthquake were relatively small (less than 1 m), and water levels returned to pre-earthquake levels in less than one hour.

Plans for cleaning, reconfiguring, and hydraulic testing of 12 WT-series wells were completed. Planning began for reconfiguring the network of hourly and monthly monitored wells.

Knowing the precision and accuracy of water-level measurements made at Yucca Mountain is important if water-level changes or trends are to be identified. A report entitled "Precision and Accuracy of Manual Water-Level Measurements Taken in the Yucca Mountain Area, Nye County, Nevada, 1988-90" (Boucher) documents both and has been approved for publication.

Activity 8.3.1.2.3.1.3 - Analysis of single- and multiple-well hydraulic-stress tests.

The geohydrologic framework at the C-Hole complex is described in a report entitled "Preliminary Hydrogeologic Assessment of Boreholes UE-25c #1, UE-25c #2, and UE-25c #3, Yucca Mountain, Nye County, Nevada" (Geldon, 1993a). This information is needed to better understand the results of the hydraulic tests that will be conducted. Also, in preparation for the long term hydraulic testing, the past C-Hole test data were analyzed by using manual graphical matching techniques. The results of the analyses are presented in a report entitled "Results and Interpretations of Preliminary Aquifer Tests in Boreholes UE-25c #1, UE-25c #2, and UE-25c #3, Yucca Mountain, Nye County, Nevada" (Geldon), which is in the final technical review process. A paper summarizing the above results entitled "Analysis of Aquifer Tests in Miocene Tuffaceous Rocks with Layered Fracture and Matrix Permeability, Yucca Mountain, Nevada" (Geldon, 1993b) was presented at the Geological Society of America Annual Meeting in Boston, Massachusetts, October 25-28, 1993.

Activity 8.3.1.2.3.1.4 - Multiple-well interference testing. Wells UE-25 C-1, 2, and 3 were instrumented, each with four transducers in packed-off intervals, to collect background pressure data. These data will be analyzed for the effects of atmospheric loading and earth tides to obtain barometric efficiency and aquifer characteristics. This work provided an opportunity to deploy the multizone packer string (which had been in development for two years) in the field. A computerized data-acquisition system utilizing a graphical programming language was developed and is being used to control the collection of pressure and temperature data.

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Planned hydraulic-stress and tracer tests in fractured, tuffaceous rocks below the water table at Yucca Mountain will require work at depths in excess of 400 m. To facilitate prototype testing of equipment and methods to be used in aquifer tests at Yucca Mountain, an analog site was selected in the foothills of the Sierra Nevada near Raymond, California. Two of nine 75- to 90-m-deep wells drilled into fractured, granitic rocks at the Raymond site have been instrumented with packers, pressure transducers, and other equipment that will be used at Yucca Mountain. Aquifer tests conducted at the Raymond site to date have demonstrated a need to modify some of the equipment and methods conceived for use at Yucca Mountain. A paper entitled "Use of an Analog Site Near Raymond, California, to Develop Equipment and Methods for Characterizing a Potential High-Level, Nuclear Waste Repository Site at Yucca Mountain, Nevada" (Umari et al.), prepared for the 1994 High-Level Waste Conference, summarizes this prototype testing.

Activity 8.3.1.2.3.1.5 - Testing of the C-hole sites with conservative tracers. Work continued on the tracer mixing tank and system design. Surface-based system components include an automated sampling tray, sample-bottle-filling system, ion-specific probes and a fluorometer for the real-time monitoring of the breakthrough curve in the pumped well. Control and synchronization of these functions will be provided by the graphical-language data acquisition computer program.

A preliminary run of the USGS heat and solute transport three-dimensional code, which is being used to develop a three-dimensional equivalent porous medium model of the C-Hole complex, was successfully completed. When developed further, the model will be used for cross-hole tracer test design and analysis of the eventual cross-hole tracer test results.

Activity 8.3.1.2.3.1.6 - Well testing with conservative tracers throughout the site. No progress 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. Column transport experiments with lithium bromide were conducted to determine whether the batch sorption data previously collected are adequate for predicting transport behavior at the laboratory scale. All preparatory work for setting up these transport tests was completed and the experiments were in progress.

Tracer tests using iodide and polystyrene microsphere tracers were carried out in three fractured tuff samples, one Bandelier Tuff fracture, and two C-Well specimens to examine the difference in transport characteristics of dissolved tracers and microspheres. Differences were identified based on the fact that dissolved solutes diffuse into the rock matrix while microspheres do not. Several sizes and types of microspheres were tested, and there is now an excellent candidate for field tests at the C-Wells. The microsphere tracer effort was designed to provide data that will be used to test a conceptual model for transport in the saturated zone consisting of flow in fractures and transport via molecular diffusion with the surrounding rock matrix. If matrix diffusion model applies at Yucca Mountain, then the saturated zone would be a significant barrier to radionuclide migration, thus providing more confidence addressing the quality condition for geochemistry and for ground-water travel time analysis as it relates to site suitability. An abstract describing this research entitled "Transport

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of Synthetic Colloids and a Nonsorbing Solute through a Saturated Natural Fracture" (Reimus et al., 1994) was presented at the American Chemical Society Meeting in San Diego, California, March 13-17, 1994.

Activity 8.3.1.2.3.1.8 - Well testing with reactive tracers throughout the site. No progress during the reporting period; this was an out-year activity.

Forecast: Routine monthly, hourly, and continuous water-level monitoring will continue; however, the configuration of the network will change as several monthly monitored wells will be changed to hourly monitoring and several hourly monitored wells will be changed to monthly monitoring. Plans will be completed for cleaning, reconfiguring, and hydraulic testing for all WT-series wells, as well as several other wells. The 1992 water-level data report will be submitted for approval. Water-level data evaluation for 1993 will continue and work will begin on the 1993 data report. Water-level data evaluation for 1994 will begin.

Comment resolution will be completed for the report entitled "Results and Interpretation of Preliminary Aquifer Tests in Boreholes UE-25c#1, UE-25c#2, and UE-25c#3, Yucca Mountain, Nye County, Nevada" (Geldon) and it will be finalized.

Data collection of background pressures for analysis of atmospheric loading and earth tide effects will continue at the C-Hole complex. Cross-hole testing at the C-holes during the forecast period will begin upon completion of the discharge pipeline and spreading basin.

Experiments to show that spheres transport in laboratory scale specimens containing fractures will be conducted, and these tests will be used to determine which particle sizes and amounts will be used in the field tests. These tests are necessary so that the technical staff will have confidence that the field experiments will yield usable results (i.e., a breakthrough curve in an interwell tracer test). The tests will also determine, by comparing to dissolved tracer breakthrough curves, whether hydrologic mechanisms or interactions with the rock surface control the transport behavior. Laboratory experiments using Li as a tracer to develop parameter values for use in the Reactive Tracer Testing Field experiments will be conducted. Details of the design of C-Wells experiments will be developed, and the choice of well flow rates of circulation will be determined. Using previous modeling results, the test duration, injection amount, concentration and duration of tracer injection, and sampling frequency will be established.

2.2.1.15 Study 8.3.1.2.3.2 - Characterization of the Saturated-Zone Hydrochemistry

Activity 8.3.1.2.3.2.1 - Assessment of saturated-zone hydrochemical data availability and needs. No progress during the reporting period; this was an unfunded activity.

Activity 8.3.1.2.3.2.2 - Hydrochemical characterization of water in the upper part of the saturated zone. Regional hydrochemical data have been collected, compiled, and analyzed for potential errors. The data will be used to help determine regional flow paths and site

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hydrologic boundaries. A draft report entitled "Regional Ground Water Chemistry Data, Death Valley Region, Southwestern United States" (Perfect et al.) describes this process.

Meetings were conducted with investigators external to the Project and with manufacturing and supply representatives to discuss field analytical capabilities and mobile laboratory design and construction. Upgrades for selected parts of the ion chromatograph system were installed at the Area 25 laboratory facility. The need for equipment to enable downhole in situ measurements of select properties and the simultaneous collection of samples was discussed.

Selected Death Valley spring samples were re-analyzed and re-runs confirmed the initial results. The results of nearly all of the analyses of these samples are on hand. Because of the loss of a few specific samples, some sites will be resampled this spring.

Activity 8.3.1.2.3.2.3 - Regional hydrochemical tests and analyses. No progress during the reporting period; this was an unfunded activity.

Activity 8.3.1.2.3.2.4 - Synthesis of saturated-zone hydrochemistry. No progress during the reporting period; this was an out-year activity.

Forecast: The regional data report will be completed and submitted for approval. Samples at site boreholes will be collected as opportunities present themselves. The final suite of samples and field data will be collected at sample sites in Death Valley National Monument.

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

Activity 8.3.1.2.3.3.1 - Conceptualization of saturated-zone flow models within the boundaries of the accessible environment. A report entitled "Conceptual Model of the Saturated-Zone Flow System at Yucca Mountain, Nevada" (Luckey et al.) is in preparation and provides the basis for constructing a numerical model of the flow system. This report is the culmination of the work of a large number of investigators. The report documents the understanding of the saturated zone flow system as of early-1993. In addition to being a catalog of previous work, the report divides the saturated zone into hydrologic units that are thought to be appropriate for modeling. Hydraulic tests, previously available only in scattered reports, are included. Several alternative conceptual models of the large hydraulic gradient north of Yucca Mountain are discussed.

The preliminary regional numerical ground-water flow model was examined to see how it might help define boundary conditions for the site scale model. This model is discussed in Activity 8.3.1.2.1.4.4. The model contains 75,760 active nodes; a subset of approximately 1500 nodes is the potential basis for the site model.

Activity 8.3.1.2.3.3.2 - Development of fracture network model. The Bullfrog Member of the Crater Flat Tuff was mapped at Little Skull Mountain. Data consisting of fracture

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geometry and physical properties (bulk density, porosity, and particle density) have been reviewed. This information will be used in formulating the conceptual model of the C-Well complex. A report of the work entitled "Fracture Data from the Bullfrog Member of the Crater Flat Tuff near Yucca Mountain, Nevada" (Ervin and Chornack) is in technical review.

The conceptual model summary for ground-water flow at the UE-25 C-hole complex is being prepared. This report draws together ideas of USGS, Lawrence Berkeley Laboratory, and Golder Associates Inc. scientists. The conceptual model will be tested using two different fracture-network models. Studies were conducted to invert simulated transient well tests in a two-dimensional fracture network model using simulated annealing. Test cases involve a simulated constant aperture network with one pumping well.

Activity 8.3.1.2.3.3.3 - Calculation of flow paths, fluxes, and velocities within the saturated zone to the accessible environment. No progress during the reporting period; this was an out-year activity.

Forecast: A report, "Conceptual Model of the Saturated-Zone Flow System at Yucca Mountain, Nevada" (Luckey et al.), will be completed and submitted for approval. The information will be transferred to the performance assessment modeling team. The conceptual model will be transformed into a hydrogeologic framework for a numerical model that will simulate in considerable detail flow within and beyond the controlled area. Various flow codes will be evaluated for use in site-scale numerical modeling. One or more codes will be selected for the initial simulations and the hydrogeologic framework will be incorporated into the mesh required by the code(s).

The conceptual model of flow at the scale of the UE-25 C-Hole complex will be used to test the utility of the TRINET and FracMan codes for interpreting hydraulic tests previously performed at the complex. When data are available from the planned tests at the UE-25 C-Hole complex, these data will be incorporated into the numerical models.

Further development and modifications will be done to the cluster variable aperture annealing program. A report on the inversion algorithm and scale effects will be completed. Knowledge obtained from the Raymond Quarry field site in California will be used to aid model development. A report on effects of matrix on flow and transport will be completed.

2.2.2 Geochemistry (SCP Section 8.3.1.3)

2.2.2.1 Study 8.3.1.3.1.1 - Ground-Water Chemistry Model

The only activity during the reporting period was the completion of review comments on the study plan.

Forecast: Work on the study plan will continue.

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

Activity 8.3.1.3.2.1.1. - Petrologic stratigraphy of the Topopah Spring Member. Work was re-initiated in this activity with the acquisition and analysis of samples through the potential repository horizon in drill core from UE-25 UZ-16. As a result of quantitative mineralogic analysis of the Topopah Spring Member, stellerite (a common zeolite) was found within the devitrified Topopah Spring Member at the potential repository horizon. The significance of this observation is that this contrasts with other core data that indicate no zeolitization of the tuff matrix in the potential repository horizon. Occurrence of thermally sensitive minerals such as zeolites closer to the potential repository than previously expected could alter the predicted thermal impacts due to repository heating. These findings were summarized in a paper entitled "Quantitative X-ray Diffraction Analyses of Samples from Drill Hole UE-25 UZ#16, Yucca Mountain, Nevada" (Chipera et al.), which was in review.

Activity 8.3.1.3.2.1.2. - Mineral distributions between the host rock and the accessible environment. Six outcrop localities of vitric or zeolitized nonwelded tuff were evaluated in terms of their potential use as surface-based test facilities to supplement experiments planned for the Calico Hills unit as part of the Exploratory Studies Facility and a report, "Geologic Evaluation of Six Nonwelded Tuff Sites in the Vicinity of Yucca Mountain, Nevada for a Surface-Based Test Facility for the Yucca Mountain Project," (Broxton et al., 1993) was published. The report provides lithologic, petrographic, mineralogic, chemical, and hydrologic data for localities at (1) vitric tuffs southeast of Yucca Mountain at Busted Butte, (2,3) vitric and zeolitic tuffs northeast of Yucca Mountain between Yucca Wash and Sever Wash, (4) vitric tuffs south of Yucca Mountain and to the south of Stagecoach Road, (5) zeolitic tuffs northwest of Yucca Mountain at Prow Pass, and (6) zeolitic tuffs northeast of Yucca Mountain in the Calico Hills. After comparing rock properties at these outcrop localities with available drill-core data for the Calico Hills unit beneath the potential repository block, the localities at Busted Butte (vitric) and Prow Pass (zeolitic) were recommended as preferred sites for surface-based tests. This potential study option is under consideration at this time.

Data collection was completed on chemical and petrographic study of 12 calcite samples from Boreholes USW G-2 and USW GU-3/G-3. The fracture calcites included samples from localities above and below the water table. Trace-element data collected by instrumental neutron activation analysis were used to draw distinctions between drill cores and calcites above or below the water table. Calcite occurrences have bearing on determining the pathways of fluid transport in the unsaturated zone and on the water chemistry of unsaturated zone transport. The significance to sorption is documented in Section 2.2.2.7, Activity 8.3.1.3.4.1.3. The data is presented in a report entitled "Calcite Deposits in Drill Cores USW G-2 and USW GU-3/G-3 at Yucca Mountain, Nevada: Preliminary Report" (Vaniman).

Compilation of petrographic, chemical, and stable-isotope data for calcite from surface calcretes and calcite from shallow (<17 m) and deeper (>17 m) fractures was completed, and a paper entitled "Inferences of Paleoenvironment from Petrographic, Chemical and Stable-Isotope Studies of Calcretes and Fracture Calcites" (Vaniman and Whelan) was

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accepted for publication in the Proceedings of the 1994 High Level Waste Conference. This data compilation indicates a unique zone of isotopically light carbon at the interface between B and K soil horizons at Yucca Mountain, which should be avoided in sampling to evaluate paleoenvironments of calcite precipitation in soils. Also summarized were the unique C and O isotopic systematics of the unsaturated zone calcites in various drillholes at Yucca Mountain. These variations indicate either time-dependent or location-dependent variations in the isotopic chemistry of recharge waters that pass through the unsaturated zone.

In fibrous mineral studies, G. Guthrie and B. T. Mossman convened a Mineralogical Society of America short course on Health Effects of Mineral Dusts (October 1993). Health Effects of Mineral Dusts, Reviews in Mineralogy, Vol. 28 (Guthrie and Mossman, 1993) was the basis of these lectures. This publication is the basis for analysis of mineral dusts at Yucca Mountain that can be considered potential inhalation hazards.

Field work was completed at the UE-25 UZ-16 drill site to characterize the fibrous minerals in dust samples near this drilling operation. Analysis of these samples by x-ray diffraction, scanning electron microscopy and transmission electron microscopy was largely completed during this period, and a report was in preparation (Guthrie et al.). This study indicates no significant impact of the drilling operation on local eolian dust compositions.

A study of potentially hazardous minerals at Yucca Mountain indicated that hazardous fibrous minerals (e.g., erionite) were not found if the altered zone above the basal vitrophyre of the Topopah Spring Member was not penetrated. A paper entitled "Distribution of Potentially Hazardous Phases in the Subsurface at Yucca Mountain, Nevada" (Guthrie et al.) describing this work was in review.

Analysis of the first samples from portal excavations at the Exploratory Studies Facility starter tunnel site began. Distributions of calcite, opal, and clays in these samples will provide a comparison with mineral distributions in the Bow Ridge Fault, permitting evaluation of mineralogic tracers of fracture versus fault infiltration.

Quantitative mineralogic analysis for UE-25 UZ-16 core samples, including all reduction of x-ray diffraction data, was completed. A report entitled "Quantitative X-ray Diffraction Analyses of Samples from Drill Hole UE-25 UZ-16, Yucca Mountain, Nevada" (Chipera et al.) detailed this information. The mineralogy of 105 samples ranging in depth from 12.0 to 513.3 m were quantitatively analyzed by x-ray diffraction. Sampling employed a maximum sample spacing of approximately 6 m and an average sample spacing of 4.9 m. This sample spacing is much closer than in previous studies, in which the average was typically >10 m. Limited alteration of the vitric nonwelded tuffs above the devitrified Topopah Spring Member (i.e., the PTn unit), with only small amounts of the zeolite heulandite in the lower 13 percent of the nonwelded glass, was found. This limited alteration suggests very limited reaction with recharge waters. Data from this study and from future studies will be used to determine the effectiveness of using the elevation of the zeolitization front beneath the potential repository to define paleo-water tables; critical localities yet unsampled are within and adjacent to the southern part of the exploration block.

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Data collection was completed on the potential impact of zeolite sorptive, thermal, and hydrologic properties on the Yucca Mountain site and a paper entitled "The Importance of Zeolites in the Potential High-Level Radioactive Waste Repository at Yucca Mountain, Nevada (Vaniman and Bish, 1993) was published in the Proceedings volume of the Zeolite '93 Conference. Results of this work included a graphical basis for evaluating the impact of a "hot repository" thermal aureole on vitric-nonwelded and zeolitized tuffs.

In interactions with Activity 1.2.3.4.1.2.1, three sorption samples that exhibited unusually high K_d values for Np were analyzed by x-ray diffraction. The samples contain opal, calcite, and sepiolite. Additional samples of opal and sepiolite were provided to Activity 1.2.3.4.1.2.1 for further sorption experiments. Sample preparation and x-ray diffraction analysis continued on other sorption samples to be used in further geochemistry/sorption studies. A particular focus in these studies will be evaluation of the effectiveness of Np retardation by calcite, an effect that may be important in the unsaturated zone at Yucca Mountain where calcite occurrences appear to be correlated with transmissive fractures.

Activity 8.3.1.3.2.1.3. - Fracture mineralogy. The complex variety of zeolites that occur within fractures of the Paintbrush Formation at Yucca Mountain were identified and the possible reactions that may lead to their deposition were examined. Zeolite assemblages that reflect precipitation from water compositions similar to those now found in the saturated zone, as well as other zeolite occurrences (e.g., erionite and phillipsite) that indicate local unsaturated zone water compositions of very different composition were identified. Samples of hollandite from fractures in USW G-4 were prepared for examination of mineral surfaces using the atomic-force microscope. It will be determined if manganese oxide minerals lining fractures below the water table at Yucca Mountain will be helpful in the retardation of radionuclides. Two papers, "Distribution of Fracture-Lining Zeolites at Yucca Mountain, Nevada" (Carlos et al., 1993) and "Equilibrium Modeling of the Formation of Zeolites in Fractures at Yucca Mountain, Nevada" (Chipera et al., 1993), discuss this work.

Forecast: The natural background levels of airborne mordenite or other minerals at Yucca Mountain will be determined before surface-disturbing activities associated with the Exploratory Studies Facility begin. The mineralogy of airborne dust in the vicinity of drilling operations and at the Sample Management Facility will be characterized by x-ray diffraction, transmission electron microscopy, and scanning electron microscopy. Staff will study the potential health risks associated with the inhalation of fibrous minerals by Project workers during drilling and Sample Management Facility and Exploratory Studies Facility operations. The significance to waste retardation of trace minerals that occur in the tuffs at Yucca Mountain will be determined. The mineralogy and chemistry of calcite in fractures at Yucca Mountain will be determined to investigate the origin of calcite-depositing fluids and to identify paleo-transport pathways for these fluids. The chemistry and distribution of fracture-lining minerals in drill core from Yucca Mountain will be determined. The chemistry of minerals lining faults and fractures in the Exploratory Studies Facility will be studied and the distribution of fracture minerals will be determined for the Paintbrush Tuff and the underlying tuffaceous beds of Calico Hills.

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2.2.2.3 Study 8.3.1.3.2.2 - History of Mineralogical and Geochemical Alteration of Yucca Mountain

Activity 8.3.1.3.2.2.1 - History of mineralogic and geochemical alteration of Yucca Mountain. Studies of the nature of the vitric-zeolitic transition at Yucca Mountain began. This boundary is expected to have a distinct effect on ground-water flow. Vitric-zeolitic transitions exposed in the Rainier Mesa tunnels have been examined as possible interim study sites until Exploratory Studies Facility construction reaches the transition in the subsurface of Yucca Mountain. Other ongoing research includes studies of alteration in the North Ramp portal and starter tunnel of the Exploratory Studies Facility. The emphasis of this research is to identify alteration features relevant to radionuclide transport issues, such as colloid transport or fast pathways.

The clay mineralogy of tuffs from Yucca Mountain was studied to understand the alteration history of the rocks and to predict potential future alterations. Twelve K/Ar dates were obtained on illite/smectite separated from the tuffs. The data suggest that the rocks at depth in the northern portion of Yucca Mountain were altered 10.0-11 Ma ago, soon after creation of the Timber Mountain caldera to the north. Both illite/smectite geothermometry and fluid inclusion data suggest that the rocks at depth in drillhole USW G-2 were subjected to post-depositional temperatures of at least 275°C. Clinoptilolite apparently became unstable at about 100°C and analcime transformed to albite above 175°-200°C. It appears cristobalite transformed to quartz at 90°-100°C in USW G-2. The reactions with increasing depth appear coupled, supporting aqueous silica activity as a controlling variable in the clinoptilolite-to-analcime reaction. Using these data as natural analogs to repository-induced thermal alteration suggests that the bulk of the clinoptilolite and mordenite-bearing rocks in Yucca Mountain will not react to less sorptive phases over the required lifetime of the potential repository. A paper describing this research entitled "Paleogeothermal and Paleohydrologic Conditions in Silicic Tuff from Yucca Mountain, Nevada" (Bish and Aronson, 1993) was published.

Evaluation of the use of K/Ar geochronology in determining the alteration history of the zeolitized portions of Miocene tuffs at Yucca Mountain was completed. The main emphasis of this research is on investigation of the ability of clinoptilolite to retain all or part of its K and radiogenic Ar during diagenesis. The preliminary K/Ar dates ranging from 2 to 13 Ma suggest that clinoptilolites can retain K and radiogenic Ar. The K/Ar dates increase with depth, and samples from below the static water level yield mostly older dates than those from above the water table. The older clinoptilolite dates may reflect primary crystallization ages, whereas the younger dates probably represent Ar loss by diffusion and continued diagenetic reactions of older zeolites with percolating fluids. The studies are designed to help understand active geochemical processes in the unsaturated and saturated zones. A report describing this research entitled "Mineralogy and Clinoptilolite K/Ar Results from Yucca Mountain, Nevada, USA: A Potential High-Level Radioactive Waste Repository Site" (WoldeGabriel et al., 1993) was published.

Investigations of the ability of clinoptilolite to retain radiogenic argon continued, with studies of clinoptilolite and other authigenic minerals from lacustrine environments for

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comparison with the burial diagenetic and hydrothermal environments of Yucca Mountain, and a draft paper was completed. Experimental investigations of argon retention were also performed. The goal of this research is not only to determine the chronology of zeolitization, but also to understand the role of paleohydrology in K/Ar systematics.

Thermal loads of 270, 210, 140, 90, and 60 MTU/ha were evaluated with regard to (1) zeolite, clay, and volcanic glass dehydration; (2) crystallization of volcanic glass to zeolite-clay-silica mineral assemblages; and (3) recrystallization of clinoptilolite-silica mineral assemblages to analcime-quartz assemblages. The effects of these partially reversible and irreversible processes were estimated with respect to retardation, changes in hydraulic properties, and thermal buffering. Data from Activity 8.3.1.3.2.2.1 were described and were important to this evaluation.

Origins of the Trench 14 deposits were investigated by x-ray fluorescence, instrumental neutron activation analysis, quantitative x-ray diffraction, ion chromatography, and petrographic analysis. This work has supported a DOE position paper on the significance of the calcite-silica deposits for site suitability and preparation of a paper on petrographic, mineralogic, and chemical constraints on the origins of calcite-silica deposits at Exile Hill continued.

A report entitled "Studies of Altered and Fractured Rocks Exposed Around Yucca Mountain" (Levy) was completed. Exposures of altered and brecciated rocks at Busted Butte and Harper Valley, which are located southeast of Yucca Mountain, that might have been formed by recent discharge of water from depth were examined to address a concern that hydrothermal processes could compromise the radionuclide isolation capability of a potential repository. This work also supports the DOE position paper on calcite-silica deposits. Ongoing research on the altered rocks at Harper Valley will provide natural analog information on potential repository hydrothermal effects. One aspect under study at present is the migration of silica during late-stage cooling of the Tiva Canyon Tuff. Secondary silica from the lower Tiva Canyon and underlying bedded Paintbrush tuffs has been separated from whole-rock samples and x-ray diffraction was used to investigate whether there are characteristic changes in crystallinity of silica with increasing distance of deposition from the source rock. This is a natural analog study to investigate how dissolved or colloidal silica could be transported and deposited in a potential repository hydrothermal environment.

Activity 8.3.1.3.2.2.2 - Smectite, zeolite, manganese minerals, glass dehydration, and transformation. A paper entitled "Dehydration and Rehydration of a Tuff Vitrophyre" (Vaniman et al., 1993) was published in the Journal of Geophysical Research. Dehydration of samples from the Topopah Spring Member basal vitrophyre was studied by thermogravimetric analysis and by isothermal heating at 50°, 100°, 200°, and 400°C for 3.4 years, followed by 1.1 years of rehydration at controlled high humidity. Thermogravimetric analysis studies showed a two-stage dehydration of the vitrophyre, with two-thirds to three-fourths weight loss occurring most rapidly at temperatures ranging from 278° to 346°C. The remaining water is lost only on second-stage heating to temperatures above 650°C. These dry-heating experiments provide an end-member characterization of glass transformations for comparison with water-saturated heating experiments in which glass alteration is prominent.

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The water contents of smectites and zeolites were measured during hydration and dehydration using an improved measurement system. The smectite data will be combined with x-ray diffraction data on smectite basal spacings to evaluate the packing density of water molecules between the layers of the crystal lattices. The results will help define the effects of smectite dehydration and rehydration in clay-bearing rocks on the thermal budget of a potential repository.

Long-term steam-heating experiments, begun one and a half years ago, continued. The materials include devitrified tuff, vitric nonwelded tuff, vitrophyre, smectite-rich altered tuff, zeolitic altered nonwelded tuff, cation-exchanged clays, opal-CT, and two standard clinoptilolites. The goal of this work is to identify changes in mineralogy or mineral structures that occur under prolonged heating in a steam atmosphere.

Forecast: Textural, mineralogical, and chemical analyses on core containing alteration features, with emphasis on faults and breccia zones, transport-related features, and natural gels will be performed. New K/Ar data will be collected. Surface and subsurface samples to study relationships between mineral alteration and hydrologic history will be collected. Special emphasis will be placed on identification of past preferential ground water pathways. This activity will complete the mineralogical and geochemical studies of Trench 14 needed to support the position paper on calcite-silica deposits. Dehydration/rehydration behavior and volume changes will be determined during short-term experiments on pure minerals. The stabilities of opal-CT, clinoptilolite, smectite, hematite, vitrophyre, devitrified, vitric, and zeolitic tuffs, will be determined in heated dry, steam, and saturated atmospheres over long periods. Studies will be done on the thermodynamics of water adsorption and desorption from zeolites. These data will be used to predict the chemical and mineralogical effects on tuffs in the vicinity of the heated repository under different thermal loading scenarios.

2.2.2.4 Study 8.3.1.3.3.1 - Natural Analog of Hydrothermal Systems in Tuff

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

Forecast: No activity is planned for FY 1994.

2.2.2.5 Study 8.3.1.3.3.2 - Kinetics and Thermodynamics of Mineral Evolution

Studies 8.3.1.3.3.2 and 8.3.1.3.3.3 were combined in this study plan under the title "Kinetics and Thermodynamics of Mineral Evolution at Yucca Mountain, Nevada." The study plan incorporates preliminary experimental results obtained at Yale University and Penn State University, and it describes an experimental procedure for moving towards a conceptual model of mineral evolution at Yucca Mountain that incorporates information on the low-temperature kinetics of mineral reactions.

This study was reinitiated on October 1, 1993. The objective of this study is to determine experimentally the stability of minerals and glasses in the volume of rock affected

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by the potential repository in order to assess impacts of waste emplacement on mineral stability, rock properties, hydrologic properties, and the resulting effects on radionuclide retardation. This study will investigate the thermodynamics of clinoptilolite, mordenite, analcime, silica minerals, and, to a lesser extent, smectite and illite. The study will also provide information on the kinetics of dissolution and precipitation reactions involving clinoptilolite, mordenite, analcime, cristobalite, smectite, illite, and possibly opaline-silica phases, all in the temperature range from 30° to 250°C. The thermodynamic data will be used to improve the design of the kinetics experiments and will ultimately be used in equilibrium thermodynamic modeling of Yucca Mountain.

These data will be used jointly to produce a conceptual model of past and future alteration of mineral assemblages. The model will incorporate the important zeolite, clay, and silica phases present at Yucca Mountain, as well as the higher-temperature feldspar minerals. The model will explicitly address the effects of time and temperature but will also incorporate variations in degree of saturation in an effort to predict the effects of partially saturated alteration at or near boiling temperatures. 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 waste emplacement.

Research has been initiated on both kinetic and equilibrium experiments dealing with zeolite synthesis. The zeolites clinoptilolite and mordenite, the two most abundant zeolites at Yucca Mountain, are being specifically treated in this research. Research has been completed on the dissolution kinetics of cristobalite, a silica phase that is abundant at the potential repository horizon at Yucca Mountain. This study incorporates recent experimental results on the reaction kinetics of cristobalite. Dissolution of silica under the repository thermal pulse is an important consequence of waste emplacement; this study will provide data needed to predict silica migration under the range of possible thermal loadings and low water/rock ratios that may impact the Yucca Mountain site.

Research is ongoing on the zeolite system model, a comprehensive study of the interphase reactivity or stability of zeolite-bearing assemblages of importance at the Yucca Mountain site. The zeolite system model will summarize and bring together the available experimental and observational data on the stability of zeolites.

Forecast: The rates and mechanisms of dissolution and of reactions leading from amorphous silica to quartz via opal and cristobalite using literature data and new laboratory experiments will be determined. In FY 1994, cristobalite dissolution kinetics will be addressed. Models of solubility, stability, and reaction evolution for the Yucca Mountain zeolite system will be developed.

2.2.2.6 Study 8.3.1.3.3.3 - Conceptual Model of Mineral Evolution

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

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This study has been combined with Study 8.3.1.3.3.2. A discussion and status is included in Section 2.2.2.5.

2.2.2.7 Study 8.3.1.3.4.1 - Batch Sorption Studies

Activity 8.3.1.3.4.1.1 - Batch sorption measurements as a function of solid phase composition. Data collection was completed on the dependence of sorption onto tuff on sample grinding, surface area, and ground water composition. The results of this study validate the procedure to determine batch sorption coefficients using crushed tuff; this is significant because it indicates that it is scientifically defensible to use batch sorption coefficients (measured with crushed tuff) in performance assessment calculations to describe radionuclide retardation (due to sorption). A report entitled "Sorption Characteristics of Yucca Mountain Tuffs as a Function of Sample Particle Size, Surface Area, and Water Composition" (Rogers and Chipera) was in review.

Studies were completed that will contribute to elucidating the role of iron oxides in radionuclide sorption. More specifically, these studies addressed the following question: can actinides (which exist in significant quantities in the inventory) be significantly retarded by iron oxides in the near- and far-field environments? Three papers on this subject were being prepared. The first, entitled "Complexation of Carbonate Species at the Goethite Surface: Implications for Adsorption of Metal Ions in Natural Waters" (van Green et al.) describes the mechanisms for carbonate adsorption onto goethite. The second, entitled "Uranyl Interactions in the Goethite/Solution Interphase Region: Formation of Binary and Ternary Surface Complexes" (Kohler et al.) focuses on developing an empirical data base, which will lead to the derivation of binding constants for uranium adsorption onto goethite in the presence of CO₂ and ethylene-diamine tetraacetate. The third, entitled "Neptunium Sorption on Hematite in Aqueous Suspension: Effects of Carbonate and EDTA" (Kohler et al.) describes the sorption of Np(V) onto hematite and discussed the effects of the presence of complexants (such as carbonate and ethylene-diamine tetraacetate) in the system. Preliminary results of the aforementioned papers indicate that actinides can be significantly retarded by iron oxides while the presence of carbonate in the ground water decreases the amount of sorption observed in the system.

A study to determine the effect of naturally occurring organic materials on the sorption of Cd and Np onto oxide minerals and tuff surfaces was completed. The results were summarized in a paper entitled "Effect of Natural Organics on Cd and Np Sorption" (Kung et al.) which was in review. These results indicated that the presence of organics does not significantly influence the sorption of Cd and Np onto tuff. This result is significant because there was concern that radionuclides may not sorb onto organically coated (neutral) tuff.

Activity 8.3.1.3.4.1.2 - Sorption as a function of sorbing element concentrations (isotherms). Data collection was completed on batch sorption experiments (conducted as a function of radionuclide concentration and temperature [25°, 60°, and 80°C]) to determine the sorption of ²³⁷Np, ¹³⁷Cs, ¹³³Ba, and ⁸⁵Sr onto tuffs from the Topopah Spring Member; onto zeolitic and vitric tuff from the bedded tuffs of the Calico Hills; and onto pure mineral

separates of calcite, hematite, montmorillonite, clinoptilolite, and quartz. Preliminary results indicated that sorption is constant or increases with increasing temperature and sorption decreases with increasing water-to-rock ratios. The implication of these results is that high temperatures will not invalidate the use of sorption as a radionuclide retardation mechanism and that the batch sorption coefficients are conservative when used in performance assessment calculations. The batch sorption coefficients were experimentally measured with a water-to-rock ratio of 20 ml to 1 g, which is larger than the expected water-to-rock ratio at Yucca Mountain. Two reports, "Effects of Water Rock Ratios on Sorption Coefficients" (Triay) and "Sorption as a Function of Temperature" (Triay), were being prepared.

Activity 8.3.1.3.4.1.3 - Sorption as a function of ground-water composition. Data collection was completed and two reports describing batch sorption studies of Np onto tuffs and pure minerals (explained in Activity 8.3.1.3.4.1.2) as a function of ground-water composition and temperature were prepared. These reports are entitled "Effects of Water Rock Ratios on Sorption Coefficients" (Triay) and "Neptunium Transport through Yucca Mountain Tuffs I: Batch Sorption Results" (Triay). The ground waters studied were from Wells UE-25 J-13 and UE-25 P-1 and from synthetic ground waters with varying amounts of carbonate. The temperatures investigated were 25°, 60°, and 80°C. Although the preliminary results of batch sorption studies indicated that the amount of Np sorption onto most tuffaceous materials is very small, the presence of calcite and clinoptilolite in the tuff samples led to increased Np sorption values. This result is important since the tuff from the Calico Hills contains a large percentage of clinoptilolite and calcite has been found in fractures at Yucca Mountain.

Activity 8.3.1.3.4.1.4 - Sorption on particulates and colloids. No progress during the reporting period; this was an out-year activity.

Activity 8.3.1.3.4.1.5 - Statistical analysis of sorption data. No progress during the reporting period; this was an out-year activity.

Forecast: The sorption strategy will continue to be pursued and Np studies will be completed. The focus on Pu and U will begin. Spectroscopic techniques will be used to determine the effect of organic coatings on radionuclide sorption onto tuffs (with emphasis on Np and U). Sorption of U and Pu as a function of radionuclide concentration using tuff samples and the effect of temperature on the sorption of U and Pu onto tuff (at 25°, 60°, and 90°C) will be studied. Sorption measurements on U and Pu as a function of ground-water chemistry (using UE-25 J-13, UE-25 P-1, and NaHCO₃ waters at a pH of 6, 7, and 8.5) will be conducted. Sorption experiments on pure mineral separates to identify the sorbing phases (in tuff) for U and Pu will be conducted. The validity of surface complexation model and parameters obtained from single mineral studies for predicting surface adsorption of Np and U on devitrified tuffs will be studied. Experiments on magnetite grains will test the assumptions about the nature and reactivity of surfaces that are important for surface-complexation adsorption of radionuclides in Yucca Mountain.

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2.2.2.8 Study 8.3.1.3.4.2 - Biological Sorption and Transport

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

Forecast: This task is unfunded in FY 1994.

2.2.2.9 Study 8.3.1.3.4.3 - Development of Sorption Models

This study is being combined with Study 8.3.1.3.4.1. When the revised study plan is completed, the discussion of this study will be included in Section 2.2.2.7.

Data collection was completed on studies of reactions of water with goethite surfaces representing two crystal faces, {010} and {100}, and a report describing this work, "Atomic Force Microscopy Studies of Natural Mineral Surfaces I: Goethite Surface Microtopography and Reactions" (Rogers), was completed. This report discusses the dissolution and reprecipitation reactions at spatial scales, reaching atomic resolution using atomic force microscopy. Results of these experiments were also presented at the Materials Research Society Symposium on the Scientific Basis for Nuclear Waste Management in Boston, Massachusetts, November 29-October 3, 1993, in a talk and abstract entitled "Surface Reactions of Goethite Observed by AFM" (Hawley and Rogers). Significant results reported include (1) goethite surfaces reacted rapidly to produce increased surface area and potentially reactive sites, (2) a thin coating, apparently not goethite, covering many of the natural goethite surfaces, was observed, and (3) the thin surface coating exhibited a comparatively slow reaction with water to produce a decrease in surface area. Thin surface coatings and surfaces apparently altered by exposure to ground water were observed on the goethite. These altered surfaces are significant because they indicate that the surfaces active in surface-complexation adsorption of radionuclides in Yucca Mountain may have compositions different from those of the bulk minerals. These compositions could be determined and used in sorption models. Magnetite grains, separated from USW G-4 core samples, were also studied using the same techniques as those used in the goethite experiments.

2.2.2.10 Study 8.3.1.3.5.1 - Dissolved Species Concentration Limits

The study plan for this study addresses Site Characterization Analysis Comment 96.

Activity 8.3.1.3.5.1.1 - Solubility measurements. Data collection was completed on the solubility of the actinides Np, Pu, and Am in water characteristic of carbonate-rich water found in Well UE-25 P-1, and a paper detailing these studies, "Measured Solubilities and Speciations from Oversaturation Experiments of Neptunium, Plutonium, and Americium in UE25p #1 Well Water from the Yucca Mountain Region" (Nitsche et al., 1994), was published. This work was significant because the water composition studied represented the likely upper limit of potential mobilizing ligands (especially carbonate) expected to contact the waste. Hence, this study is likely to give an upper bound on the solubilities of these important actinides under fairly oxidizing conditions. Initial evidence on the oxidation state

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distribution of Pu and the identification of solids precipitated in these waters was also presented in Nitsche (1994).

Staff continued to determine the solubility of Np, Pu, and Am in a controlled experiment with carbonate-free water at pH values of 6, 7, and 8.5 from oversaturation conditions. Assays indicated that steady-state conditions were essentially achieved.

Activity 8.3.1.3.5.1.2 - Speciation Measurements. This work focused primarily on the speciation of Np(V) hydrolysis and carbonate-formation reactions, both at room temperature and elevated temperatures. Because understanding the Np-hydrolysis reaction is a prerequisite for interpreting any Np experiment, considerable effort has been made to determine the thermodynamic equilibrium binding constant for this reaction. Combined spectroscopic approaches were used to determine this constant.

In the paper "¹³C and ¹⁷O NMR Binding Constant Studies of Uranyl Carbonate Complexes in Near-Neutral Aqueous Solution" (Clark et al.), the binding constant for uranyl carbonate complexes was determined with both ¹³C and ¹⁷O nuclear magnetic resonance techniques. The results compared favorably to those recommended by the NEA data base, and hence show the power and reliability of the technique.

The application of pulsed photoacoustic spectroscopy to determine equilibrium constants in dilute radionuclide solutions continued. A paper in preparation entitled "Plutonium Carbonate Speciation Changes as Measured in Dilute Solutions with Photoacoustic Spectroscopy" (Tait et al.) discussed investigations of speciation and oxidation state of Pu(IV) carbonate solutions as a function of pH, carbonate concentration, and temperature.

Two papers were presented at the Migration '93 Conference in Charleston, South Carolina, December 12-17, 1993. The first, "Oxygen-17 and Carbon-13 NMR Studies of Uranyl and Neptunyl Carbonate Complexes in Near-Neutral Solution" (Clark and Palmer, 1993), discussed the use of ¹⁷O and ¹³C nuclear magnetic resonance in determining the structure and equilibrium constants for hexavalent uranium and neptunium carbonate species. The second, "Speciation of Neptunium(V) Carbonates as a Function of Temperature Using Absorption Spectroscopies" (Tait et al., 1993), discussed interim results of the temperature dependence of the equilibrium constants between $\text{NpO}_2(\text{CO}_3)^-$ and $\text{NpO}_2(\text{CO}_3)_2^{-3}$ as determined from temperature-dependent near-infrared absorption spectroscopy. Final interpretation of these interim results depends on the results of Np-hydrolysis experiments discussed above.

Activity 8.3.1.3.5.1.3 - Solubility Modeling. Modeling efforts concentrated on importing a QA-approved version of EQ3/6. Its use for finding inconsistencies in the data base will commence in the second half of FY 1994.

Forecast: Solubility studies for Np, Pu and Am in UE-25 J-13, UE-25 P-1 and neutral electrolyte solutions from undersaturation at three temperatures and three pH values using pure crystalline or amorphous phases of the radionuclides will be completed. Solubility studies for uranium from oversaturation and undersaturation will be started. Temperature-dependent, higher concentration conventional spectrophotometric (ultraviolet-visible) studies

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of the speciation of Np(V) in synthetic carbonate ground waters will continue, and temperature-dependent photoacoustic studies of Pu(V), Pu(VI), and Np(V) at extreme dilution in synthetic carbonate ground waters will be completed. Modeling of all spectroscopic data to extract thermodynamic constants will be completed. Nuclear magnetic resonance species identification and thermodynamic studies of U(VI), U(V), Np(V), Pu(VI), and Pu(V) in synthetic carbonate ground waters will be completed. Thermochemical modeling codes will be used to conduct solubility and speciation modeling of radionuclides. Thermochemical data bases for actinides will be identified, acquired, and modified for use with appropriate computer codes.

2.2.2.11 Study 8.3.1.3.5.2 - Colloid Behavior

The study plan for this study addresses Site Characterization Analysis Comment 96.

Activity 8.3.1.3.5.2.1 - Colloid formation characterization and stability. No progress during the reporting period; this was an unfunded activity.

Activity 8.3.1.3.5.2.2 - Colloid modeling. No progress during the reporting period; this was an unfunded activity.

Forecast: Staff will resume Pu(IV) colloid studies concerning chemical behavior and physical properties using photoacoustic spectroscopy, dynamic light scattering, and chemical reactivity with emphasis on near-neutral conditions.

2.2.2.12 Study 8.3.1.3.6.1 - Dynamic Transport Column Experiments

Activity 8.3.1.3.6.1.1 - Crushed tuff column experiments. A report entitled "Neptunium Transport through Yucca Mountain Tuffs II: Column Experiments" (Triay) summarizing the transport of Np through crushed tuff columns using tuff from the Topopah Spring Member, the vitric and zeolitic Calico Hills in waters from UE-25 J-13 and UE-25 P-1 was in preparation. The results of this work are expected to validate the sorption data (obtained with batch sorption experiments) under flowing conditions. The expected results would lead to the important conclusion that using batch sorption coefficients to describe Np retardation in transport calculations leads to accurate or conservative predictions of Np release to the accessible environment.

Studies of the transport of Pu(V) in UE-25 J-13 and UE-25 P-1 waters through crushed tuff from Yucca Mountain began. These experiments are important because Pu sorption is assumed in performance assessment calculations. The sorption data used in performance assessment has not yet been validated under flowing conditions.

Activity 8.3.1.3.6.1.2 - Mass transfer kinetics. The report entitled "Neptunium Transport through Yucca Mountain Tuffs II: Column Experiments" (Triay), mentioned in Activity 8.3.1.3.6.1.1, also summarizes the results of studying transport of Np through crushed

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tuff columns as a function of ground-water flow rate using tuff from the Topopah Spring Member, the vitric and zeolitic Calico Hills, and in waters from UE-25 J-13 and UE-25 P-1. The results of these experiments are important because they address the validity of using batch sorption coefficients in the event of slow kinetics of speciation, slow sorption kinetics, or the formation of actine colloidal species. The results of these experiments are expected to lead to the conclusion that kinetic effects do not invalidate the utilization of batch sorption coefficients to represent Np retardation in performance assessment calculations.

Activity 8.3.1.3.6.1.3 - Unsaturated tuff columns. A study to evaluate the use of the unsaturated flow apparatus to study transport through unsaturated tuffs was completed. It concludes that the unsaturated flow apparatus is a useful tool for the study of radionuclide migration through unsaturated intact tuff. A report entitled "Measurement of Unsaturated Hydraulic Conductivity in Yucca Mountain Tuff" (Conca, 1993) was published.

A study of selenite transport through unsaturated tuff columns was completed. These experiments were intended to test whether sorption coefficients obtained using batch sorption experiments can adequately describe selenite transport through unsaturated tuff. A paper entitled "Selenite Transport in Unsaturated Tuff from Yucca Mountain" (Conca), describing the results was prepared for presentation at the 1994 High-Level Waste Conference.

Activity 8.3.1.3.6.1.4 - Fractured tuff columns. Staff began a study of radionuclide transport through three fractured tuff columns. A preliminary identification of the major minerals coating these fractures was made. Experiments were also initiated to elucidate radionuclide sorption onto these minerals in order to interpret the transport through fractures.

Activity 8.3.1.3.6.1.5 - Filtration. A report entitled "Colloid-Facilitated Radionuclide Transport at Yucca Mountain" (Triay et al., 1994) was published. This report described efforts to evaluate whether colloids will significantly increase radionuclide release from a potential high-level nuclear waste repository at Yucca Mountain. The evidence of the existence of colloids from sampling studies and observation of colloid transport at the field scale are reviewed in this report. The relevance of colloid transport laboratory and field experiments to the conditions at Yucca Mountain are discussed. Research needs are identified in the areas of: colloid sampling, colloid generation, colloid stability, radionuclide sorption onto colloids, and colloid migration. The colloid transport calculations that will allow evaluation of the data to assess the importance of colloid-facilitated radionuclide transport at Yucca Mountain are presented.

Forecast: Staff will determine the effects of sorption and speciation kinetics on the transport of U and Pu using crushed rock columns. Solid rock column experiments will be conducted to assess the validity of using batch sorption K_d s to describe the transport of U, Np, and Pu through saturated and unsaturated solid tuff. Staff will determine the effect of fracture coatings on radionuclide transport through fractured media for nonsorbing and sorbing radionuclides such as Np, Tc, U and Cs. Solid and fractured tuff columns will be used under various degrees of saturation to assess the potential for colloid-facilitated radionuclide transport at Yucca Mountain. The stability of colloids as a function of temperature and ground water chemistry will be determined.

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2.2.2.13 Study 8.3.1.3.6.2 - Diffusion

Activity 8.3.1.3.6.2.1 - Uptake of radionuclides on rock beakers in a saturated system. Experiments to investigate the diffusion of Np through rock beakers made from samples of the Topopah Spring Member and zeolitic Calico Hills were initiated. These experiments were performed using water from UE-25 J-13 and UE-25 P-1.

Activity 8.3.1.3.6.2.2 - Diffusion through a saturated tuff slab. During this reporting period the study of the diffusion of Pu(V) through intact tuffs G4-270 and G4-1532 and waters from UE-25 J-13 or UE-25 P-1 was initiated.

Activity 8.3.1.3.6.2.3 - Diffusion in an unsaturated tuff block. No progress during the reporting period; this was an out-year activity.

Forecast: The uptake of U and Pu by saturated tuffs under diffusive conditions will be determined. The diffusion of conservative and nonconservative tracers in unsaturated tuff blocks will also be determined.

2.2.2.14 Study 8.3.1.3.7.1 - Retardation Sensitivity Analysis

This work seeks to provide a technical basis that will ensure that performance assessment models contain the most important geochemical phenomena and interactions for radionuclide transport through simulation of radionuclide transport with complex chemical behavior on the time and spatial scales required for regulatory compliance assessments. Development of the LEHGC code continued for use in explicitly modeling geochemical processes that control retardation. Related efforts in support of this activity are also reported under Section 2.7.5.2, under Development/Validation of Retardation Model for Performance Assessment.

Activity 8.3.1.3.7.1.1 - Analysis of physical/chemical processes affecting transport. The coupled thermo/fluid/stress module of FEHM (Finite Element Heat Mass Transfer Code) was being brought into the PVCS configuration management system. The code has been verified on some simple analytical stress solutions. A general tabular relative permeability model has been constructed and will be installed into FEHM. This coupled/thermo/fluid/ stress module provides a way to evaluate near-repository processes that affect transport.

Activity 8.3.1.3.7.1.2 - Geochemical/geophysical model of Yucca Mountain and integrated geochemical transport calculations. A three-dimensional model of Yucca Mountain using the best available data was generated. Both flow and transport solutions were generated, and it was found that multidimensional flow effects are evident. A video was produced to display the results, and the video was shown at the DOE-NRC Technical Exchange in October 1993 and the Project Technical Program Review in February 1994. This Project-wide integrating process modeling task in quantifying radionuclide release to the environment provides a detailed foundation for the Total System Performance Assessment. Two-dimensional cross sections near Antler Ridge were constructed for sensitivity analysis for

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Np sorption data and ^{36}Cl data. Preliminary flow and transport calculations were run. This work was initiated because of the significance of Np found as a result of the Total System Performance Assessment dose calculations without time constraints (>10,000 years). A beta version of the reuse component GZSOLVE has been completed and has been tested in FEHM. It is undergoing final acceptance into the Software Quality Assurance Configuration Control System. A preliminary version of the memory managed version of FEHM is being made available to selected members of the Project modeling community for evaluation and testing.

Activity 8.3.1.3.7.1.3 - Transport models and related support. A two-dimensional, dual permeability model was generated to support a study of unusually rapid travel times of ^{36}Cl . The sensitivity of transport to flow-rate changes was investigated. Initially there seemed to be an attenuating effect of some hydrologic units on downward flow, which was probably caused by greater horizontal flow at higher infiltration rates. The dual permeability capability and this analysis showed that fractures may need to be more realistically modeled.

Forecast: Sensitivity analyses will continue, using the LEHGC code to develop criteria to assess the adequacy of use of K_d or retardation factor in representing radionuclide retardation in fractured porous rock at Yucca Mountain.

The unsaturated grid generator and simulation capability developed to produce a locally refined model based on high-flow areas identified in previous coarser grid models will be used. Transport calculations performed with this new grid will reveal new sensitivities to K_d s of the hydrologic units. Processes that affect the transport of radionuclides will be studied to support simplifying assumptions made by performance assessment. Code development is required to simulate various transport processes that may occur. Algorithms for various processes will be produced and optimization of the transport codes such as TRACRN, FEHMN, and CTCN will be conducted. Baseline documentation will be produced and codes TRACRN, FEHMN, and associated multiuse component (GZSOLVE) will be brought into compliance with programmatic software requirements.

2.2.2.15 Study 8.3.1.3.7.2 - Demonstration of Applicability of Laboratory Data to Repository Transport Calculations

Activity 8.3.1.3.7.2.1 - Intermediate-scale experiments. No progress during reporting period; this was an out-year activity.

Activity 8.3.1.3.7.2.2 - Field-scale experiments to study radionuclide transport at Yucca Mountain. During this reporting period, the study plan was being developed for testing in the Calico Hills. The purpose is to evaluate new data available from the surface-based testing program and to evaluate needs related to radionuclide transport for input on accessing the Calico hills by the Exploratory Studies Facility.

Activity 8.3.1.3.7.2.3 - Natural analog studies of radionuclide transport. No progress during the reporting period; this was an out-year activity.

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Activity 8.3.1.3.7.2.4 - Data on radionuclide transport from other U.S. Department of Energy sites (Anthropogenic analogs). No progress during the reporting period; this was an out-year activity.

Forecast: The study plan and preliminary design of field tests proposed for the Calico Hills nonwelded unit will be completed.

2.2.2.16 Study 8.3.1.3.8.1 - Gaseous Radionuclide Transport Calculations and Measurements

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

Forecast: No activity is planned for FY 1994.

2.2.3 Rock Characteristics (SCP Section 8.3.1.4)

2.2.3.1 Activity 8.3.1.4.1.1 - Development of an Integrated Drilling Program

The YMSCO uses a consolidated work scope process as a means of integrating the site characterization drilling program. This process serves as an interface between the Technical Implementation Plan and Test Planning Packages for specific Surface-Based Testing activities. It is completed primarily for Surface-Based Testing activities that potentially involve multiple investigators. The goal is to identify requirements from primary and secondary studies, and to define a set of consolidated requirements that meet as many secondary needs as possible while not compromising the primary purpose of the activity. For example, in a borehole drilled in support of the Systematic Drilling Program, the needs of other activities can be met through distribution of core or cutting samples or through testing in the borehole after it is completed. By maximizing the benefit of each activity, the overall cost-effectiveness of the program is increased.

During the reporting period, consolidated work scopes were developed for planned Boreholes USW SD-9 and USW SD-7 (consolidated with planned Borehole USW SRG-4). An addendum to consolidated work scopes for USW SD-9 and USW SD-12 was also issued. All of these systematic drilling boreholes support the collection of geologic and engineering data for design of the Exploratory Studies Facility.

The consolidated work scope for Borehole USW UZ-7A was in progress. This is a borehole planned to be drilled in the Ghost Dance fault zone, near existing Well USW WT-2. A letter was sent to the affected units of government and stakeholders, explaining the work scope consolidation process and the process for requesting core or rock samples from the Project.

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Forecast: Consolidated work scopes for Borehole USW UZ-7A will be completed. As planning for FY 1995 progresses, consolidated work scopes for boreholes to be drilled in the first half of FY 1995 will begin.

2.2.3.2 Activity 8.3.1.4.1.2 - Integration of Geophysical Activities

The Geophysics Integration Task Force continued to address geophysical testing issues to facilitate the efficient use of geophysical methods in site characterization. A key focus of this group during the current reporting period was the use of geophysical methods to support design of the Exploratory Studies Facility. The team organized a meeting between Exploratory Studies Facility designers and scientific investigators carrying out borehole logging to determine a schedule for logging activities to support design. The task force also brought together a group of geophysicists to identify effective ways of using geophysics to provide information on the orientation of the Ghost Dance fault down to repository depth. A program of geophysical logging in existing boreholes, vertical seismic profiling, high-resolution seismic reflection lines, and associated magnetic and gravity surveys were planned and implemented.

The Geophysics Integration Task Force also began the planning process for geophysical testing in FY 1995. Geophysical tests proposed for FY 1995 were examined to ensure that they supported the program priorities. Work continued on compilation and integration of existing and planned geophysical data and tests. Section 9.0 (Geophysical Studies) of the Site Characterization Activities Catalog (CRWMS M&O) contains a compilation of geophysical tests derived from the Site Characterization Plan and individual study plans. In addition, work continued on developing a bibliography of known geophysical testing results related to the Project and general vicinity.

Forecast: The Geophysics Integration Task Force will continue to evaluate the need for, and to plan and schedule, geophysical testing within the site characterization program, and to ensure the application of geophysical test results within the program. Consideration will be given to technological advances in geophysical methods in order to incorporate new and potentially useful geophysical test methods into existing and future study plans.

The Geophysics Integration Task Force will endeavor to ensure that objectives, scope, and methods for geophysical tests are well-defined, geophysical and nongeophysical testing programs are integrated, test linkages and information needs are established, the technical need and adequacy for all proposed geophysical tests is well understood, the conduct of the geophysical tests is justified, and that implementation of a geophysical test will contribute to the development of models and assessments to be used for the determination of site suitability and license application.

Work will continue on the compilation of a Preliminary Draft Geophysics Catalog for FY 1994-95. A bibliography of all relevant geophysical publications will be issued in draft form for review and comment.

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2.2.3.3 Study 8.3.1.4.2.1 - Characterization of the Vertical and Lateral Distribution of Stratigraphic Units Within the Site Area

Activity 8.3.1.4.2.1.1 - Surface and subsurface stratigraphic studies of the host rock and surrounding units. Development of the three-dimensional computer-based stratigraphic and structural synthesis continued with compilation of documentation of all supporting data used in construction of the subdivided Topopah Spring Tuff demonstration model. That computer-interactive stratigraphic synthesis was completed in April 1993 and has been used by engineers performing conceptual design calculations.

Further development of the three-dimensional stratigraphic and structural synthesis continued. Compilation of additional data for the LYNX-based synthesis continued with development of structure contour and isopach maps (base of Tiva Canyon Tuff, units between the base of the Tiva Canyon and top of the Topopah Spring), entry of fault structure into LYNX files (including updated fault geometry and reinterpretation of the fault geometry in Drill Hole Wash), and compilation of stratigraphic contacts (from Drillholes UE-25 NRG-2, 2A, 3, 4, 5, and UE-25 RF-3, 8). Consistency checks were completed on well data through development of structure contour and isopach maps, including all available data on NRG, RF, and UZN holes. Fault geometries (Solitario Canyon, Bow Ridge, Ghost Dance, and Sever Wash faults; two faults in Drill Hole Wash; the potential fault in Yucca Wash, and part of the Dune Wash fault) have been entered through AutoCAD. These faults have been described from the topographic surface down to an elevation of 610 m above sea level. Additional isopach maps (pre-Tiva Canyon, pre-Yucca Mountain, and pre-Pah Canyon bedded tuff units; the Yucca Mountain Tuff; Pah Canyon Tuff; and subunits of the Topopah Spring Tuff) were digitized for future inclusion in the three-dimensional model. Isopach maps have been expanded beyond the boundaries of the modeled area to correct for edge effects. Offsets of stratigraphic units across modeled faults were established for the full volume of the model. Draft ARC/INFO drillhole and isopach data bases were updated and validated; a conversion was developed to utilize ARC/INFO data bases directly into LYNX.

Site-scale detailed modeling of the area near the North Ramp of the Exploratory Studies Facility was completed and made available to design engineers in October 1993 as two-dimensional sections in support of conceptual design, including documentation of techniques of model construction, supporting data, and assumptions. This effort was completed in support of geologic and geotechnical aspects of Exploratory Studies Facility construction.

Measurement and compilation of a stratigraphic measured section was completed from the west slope of Yucca Mountain across Yucca Crest near Antler Ridge, for eventual inclusion in the three-dimensional modeling.

An isopach map for the nonwelded to partially welded top of the crystal-rich caprock of the Topopah Spring Tuff was completed. This new subdivision represented a major contact in the thermomechanical stratigraphy and the hydrogeologic stratigraphy. The USGS conducted lithologic logging of new and existing boreholes. Preliminary descriptions of lithologic contact tables were completed for Boreholes USW NRG-7/7A, USW UZ-14;

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USW UZN-27, 31, 32, 33, 34, 35, 37, 53, 54, 55, 57, 58, 59, 61, and 62. Detailed graphical lithologic logs were completed for Boreholes UE-25 NRG-1, 2, 2A, 2B, 3, 4, 5, UE-25 RF-3, 8, UE-25 UZ-16, and USW NRG-6. Data were forwarded to the LYNX modelers for entry into the three-dimensional lithostratigraphic site-scale model.

Logs from selected North Ramp boreholes were examined for characterization of geophysical properties of microstratigraphic units and contacts in boreholes with noncored intervals. The staff plotted dry bulk-density and porosity data versus depth for the interval between the Tiva Canyon and Topopah Spring tuffs of Boreholes USW UZN-37, 54, 55, and UE-25 UZ-16 to correlate stratigraphic data.

Units between the Topopah Spring and Tiva Canyon tuffs in the closely spaced Boreholes UE-25 UZ-16 and USW UZN-53, 54, and 55 were correlated, and a preliminary set of graphical logs that display the observed variations was prepared.

Siting of Borehole USW UZ-7A was aided by compiling geologic cross sections; detailed maps along the Ghost Dance fault; lithologic logs from boreholes USW WT-2, USW UZ-7, and UE-25 UZ-16; borehole geophysical logs from USW WT-2 and UE-25 UZ-16; vertical seismic and seismic reflection profiles near USW WT-2; and a magnetic profile across the Ghost Dance fault.

Integration of lithologic information from boreholes was under way and correlation of lithologic units between Trench NRT-1 and UE-25 NRG-2, 2A, 2B, 2C, and 2D is completed. Staff participated in a review of the lithostratigraphy of the rocks west of and adjacent to the Bow Ridge fault with respect to the ability to tunnel through these rocks by various methods.

Geologic mapping, lithologic studies of core from boreholes, and surface and borehole geophysical studies were integrated to produce a preliminary geologic cross section along the North Ramp alignment of the Exploratory Studies Facility. The ramp will transect the Bow Ridge and Drill Hole Wash faults and numerous minor faults, and traverses two thick welded tuffs (Tiva Canyon and Topopah Spring) and several nonwelded tuff units (Pah Canyon, Yucca Mountain, and Ranier Mesa). The Bow Ridge fault is shown on the cross section to be a west-dipping normal fault with about 125 m of dip-slip separation. Geometry of the Drill Hole Wash fault is uncertain, but is considered to consist of numerous strands that accommodate a complex net oblique-slip displacement. The relationships summarized above are the subject of a presentation at the 1994 High-Level Waste Conference entitled "Integrated Geology and Preliminary Cross Section Along the North Ramp of the Exploratory Studies Facility, Yucca Mountain" (Buesch et al.).

A talk describing revised stratigraphic nomenclature and macroscopic identification of lithostratigraphic units exposed at Yucca Mountain, Nevada, (Buesch) was presented at the Committee for the Advancement of Science at Yucca Mountain Symposium in Denver, Colorado, December 1, 1993. A proposed open-file report on the same subject, entitled "Revised Stratigraphic Nomenclature and Macroscopic Identification of Lithostratigraphic Units of the Paintbrush Group Exposed at Yucca Mountain, Nevada" (Buesch et al.), is part

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of an effort to develop a uniform nomenclature that will facilitate both surface and subsurface geologic mapping.

Activity 8.3.1.4.2.1.2 - Surface-based geophysical surveys. Shallow and intermediate seismic reflection surveys are being planned across Crater Flat and Yucca Mountain to (1) study the position of marker stratigraphic horizons that are buried beneath the alluvial deposits of washes and valleys, and (2) detect structural features, to depths of about 10 km, that characterize the tectonic setting of Yucca Mountain and thus have a direct bearing in performance assessment of the potential repository. Requisitions and final requests for proposals for the acquisition and processing of the seismic reflection data were prepared and submitted in March 1994.

Gravity and ground magnetic measurements were obtained along a mile-long traverse across the Ghost Dance fault systems. Gravity recordings were taken about every 48 m along the profile and about 23 m near the fault; magnetic measurements were made about 15 m apart. Combined with data obtained from seismic reflection profiling across the fault zone (see Activity 8.3.1.4.2.2.5), a preliminary analysis of the surface-based geophysical surveys (detailed gravity results are not yet available) suggest that the Ghost Dance fault as presently mapped is part of a complex zone of faulting and fracturing that is several hundred meters wide, and that this width projects downward to a depth of about 1 km. These findings are reported in an abstract entitled "Geophysical Investigations of the Ghost Dance Fault, Yucca Mountain, Nevada" (Oliver et al., 1994), published in the Geological Society of America Abstract of Programs for the 90th Annual Cordilleran Section Meeting in San Bernardino, California, March 21-23, 1994.

Gravity and magnetic data collected across Yucca Wash neither indicate, nor preclude, the existence of vertical offsets on the proposed Yucca Wash fault. A broad magnetic high whose source is buried at shallow depths and most likely has steep edges. This anomaly coincides closely with the relatively abrupt change in water-level elevation (300 m over a horizontal distance of 2 km) north of the potential repository site at Yucca Mountain, but additional geophysical data are needed to better define the source of the anomaly, its possible relationship with the hydrologic gradient, and whether it provides a constraint on the movement of the proposed Yucca Wash fault. The results of this investigation are discussed in a paper, "Gravity Investigations of Yucca Wash, Southwest Nevada" (Langenheim and Ponce), accepted for presentation at the 1994 High-Level Waste Conference. A paper, "Gravity and Magnetic Study of Yucca Wash, Southwest Nevada" (Langenheim et al.), was also being prepared as a USGS open-file report.

Activity 8.3.1.4.2.1.3 - Borehole geophysical surveys. A work scope was prepared for magnetometer studies to be run in water table holes re-opened during FY 1994 for hydrologic testing. A magnetometer log was acquired in borehole USW WT-2 in October, and magnetometer and magnetic susceptibility logs were re-run in November 1993 using centralizers. It was determined that centralizers will have to routinely be used in the large-diameter boreholes.

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Water content and porosities within the unsaturated zone were computed from density and epithermal neutron logs obtained in 15 water table boreholes. The separation between the water content and porosity logs clearly demarcated the lithophysal zones within the Topopah Spring Tuff. Total porosity increased as lithophysal abundance increased, and hence, saturation dropped in the zones with high lithophysal abundance. The use of density and epithermal neutron logs in determining water content and porosity is described in a paper entitled "Saturation Levels and Trends in the Unsaturated Zone, Yucca Mountain, Nevada" (Nelson), that was accepted for presentation at the 1994 High-Level Waste Conference. The paper was previewed at the Advancement of Science Symposium, along with an ad-hoc poster describing Borehole UE-25 UZ-16.

A talk entitled "Assessment of Geophysical Logs from Borehole USW G-2, Yucca Mountain, Nevada" (Nelson) was given at the 5th Minerals and Geotechnical Logging Symposium in Tulsa, Oklahoma, October 1993. The presentation was based on a comprehensive evaluation of various logging methods used to obtain information on stratigraphic units and properties of rocks penetrated in boreholes at Yucca Mountain. A report of the same name was published (Nelson and Schimschal, 1993).

Activities 8.3.1.4.2.1.4 - Petrophysical properties testing and 8.3.1.4.2.1.5 - Magnetic properties and stratigraphic correlations. No progress during the reporting period; this was an unfunded activity.

Forecast: The next version of the LYNX-based three-dimensional stratigraphic and structural synthesis will be completed in the next reporting period. The new version will include units from the base of the Topopah Spring Tuff to the topographic surface. This version has been constructed using a surface-handling approach to facilitate integration with other modeling systems used by the Project.

Graphical lithologic logs are nearly completed and will be submitted for boreholes USW G-1, G-2, G-3, and G-4 as will tables of basal contacts for eight additional boreholes. Completion of graphical logs or tables of basal contacts for other boreholes will be prepared depending on the drilling schedule. Boreholes that are planned for the remainder of FY 1994, or that are in the initial stages of being drilled include USW SD-7, 9, and 12.

Acquisition of the shallow-to-intermediate seismic reflection profile across Crater Flat and Yucca Mountain is expected to be completed during the next reporting period. Processing of the data obtained is anticipated in the first part of FY 1995.

Development of water saturation algorithms from borehole logging will continue. Magnetometer and magnetic susceptibility data will be obtained from water table holes opened for hydrologic testing as the holes become available.

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2.2.3.4 Study 8.3.1.4.2.2 - Characterization of the Structural Features Within the Site Area

Activity 8.3.1.4.2.2.1 - Geologic mapping of zonal features in the Paintbrush Tuff.

Compilation of Ghost Dance fault and fracture data continued throughout the six-month period. Field checks and extensive technical data reviews were made of the FY 1992-1993 Ghost Dance fault 1:480-scale map sheets in preparation for final release.

Ongoing detailed mapping at a scale of 1:240 of structural features within the potential repository area indicates the presence of several previously unrecognized structural features. Minor north-trending west-side-down faults occur east and west of the Ghost Dance fault and suggest a total width to this fault system of nearly 366 m. A zone of near-vertical N30°-40° W-trending faults, at least 274 m wide, has been identified in the northern part of the area being mapped and may traverse across the potential repository area, although additional detailed field studies are needed to better understand these structural complexities. This fault zone is being referred to as the "Sundance fault zone," and is the subject of a paper entitled "The Sundance Fault: A Newly Recognized Shear Zone at Yucca Mountain" (Spengler et al.), which was accepted for presentation at the 1994 High-Level Waste Conference. The report will also be issued as a USGS open-file report.

Detailed petrographic and geochemical studies to better define the internal stratigraphy of the Tiva Canyon Tuff are being conducted to support the mapping of the Ghost Dance fault and other structures in the potential site area. Results of the examination of a suite of 35 outcrop samples collected from a 91.5 m thick vertical transect of the Tiva Canyon along the south flank of Antler Ridge indicate that devitrification textures and vapor phase mineralogy, in addition to other physical attributes such as pumice variability (flattening) and crystal content, can be used as criteria to distinguish lithologic zones within the Tiva Canyon. Moreover, these studies show that the petrographic structures and chemistry of the ground mass vary systematically within recognizable lithologic zones and may be used to characterize and vertically divide lithostratigraphic zones within this unit. A paper entitled "Petrographic and Geochemical Characterization of the Tiva Canyon Tuff, Antler Ridge, Yucca Mountain, Nevada" (Singer et al.), was accepted for presentation at the 1994 High-Level Waste Conference.

Preliminary detailed examination of thin sections prepared from rock samples collected from a vertical transect of the lower part of the Tiva Canyon Tuff along the south flank of Whaleback Ridge was begun. Thin-section modes obtained for samples spanning the upper lithophysal/upper cliff boundary and upward to the top of the upper cliff zone show that the contact as inferred from the petrologic data agree with that determined on the basis of field studies.

The Isotope Geology Support Group collected samples from measured stratigraphic sections and geochemical reference sections of the Topopah Spring and Tiva Canyon tuffs for geochemical characterization. Graphic representations of chemical data from the Tiva Canyon sample suites from Antler and Whaleback Ridges, including raw x-ray fluorescence data, were prepared. The trace element data for the Antler Ridge samples were reviewed with special

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references to identifying the boundary between the upper lithophysal and upper cliff zones. Regression analyses of geochemical parameters were also performed on these samples.

A preliminary measured section of units from the crystal-poor upper lithophysal zone of the Topopah Spring Tuff to the mixed pumice subzone of the crystal-rich upper nonlithophysal zone of the Tiva Canyon Tuff along Solitario Canyon was completed. Mappers began the measured section at Borehole USW UZN-80 and ended approximately 50 m north of Borehole USW UZN-62. These preliminary data were synthesized, compiled, and sent to the LYNX 3-D lithostratigraphic modelers (SCP Activity 8.3.1.4.2.1.1, Surface and subsurface stratigraphic studies of the host rock and surrounding units). Staff began a detailed measured section along Solitario Canyon cliff, measuring units from the crystal-rich nonlithophysal zone of the Topopah Spring Tuff to the columnar subzone of the crystal-poor lower nonlithophysal zone of the Tiva Canyon Tuff.

A stratigraphic section was measured and sampled at the northwest end of Isolation Ridge traversing the nonwelded tuffs between the Pah Canyon and Tiva Canyon tuffs. Staff observed that several of these units can be identified in core from the North Ramp area and noted that the Pah Canyon Tuff consists of at least six flow units. The basal Tiva Canyon Tuff varied dramatically from Castle Point to Busted Butte. Mapping at a scale of 1:3,600 has begun near Isolation Ridge to determine the detailed stratigraphy of the bedded tuffs between the Topopah Spring and Tiva Canyon tuffs. Correlation of individual beds, in addition to the major stratigraphic units of the Tiva Canyon, Yucca Mountain, Pah Canyon, and Topopah Spring tuffs, will provide stratigraphic constraints for structural and hydrogeologic modeling of Yucca Mountain.

Reports resulting from studies being conducted in this activity, in addition to those cited earlier, include:

1. An abstract entitled "Intraformational Deformation in the Tuffs and Lavas of Calico Hills Exposed near Yucca Mountain, Nevada" (Buesch and Dickerson, 1993) was published. The development of part of the Southwest Nevada Volcanic Field as recorded by the 12.9 Ma tuffs and lavas of Calico Hills is summarized, contributing information on extensional tectonism in the Yucca Mountain area.
2. A paper "Evidence for a Welded Tuff Within the Rhyolite of Calico Hills" (Dickerson and Hunter), accepted for presentation at the 1994 High-Level Waste Conference, describes a welded pyroclastic deposit in the Rhyolite of the Calico Hills, the origin of which may have a bearing on fluid flow within the Calico Hills unit in the unsaturated zone, as well as on the amount and distribution of zeolitized tuff within the formation.
3. A paper "Structural Character of the Northern Segment of the Paintbrush Canyon Fault, Yucca Mountain, Nevada (Dickerson and Spengler), accepted for presentation at the 1994 High-Level Waste Conference, presents the results of detailed mapping of exposed features along the northern part of the Paintbrush Canyon fault. This feature represents the easternmost block-bounding fault at Yucca Mountain,

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separating Fran Ridge from Midway Valley and extending northward across Yucca Wash to at least the southern margin of the Timber Mountain Caldera complex. The discontinuously exposed fault scarp dips westward 41° to 74° , and vertical offsets of 210 m in the Rhyolite of Comb Peak and 360 m of the Topopah Spring Tuff can be demonstrated. The fault data will aid in the construction of the computer-assisted three-dimensional lithostratigraphic model of Yucca Mountain.

Activity 8.3.1.4.2.2.2 - Surface-fracture network studies. Fracture mapping at the Antler Ridge pavement exposure of the Ghost Dance fault system began in December 1993. Data were obtained along traceline surveys. Preliminary sketch maps of six cells (each approximately 7.5 m by 7.5 m) were developed along with stereonet pole plots of fracture data. Fracture trends were identified based on orientation. All survey points were incorporated into the fracture-trace drawings, prepared at a scale of 1:60.

Additional field checking and data acquisition were conducted in February and March 1994, and the Antler Ridge pavement mapping was completed. AutoCAD drawings were prepared for data from mapped fracture traces.

Activity 8.3.1.4.2.2.3 - Borehole evaluation of faults and fractures. No progress during the reporting period; this was an unfunded activity.

Activity 8.3.1.4.2.2.4 - Geologic mapping of the Exploratory Studies Facility. Photo-mosaics from station 0+00 to 1+96 of the upper bench of the Starter Tunnel were assembled, and photogrammetric mapping of the upper bench of the Starter Tunnel to station 1+60 was completed. Work continued on a data base to accept data directly from the Kern DSR-11 analytical plotter. Spatial and attribute data were incorporated into the ArcCAD GIS system, and preliminary analysis was conducted.

Field mapping of the Exploratory Studies Facility North Ramp Starter Tunnel was completed in October 1993. The work included detailed line surveys along both walls (on the lower bench), full-periphery mapping of tunnel walls, and collection of various samples as part of the consolidated sampling program.

A fracture fingerprint diagram was prepared and fracture data from one wall of the North Ramp Starter Tunnel were tabulated. A data file was created incorporating all of the North Ramp Portal map points, and an AutoCAD drawing produced as part of the preparation of a North Ramp Portal map. The detailed line survey data from the Exploratory Studies Facility were also entered into a data file designed to create histograms and other graphic displays for reporting purposes. Composites of the field map and the edited full-periphery map formed the basis of an analysis report, "Full-Periphery Geologic Map: North Ramp Starter Tunnel ESF" (Beason), that was in technical review.

Fracture fingerprint drawings from data collected in the Starter Tunnel, portal cut, and drainage channel of the North Ramp were produced. Topographic data from the portal cut and drainage channel were merged into one AutoCAD drawing, and data points from the

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portal mapping and a combination of data points from the drainage channel, NRG-1 pavement, and the portal cut were reduced.

Test Alcove 1 of the Exploratory Studies Facility was inspected to determine if the alcove had penetrated a shear zone. The recommendation was made that excavation be extended to fully penetrate the zone. The zone appeared to widen to the northwest, resulting in the alcove being slightly longer than originally anticipated. The alcove was eventually extended to station 1+13. Mapping of Test Alcove 1 to Station 1+13 was completed in January 1994. Detailed line surveys of both walls and the face along with full-periphery mapping of the tunnel and a sketch of the alcove face were developed. A brief analysis was made to determine if Test Alcove 1 or holes drilled from the end of the alcove would intercept a small fault observed in the north wall of the North Ramp portal cut. The results were received by YMSCO for review.

Work began on compilation of the AutoCAD version of the drainage channel map describing the east side of Exile Hill. A complete analysis of the fracture data from the Starter Tunnel right slash cut was conducted. The results were received by YMSCO for review.

The mapping staff performed a geotechnical analysis of testing Alcove 1; the analysis consisted of evaluating possible wedge failures in the walls, crown, and face of the alcove using the Unwedge software program. The results were received by YMSCO for review.

Activity 8.3.1.4.2.2.5 - Seismic tomography/vertical seismic profiling. Design specifications for underground testing in the Exploratory Studies Facility were finalized; changes to the plan were submitted to the Exploratory Studies Facility Test Coordination Office.

Processing of the vertical seismic profiling data acquired from USW NRG-6 and USW WT-2 boreholes was started. The near-offset vertical seismic profiling sites were completed and analyzed for interval Poisson's ratio information at both boreholes. The data were rotated/examined for the far-offset information at USW NRG-6 and USW WT-2 and for the walkaway data across the Ghost Dance fault from USW WT-2. Three high-resolution surface reflection lines were acquired at Yucca Mountain.

Subsequent processing of the vertical seismic profiling and reflection data showed a systematic change in velocity structure between the results at USW WT-2 and USW NRG-6, and also a difference in the reflection data from Line 1 to Line 2. A depth section along Line 1 was produced using the velocity obtained from the vertical seismic profiling in USW WT-2. This depth section was consistent with reflections identified in the vertical seismic profiling at USW WT-2.

The initial results of processing and interpreting the data (near offset velocities and Poisson's ratio, far offset, shear-wave polarization, reflection analysis, and walkaway vertical seismic profiling) from the FY 1993 vertical seismic profiling field work at the USW NRG-6 and USW WT-2 boreholes are summarized in an interim report entitled "Analysis Paper:

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Data Reduction NRG-6/WT-2 VSP" (Daley and Majer), which was received by YMSCO for review.

The analysis paper entitled "Ghost Dance Surface Reflection Profiles" (Majer and Karageorgi) was in DOE review. This paper contained primary findings and progress of the data processing of two of the three surface reflection lines which were collected in late October 1993. Some of these findings are discussed under Activity 8.3.1.4.2.1.2, in Section 2.2.3.

Forecast: Three stratigraphic sections (locations to be determined) will be measured, and petrographic analysis of samples will continue to provide data for construction of the stratigraphic model. Mapping near Isolation Ridge will continue and development of a strip map on the west face of Yucca Mountain near USW UZ-6 is planned.

Fracture mapping at the Antler Ridge exposure was completed during this reporting period, and compilations and presentations of data and maps will follow early in the next reporting period. The results of this mapping will be incorporated into a report to DOE describing lithologic, structural, and fracture mapping of the Antler Ridge site.

Completion of the review of the Tiva Canyon fracture compilation and incorporation of review comments are anticipated in the next reporting period. A field review of data collected from Pavement 2001 at Fran Ridge (FY 1993 work) is also expected in the upcoming reporting period.

Staff will continue compilation of the North Ramp Starter Tunnel data. A report including full-periphery maps of both the starter tunnel and Test Alcove 1, detailed fracture data and analysis from both excavations, a surface map of the portal and drainage channel, and a geologic cross-section through the portal excavation and starter tunnel is expected to be completed by the end of this fiscal year.

Responses and incorporation of parts of comments will be completed prior to publication of the detailed geologic maps (1:480 scale) describing the potential repository area. Field studies will be completed at the Antler Ridge pavement, and results of the study will be published. Geologic mapping at 1:6,000 scale will continue north of Yucca Wash.

Additional vertical seismic profiling and surface reflection work will continue to provide further structural detail for the three-dimensional lithostratigraphic site scale model and the Exploratory Studies Facility design.

2.2.3.5 Study 8.3.1.4.2.3 - Three-Dimensional Geologic Model

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

Forecast: No activity is planned for FY 1994.

2.2.3.6 Study 8.3.1.4.3.1 - Systematic Acquisition of Site-Specific Subsurface Information

Activity 8.3.1.4.3.1.1 - Systematic drilling program. On January 28, 1994, the LM-300 rig began drilling USW SD-12 (the first drillhole of the Systematic Drilling Program). The hole is targeted for a depth of approximately 702 m, penetrating 92 m into the saturated zone. Core samples obtained from the upper portion of the hole are intended to provide information related to the design of the Exploratory Studies Facility main test level in the southern portion of the potential repository. Core samples obtained from the remainder of the hole will provide other geologic information required for understanding the deeper portions of the repository block. In order to provide monitoring of in situ hydrologic conditions before, during, and after construction of the drift, the hole will be instrumented under Study 8.3.1.2.2.3, Characterization of Percolation in the Unsaturated Zone—Surface-Based Study; Activity 8.3.1.2.2.3.2, Site vertical boreholes studies (see Section 2.2.1.7).

Final preparations for starting drilling of the second drillhole of the Systematic Drilling Program, USW SD-9, were initiated. Drillhole USW SD-9 is located north of USW SD-12.

Hypotheses regarding stratigraphic control of material properties (Rautman et al., 1993) were tested; results of the testing will be presented in an article entitled "Spatial Variability of Hydrologic Properties in Volcanic Tuff" (Istok et al.). The results confirm that porosity is essentially a function of stratigraphic elevation within the shaly base microstratigraphic subzone at the base of the Tiva Canyon Member.

Forecast: During the remainder of FY 1994, remaining prerequisites for drilling of USW SD-9 will be completed. Current plans involve drilling USW SD-9 in two stages using a smaller drill rig than the LM-300. The first stage will meet engineering requirements for the Exploratory Studies Facility main drift design and is targeted for a depth of roughly 336 m. For the second stage, a larger-capacity rig will be moved onto the pad and the hole deepened to a planned depth of about 663 m (92 m into the saturated zone). Because the LM-300 is unavailable for drilling USW SD-9, the final hole diameter will be too small for the standard unsaturated zone instrumentation string (Study 8.3.1.2.2.3, Characterization of Percolation in the Unsaturated Zone—Surface-Based Study). Tentatively, a slim-hole instrumentation package for unsaturated zone hydrology measurements will be installed upon completion of the second stage drilling, hole conditions permitting.

Planning is under way for Drillhole USW SD-7 (also part of the Exploratory Studies Facility Soil and Rock Properties Study). This hole is to be located at the transition from the South Ramp to the main test level.

Preparation activities for drilling additional holes continue and include: (1) revising data reports covering the entire surface transect data set, (2) collecting and testing additional samples, if necessary, to resolve outstanding issues, (3) evaluating data using statistical and geostatistical methods, and (4) preparing a final report on the surface transect sampling project. In addition, laboratory results of the outcrop sampling studies conducted at Yucca Mountain over the past several years will be presented in two data reports.

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Site characterization field activities will be conducted for drillholes currently in progress or anticipated to be drilled during the reporting period. These activities include (1) on-site supervision and monitoring of drilling operations; (2) creating detailed geologic logs of core, including descriptions of lithology, units contacts, fracturing and faulting, alteration phenomena, core recovery and rock quality; (3) monitoring geophysical logging of drillholes, including downhole video logging during drilling to determine hole conditions relevant to drilling decisions; and (4) supporting field activities related to the remaining North Ramp and South Ramp drillholes.

Final (and appropriate interim) Technical Data Information Forms data-transfer reports for each drillhole will be submitted. For all SD-series drillholes, "framework" rock property measurements will be obtained, including porosity, bulk density, particle density, and matrix permeability. In addition, water content will be measured on core samples preserved on the rig-floor (to protect in situ conditions). Laboratory testing will be performed as a collaborative effort with Study 8.3.1.3.2.2.

Classical and geostatistical techniques will be used to evaluate laboratory and field data from drillhole samples, summarize framework material properties, and determine whether changes are required in the drilling and sampling program.

2.2.3.7 Study 8.3.1.4.3.2 - Three-Dimensional Rock Characteristics Models

Activity 8.3.1.4.3.2.1 - Development of three-dimensional models of rock characteristics at the repository site. A work agreement was developed to govern geostatistical and other modeling work performed on thermal properties data acquired under Study 8.3.1.15.1.1 (see Section 2.2.11.1). The raw thermal properties data are being entered into a LYNX model in order to display it in the correct geologic framework. The LYNX model will then be used as the basis for performing the geostatistical simulations.

Welded/nonwelded stratigraphic models were developed for the Total System Performance Assessment-1993 analysis. These models provided the first objective and quantitative assessment of uncertainty in the location of geologic contacts as a result of less-than-exhaustive site knowledge. A somewhat expanded description of the modeling process and the resulting models was prepared for inclusion as Chapter 6 in the Total System Performance Assessment-1993 report (Wilson et al.). Development of these welded/nonwelded stratigraphic models is also reported in "Development of Stochastic Indicator Models of Lithology" (Rautman and Robey), prepared for presentation at the 1994 High-Level Waste Conference.

A previously reported modeling exercise focused on rock quality designation values along the projected trace of the Exploratory Studies Facility North Ramp was brought to a temporary conclusion in order to train modeling staff in using the LYNX GMS system. Several kriged (estimated) models of rock quality designation along the North Ramp were constructed using drill-run and 3.05-m-composite rock quality designation values from the several NRG drillholes. The study confirmed previously reported preliminary interpretations

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that rock quality designation is controlled largely by near-vertical structural features in Drill Hole Wash. The implications of two other observations need to be considered in future modeling activities. First, there were a number of scale effects observed in the data. Modeled rock quality designation values are sensitive to whether the input data are for 3.05-m composites or for the individual core runs (generally much shorter than 3.05 m). This observation emphasizes the issue of scale of available physical data at Yucca Mountain relative to the scales of geostatistical simulations (Journel and Huijbregts, 1978). Second, the drillhole rock quality designation data appear to disagree with similar values determined from line scans in the Exploratory Studies Facility starter tunnel. The source of this apparent disagreement is not immediately evident, but probably originates in differences in measurement technique.

A preliminary LYNX model of several stratigraphic units at Yucca Mountain was constructed using a stacked-isopach and surface-modeling approach. In this modeling method, absolute geometric position is largely ignored, and the selected stratigraphic units are built using thickness measurements (rather than contact elevations). In effect, the original depositional form of the unit is recreated. The method is advantageous in that it ignores faults (all faults are assumed to be "removed" using simple dip-slip motion), and thus is not limited by the highly faulted nature of Yucca Mountain and the fact that many fault blocks contain no drillhole penetrations. Once the various computer "surfaces" are converted to rock-unit "volumes" in LYNX, the results can be "refaulted" and "hung" from an appropriate structure contour surface, such as that being generated under Study 8.3.1.4.2.1, Characterization of the Vertical and Lateral Distribution of Stratigraphic Units Within the Site Area, (Section 2.2.3.3). Introduction of material-properties models into the appropriate stratigraphic volumes prior to "faulting" offers the opportunity to avoid some of the problems encountered with apparent dips (due to multiple, closely spaced faulting) during the indicator (welded/nonwelded) modeling exercise conducted for Total System Performance Assessment-1993.

Revised source code (Version 1.4) for the GSLIB geostatistical software package was received from the Stanford Center for Reservoir Forecasting. The changes consist primarily of debugging and execution improvements, and ultimately will be incorporated into the next printing of the source code. This continues previous practices of, under which industrial affiliates of the Center receive results of geostatistical research activities one to two years prior to general public availability. Portions of the GSLIB software package that were found to be of particular value in modeling for the Project are described in "Development of Integrated Geostatistical Modeling Software: An Interim Status Report and Plan" (Rautman) that was received by YMSCO. This report also outlines future development plans to customize the routines for "production" use in this activity.

Forecast: The study plan will be completed and be transmitted to YMSCO and the necessary review and revisions will be completed during FY 1994 prior to submitting the study plan to NRC.

Plans are being developed for a more focused software development effort to allow explicit integration of a geometric model of Yucca Mountain with numerical material properties models. The intended methodology is probabilistic in nature, yet makes use of

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geologically-based deterministic correlations between the statistical distribution of important hydrologic properties and the microstratigraphic or zonal subdivisions of the thick ash-flow tuff sequences at Yucca Mountain (Rautman et al., 1991). The use of the observed correlations allows abundant soft information from the geologic setting to be incorporated in a theoretically rigorous manner that will reduce excessive uncertainty in modeling of material properties away from measured control points. The result will be more tightly constrained "numerical rocks" for use in performance calculations without unduly proscribing the residual uncertainty that is inherent in any geologic investigation.

Updates will be developed for GSLIB- and LYNX-based geologic and material properties models to provide cross sections along developing ramp alignments in support of Soil and Rocks Properties Study, Exploratory Studies Facility ramp design, and construction monitoring.

2.2.4 Climate (SCP Section 8.3.1.5)

2.2.4.1 Study 8.3.1.5.1.1 - Characterization of Modern Regional Climate

Activity 8.3.1.5.1.1.1 - Synoptic characterization of regional climate. No progress during the reporting period; this was an unfunded activity.

Forecast: In the second half of FY 1994, resolution of the comments on the study plan will be submitted to DOE. No other activity is funded in FY 1994. When the study is reactivated, it will utilize precipitation samples being collected as part of Activity 8.3.1.5.2.1.5, Studies of calcite and opaline silica vein deposits. (See Section 2.2.4.7).

2.2.4.2 Study 8.3.1.5.1.2 - Paleoclimate Study: Lake, Playa, and Marsh Deposits

Activity 8.3.1.5.1.2.1 - Paleontologic analyses. No progress during the reporting period; this was an out-year activity.

Activity 8.3.1.5.1.2.2 - Analysis of the stratigraphy-sedimentology of marsh, lacustrine, and playa deposits. Initial interpretations of late Pleistocene climate were made based on aquatic microfossil data collected from sedimentary deposits in the Las Vegas Valley. Those interpretations are intended to provide a realistic estimation of atmospheric effective moisture during a glacial climate state. Once verified with additional data, the estimations of effective moisture will form one set of boundary conditions for hydrological models of the future that are an integral part of the site characterization program, and which bear directly on questions concerning the effects of future climatic conditions on repository performance.

The microfossil data collected from Quade's unit D (Quade, 1986), which represents deposition in a maximal extension of marshes, wetlands, and shallow lakes on the Las Vegas Valley floor, estimate that mean annual precipitation may have been three to four times higher than modern, and that average summer air temperatures were about 10° to 15°C cooler

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than today. Modern day levels of effective moisture show a moisture deficit of about 1000 mm of precipitation, but the sites common to the modern analogs for the fossil assemblages show a moisture deficit of about 100 to 400 mm of precipitation. A more detailed discussion of these interpretations is given in several papers to be published in the Proceedings of the 1994 High-Level Waste Conference, including, "Molluscs as Climate Indicators: Preliminary Stable Isotope and Community Analysis" (Sharpe et al.); and "Late Glacial Climate Estimates for Southern Nevada and the Ostracode Fossil Record (Forester and Smith).

Study was initiated of fossil ostracodes and aquatic gastropods extracted from a core taken in late Holocene (4 ka) sediments from the Pahranaagat Mountains by personnel from Desert Research Institute. Preliminary data suggest that the modern day shallow saline lake contained fresh water in the relatively recent past and may have had sufficient surface-water input to have been converted into a through-flowing stream. The commonness of wetter-than-modern climate episodes is also supported by pollen analyses from the same core and by a detailed tree ring record under investigation as part of Study 8.3.1.5.1.3 (see below).

Stable-isotope values from biogenic carbonate (ostracodes, mollusks) collected from the late-Pleistocene sediments in the Las Vegas Valley and from the core in the Pahranaagat lakes are under study. Over 200 samples have been prepared and await analyses. Initial estimations of the isotopic composition of late-Pleistocene water suggest that the wetlands were supported by precipitation derived from polar air masses, implying enhanced winter precipitation activity. The estimated range of oxygen isotope values for this precipitation is very similar to values obtained by Benson and Klieforth (1989) from Pleistocene ground water near Yucca Mountain. Isotope values obtained from terrestrial snails (see reference to Sharpe et al., above) may indicate summer precipitation had a polar isotope signature, implying summers were characterized by a winter-like style of atmospheric circulation. A winter-like circulation during summers would greatly reduce evaporation both because of increased precipitation and greatly reduced average summer temperatures.

A climate workshop was convened in Denver to enable Program personnel to discuss ways of better integrating climate information derived from fossil and isotope data with that derived from regional scale models. Discussion included ways to evaluate model reconstruction of past climate and of focusing model runs on climate scenarios, derived from fossil and isotope data, most likely to produce either fracture flow within Yucca Mountain or elevate the water table, potentially decreasing radionuclide travel time.

Activity 8.3.1.5.1.2.3 - Geochemical analyses of lake, marsh, and playa deposits. No progress during the reporting period; this was an out-year activity.

Activity 8.3.1.5.1.2.4 - Chronologic analyses of lake, playa, and marsh deposits. No progress during the reporting period; this was an out-year activity.

Forecast: Staff will continue to subsample the cores collected from lake, playa, and marsh deposits throughout southern Great Basin to provide dates for the deposits. These studies are closely integrated with those of Study 8.3.1.5.1.3 discussed below.

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2.2.4.3 Study 8.3.1.5.1.3 - Climatic Implications of Terrestrial Paleoecology

The DOE has committed grant monies to the Desert Research Institute, University of Nevada, Reno to provide data concerning paleoclimatic tasks specified in parts of the Site Characterization Plan. Desert Research Institute has agreed to follow USGS quality assurance techniques in its studies, thus allowing the use of Desert Research Institute data in USGS studies.

Activity 8.3.1.5.1.3.1 - Analysis of pack rat middens. This study focused on the development, integration, and interpretation of four discrete forms of terrestrial climate proxy records; pollen and plant macrofossils, tree rings, vertebrate fossils, and terrestrial snails. Climate interpretations from each of these data sources have begun to define, in general terms, the characteristics of both the climate-extreme boundary conditions that occurred during the late Pleistocene and the variability of climate during the Holocene. Interpretations based on studies to date are given in several reports accepted for presentation at the 1994 High-Level Waste Conference, including:

1. "Potential of Vertebrate Studies for Assessing Past Climate Variations" (Livingston).
2. "Tree-Rings and Climate: Implications for Great Basin Paleoenvironmental Studies" (Graybill et al.).
3. "Late Holocene Climate Derived from Vegetation History and Plant Cellulose Stable Isotope Records from the Great Basin of Western North America" (Wigand et al.).
4. "Molluscs as Climate Indicators: Preliminary Stable Isotope and Community Analysis" (Sharpe et al.).

Some of the study results and interpretations are summarized in the following paragraphs.

Preliminary interpretations of late Pleistocene (about 23 to 12 ka) plant macrofossils from packrat middens suggest that precipitation varied from as much as five to only two times modern, where modern is taken as the 112 mm average recorded at the Corn Creek Wildlife Refuge. Similarly mean annual temperatures during this period were likely 7° to 9° colder than the modern average of 17°C at Corn Creek Spring. Pollen data from the late Holocene Pahrnat core suggest that the lower treeline moved up and down the local slopes many times in response to variations in Holocene effective moisture.

A long record (9 ka) from tree rings from sites in southern Nevada shows there were Holocene episodes, commonly decadal to century in length, that were both wetter and drier than today. The most recent wet episode existed from about 1400 to 1900 and followed a drier than modern episode that existed from about 900 to 1400. Other wet and dry episodes have generally persisted for shorter periods of time than these most recent examples.

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A GIS vertebrate fossil data base is under construction and will include information about vertebrate fossils from about 25 to 30 ka to modern. Once complete, probably around the end of this summer, the data base will allow rapid access to vertebrate fossil data so that, among other things, species distribution maps can be assembled and used in conjunction with other data to interpret or verify climate interpretations from other data sources. A study of the packrat *Neotoma* skull morphology over wide geographic ranges to determine if certain changes in the skull parameters can be expressed in climate terms is under way. Other studies from rock shelters near Pahrump and at other localities are also nearing completion.

A comparative study of the isotope values from modern terrestrial snails, collected along an elevation gradient in the Spring Range, and those from terrestrial snails, collected from the late-Pleistocene fossil record on the valley floor near Cactus Springs, was completed. The values from the fossil taxa are more negative than the very wide range of values obtained from modern snails. Those more negative late-Pleistocene values could be due to the snails acquiring the isotope signature from local springs and wetlands recharged by winter water. Conversely, those values could also arise from a winter-like atmospheric circulation pattern during the summer, as has been suggested by some of the global circulation models for this time period.

Activity 8.3.1.5.1.3.2 - Analysis of pollen samples. No progress during the reporting period; this was an out-year activity.

Activity 8.3.1.5.1.3.3 - Determination of vegetation-climate relationships. No progress during the reporting period; this was an out-year activity.

Forecast: During the last half of FY 1994, the studies discussed above will proceed using both paleontologic and isotopic records to identify climate change in southern Nevada. All of these studies are closely integrated with Study 8.3.1.5.1.2 (Paleoclimate Study: Lake, Playa, and Marsh Deposits).

2.2.4.4 Study 8.3.1.5.1.4 - Analysis of the Paleoenvironmental History of the Yucca Mountain Region

Activity 8.3.1.5.1.4.1 - Modeling of soil properties in the Yucca Mountain region. No progress during the reporting period; this was an out-year activity.

Activity 8.3.1.5.1.4.2 - Surficial deposits mapping of the Yucca Mountain area. During surficial deposit mapping of the northern third of the Yucca Mountain region, a lithologically distinctive older gravel was recognized and mapped along Fortymile Wash, four miles east of the proposed repository area. The characteristics of this gravel, considered with the known geochronology and volcanic stratigraphy of the region, provide evidence for a probable late Miocene age for the gravel, and for a late Miocene establishment of Fortymile Canyon, coincident with a reversal of drainage direction in the east moat of the Timber Mountain caldera. The position and age of this gravel are significant in constraining the erosional and tectonic history of Fortymile Wash and Yucca Mountain, and in providing further geologic

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evidence for the predominance of Late Miocene geomorphic and tectonic activity relative to activity in post-Miocene time. These results are discussed in a report entitled "Late Cenozoic Evolution of Fortymile Wash: Major Change in Drainage Pattern in the Yucca Mountain, Nevada Region During Late Miocene Volcanism" (Lundstrom and Warren) that will be presented at the 1994 High-Level Waste Conference.

Mapping of the remaining central and southern surficial deposit map area is in progress, as are isotopic, geochemical and thermoluminescence analyses to better constrain age estimates of the predominantly Quaternary surficial deposits mapped to date. An internal memorandum was prepared providing recommendations for reference sections of surficial deposits to be considered for an increased emphasis on age control on Quaternary deposits at Yucca Mountain, in response to discussions at the Project Technical Program review and Yucca Mountain Tectonics Workshop. The map of surficial deposits of the northern area is in technical review.

Activity 8.3.1.5.1.4.3 - Eolian history of the Yucca Mountain region. No progress during the reporting period; this was an unfunded activity.

Forecast: Mapping will continue in the adjoining central and southern map area and reports for individual 1:12,000 quadrangles will be submitted for review as mapping is completed. Geochronological investigations of mapped deposits will continue as necessary to provide critical constraints on geomorphic and tectonic rates and on the responses of the Yucca Mountain landscape to Quaternary climatic changes.

2.2.4.5 Study 8.3.1.5.1.5 - Paleoclimate-Paleoenvironmental Synthesis

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

Forecast: No activity is planned in FY 1994.

2.2.4.6 Study 8.3.1.5.1.6 - Characterization of the Future Regional Climate and Environments

The draft study plan was in DOE review. If approved as written, the scope of work will be modified for each of the four activities identified in the Site Characterization Plan for this study. These modifications were made to account for recent developments in climate modeling and to focus the study more directly on Project interests. Modifications to controlled requirements documents affected by these proposed activity changes were transmitted in conjunction with the draft study plan.

Activities 8.3.1.5.1.6.1 - 8.3.1.5.1.6.4. The transition plan to consolidate responsibility for future climate modeling activities (Activities 8.3.1.5.1.6.1 and 8.3.1.5.1.6.4) was issued as a Project controlled document, and the transition considered complete on October 1, 1993.

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A readiness review was conducted on October 26-27, 1993, in conjunction with an annual audit of a contract with the National Center for Atmospheric Research. The resumption of technical work was authorized following the successful conclusion of the review and audit.

A climate integration meeting was held in Denver, Colorado on October 28, 1993, with climate program personnel. The purpose of the meeting was to improve program integration and communication, in particular between the data collection and analysis activities and the future climate modeling activities. Since that meeting, regular communication has been maintained, and similar interactions with hydrology and performance assessment modelers are planned.

Evaluating the behavior of climate models for several known climate states is an important prerequisite to modeling potential future climate states and possible impacts on waste isolation performance. A paper describing a preliminary model analysis of a selected past climate state, entitled "Paleoclimate Validation of a Numerical Climate Model" (Schelling et al.), was prepared for the 1994 High-Level Waste Conference.

Forecast: With completion of the readiness review and submittal of the draft study plan, emphasis will be on validating the regional climate modeling code, RegCM2, obtained as an acquired code for Project use. As part of this validation effort, a control run will be made to evaluate code performance against current climate meteorological data. If successful, the climate of about 16,000 years ago (when the climate in the vicinity of Yucca Mountain was cooler and wetter than at present) will then be modeled. Preliminary results from this paleoclimate run will be presented at the 1994 High-Level Waste Conference, although complete results are not expected until late in the fiscal year.

A second major effort will emphasize the initial development of methods for interpolating regional scale numerical climate modeling results, in both spatial and time domains, to site-scale using empirically derived information, and for transforming climate modeling output into information useful for future hydrology performance assessment.

2.2.4.7 Study 8.3.1.5.2.1 - Characterization of the Quaternary Regional Hydrology

Activity 8.3.1.5.2.1.1 - Regional paleoflood evaluation. No progress during the reporting period; this was an out-year activity.

Activity 8.3.1.5.2.1.2 - Quaternary unsaturated zone hydrochemical analysis. This activity has been deleted and the scope of work moved to Study Plan 8.3.1.2.2.7.

Activity 8.3.1.5.2.1.3 - Evaluation of past discharge areas. Work accomplished focused on geochronological investigations of samples from discharge sites and on the acquisition of strontium and uranium isotopic compositions from waters collected from a perched zone in Drillhole USW UZ-14.

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Hydrogenic discharge deposits at the southern end of Crater Flat and along Highway 95 continue to be the focus of U-series disequilibrium and thermoluminescence geochronological investigations. Several new samples from both sites were analyzed for U and Th isotopic compositions. Resulting ages are consistent with previous age estimates and indicate hydrogenic activity throughout the last glacial cycle. Interpretations of the ages and ground-water origins were presented at the 1993 Fall meeting of the American Geophysical Union in a paper, together with a published abstract, titled "U-Th Dating of Climate-Controlled Water Table Fluctuations, Yucca Mountain, NV" (Paces and Taylor, 1993). The potential for pedogenic processes to cause secondary mobility of carbonate as well as the uranium inherited in the primary carbonate is a potential problem with the interpretation of U-series disequilibrium ages of carbonates. Recent thermoluminescence dating of several fine-grained, noncalcareous sediments from these same deposits suggests a similarly young, late-Pleistocene depositional age. Thermoluminescence age estimates are not affected by repeated soil saturation or by primary or secondary carbonate deposition.

Strontium and U isotopic compositions of bailed and pumped water from the perched-water zone in USW UZ-14 were also obtained during the reporting period. Both isotopes reflect mixing of at least some components in the early stages of pumping. However, isotopic compositions of both elements mimic changes in pH and specific conductance during pumping and plateau at a constant composition reflecting the characteristics of the "representative" reservoir. The average Sr isotopic composition of bailed samples is also identical to that of the "representative" pump test water. Both isotopes indicate that UE-25 J-13 water is not capable of accounting for the representative end member. In addition, solids suspended in early pump test water, as well as bailed sample "C", show evidence of anthropogenic contamination of heavy trace metals, including high Pb and Zn in particular. Until the source of this contamination can be determined, caution must be exercised in interpreting anomalous hydrochemical data from nonrepresentative samples. Both Sr and U isotopic data are compatible with an infiltration source for perched-zone waters. Strontium isotopes in vein and fracture-filling calcites have been used to provide data on past water movements within the mountain. These data are summarized in an abstract entitled "Paleohydrology from Strontium Isotopes at Yucca Mountain, Nevada" (Marshall et al.) to be presented at the Eighth International Conference on Geochronology, Cosmochronology, and Isotope Geology in June 1994. Calcite vein material from USW UZ-14 and other holes has been requested for U-series disequilibrium dating to provide a chronological framework in which to place this work.

Activity 8.3.1.5.2.1.4 - Analog recharge studies. Meteorological, streamflow, and water-quality data collected from two small basins in central Nevada from 1986 through 1992 were used to develop estimates of average annual ground-water recharge for two study basins. The data were presented in two reports: the first was entitled "Meteorological, Stream Discharge, and Water-Quality Data for 1986-91 from Two Basins in Central Nevada" (McKinley and Oliver, 1994); and the second, in review, entitled "Meteorological, Stream Discharge, and Water-Quality Data for 1992 from Two Basins in Central Nevada" (McKinley and Oliver). Results of the three modeling approaches utilizing the data support the conclusion that reasonably accurate estimates of average-annual recharge to ground water range from about 1 to 3 cm/yr for 3-Springs Basin (the drier site), and from about 30 to

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32 cm/yr for East Stewart Basin (the wetter site). The most reliable estimates were those derived from a reduced form of the chloride-ion, water-balance model because they reflect integrated, basin-wide processes in terms of three measured variables: precipitation amount, precipitation chemistry, and streamflow chemistry. A report describing results of the analyses entitled "Estimates of Ground-Water Recharge Rates for Two Small Basins in Central Nevada" (Lichty and McKinley) was in technical review.

Funding for continued data collection for the geochemistry of arid-zone infiltration activity was terminated. Project activities during the period have been aimed at closing out the effort as rapidly, inexpensively, and nondestructively as possible. The five microwatershed sites have been removed; all the soils pits and stilling ponds filled and the ground surface returned to the original contours; and the sites have been inspected and approved as completely restored by the staff of Organ Pipe Cactus National Monument. Progress continues on the long-term meteorological data report.

Activity 8.3.1.5.2.1.5 - Studies of calcite and opaline silica vein deposits. Scoping studies were performed of the gas compositions of liquid/vapor inclusions hosted by secondary calcite from USW G-1 using Quadrupole Mass Spectrometry. These studies revealed high percentages of N_2 and O_2 in roughly atmospheric proportions demonstrating that the calcite probably formed in a vadose environment open to the surface of Yucca Mountain (i.e., the unsaturated zone). Surprisingly high concentrations of CH_4 also were present and it is unclear whether this gas reflects exsolution from unsaturated zone pore waters or post-calcite-precipitation breakdown of included organic matter. These results are detailed in a paper, "Fluid Inclusion Studies of Calcite Veins from Yucca Mountain, Nevada, Tuffs: Environment of Formation" (Roedder et al.), prepared for presentation at the 1994 High-Level Waste Conference.

Study of the geochemistry of carbon dioxide and water in the soil zone in the Yucca Mountain area is continuing. Soil pits were excavated and thermocouple and lateral gas-sampling-probes were installed at both the U.S. Ecology (southeast of Beatty) and Pagany Wash trench sites, and periodic monitoring of the soil moisture, content and C/O isotopic composition of soil CO_2 , and soil inorganic/organic C contents continued at six sites. Preliminary results of this work are reported in a paper titled "Isotopic Studies of Yucca Mountain Soil Fluids and Carbonate Pedogenesis" (McConnaughey et al.) to be presented at the 1994 High-Level Waste Conference.

Precipitation sample collection in support of Activity 8.3.1.5.1.1 (Characterization of Modern Regional Climate) continued from five sites in the vicinity of Yucca Mountain and five regional sites at Rainier Mesa (Stockade Pass), Pahute Mesa (Rattlesnake Wash), Fortymile Wash (near confluence with east Cat Canyon), Beatty, and Stateline, Nevada. The $\delta^{18}O$ values of approximately 45 water samples or standards were determined as part of procedure development.

The $\delta^{13}C$ and $\delta^{18}O$ values were measured for approximately 450 calcite samples (from drill core, soil calcrete, spring deposit, and microfossil and mollusc samples) and 300 CO_2 samples (from both soil and rock).

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In addition to the papers cited in the above paragraphs, the following reports detailing results of this activity were being prepared for presentation at the 1994 High-Level Waste Conference:

1. "Paleoclimatic and Paleohydrologic Records from Secondary Calcite: Yucca Mountain, Nevada" (Whelan et al.). The conclusion is drawn that secondary calcite in the unsaturated zone was formed by infiltration of surface-derived (and soil-zone buffered) waters of meteoric origin, based on stable isotope analyses of calcite and opal, fluid inclusion formation conditions and gas compositions, strontium isotope ratios, and rare-earth-element compositions.
2. "Paleohydrologic and Paleoclimatic Inferences from Calcite Petrography, Chemistry, and Stable Isotope Studies" (Vaniman and Whelan). It is reported that chemical, petrographic, and isotopic data are consistent with models suggesting that calcites in deep veins of the unsaturated zone at Yucca Mountain were precipitated from surface-derived waters. However, the data also indicate that calcites at depth formed in a variety of environments and from fluids significantly different from those that precipitate calcite in calcretes at the surface. The differences are attributed to chemical and isotopic modification of the fluids as they migrate downward through the near-surface biologically mediated environments (e.g., roots and their decay products) and into deeper horizons.

Forecast: The geochemistry of arid-zone infiltration activity will be terminated with the disposal of the meteorological tower. A data report with data from two analog recharge basin studies will be completed, as well as a report with the results of analyses of the data. A data report of the long-term meteorological data from the arid-zone infiltration activity will be completed. Collection and analysis of calcite and opaline-silica vein samples from cores and field sites will continue. Data for paleodischarge deposit studies and dating of opaline silica vein deposits will be compiled in data reports.

2.2.4.8 Study 8.3.1.5.2.2 - Characterization of Future Regional Hydrology due to Climate Change

Activity 8.3.1.5.2.2.1 - Analysis of future surface-water hydrology due to climate changes. No progress 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. No progress during the reporting period; this was an unfunded activity.

Activity 8.3.1.5.2.2.3 - Evaluation of possible future changes of the climate and regional geologic framework on the regional saturated zone hydrology. No progress during the reporting period; this was an out-year activity.

Forecast: No activity is planned for FY 1994.

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2.2.5 Erosion (SCP Section 8.3.1.6)

The topical report on erosion is currently being reviewed by NRC. Section 2.1.2 discusses the activities which occurred during this reporting period.

Forecast: Questions and comments will be addressed when they are received.

2.2.6 Postclosure Tectonics (SCP Section 8.3.1.8)

2.2.6.1 Study 8.3.1.8.1.1 - Probability of Magmatic Disruption of the Repository

The revised study plan provides an increased emphasis on the intrusive component of a future volcanic event. This responds directly to a comment by the NRC that the intrusive component may be underestimated in volcanism studies. The revised study plan includes discussion of the intrusive component of volcanic events both for probabilistic assessment and assessments of the effects of volcanism. Moreover, the revised study plan presents new information on the logic of how studies of the intrusive component of volcanic events are incorporated into overall volcanism studies (data gathering, probabilistic and consequence studies). Presentations entitled "Probabilistic Volcanic Risk Assessment" (Crowe), summarizing progress in probability studies, and "Update on Volcanism Investigations" (Perry), were made to the Structural Geology and Geoengineering Panel of the NWTRB in San Francisco, California, March 8-9, 1994.

Activity 8.3.1.8.1.1.1 - Location and timing of volcanic events. No progress 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. New sets of spatial prediction models were developed by identifying clusters of similar volcanic centers and then merging adjacent clusters. The clusters were identified for combinations of Pliocene and Quaternary volcanic centers and Quaternary volcanic centers. The cluster joining ends for Pliocene and Quaternary volcanic centers with identification of the Crater Flat volcanic zone, a northeast Structural zone and an unnamed east-west zone. The cluster joining ends for the Quaternary centers with identification of the Crater Flat volcanic zone.

Thirteen structural models were identified for the Yucca Mountain region and divided into 19 subsets for assessment of the structural controls of basaltic volcanic activity. These structural models are incorporated into estimations of the probability of repository disruption, a key parameter in assessing the suitability of the Yucca Mountain site and an information feed to performance assessment studies.

Preliminary results show that Pliocene and Quaternary volcanic activity in the Yucca Mountain region occurred primarily in alluvial basins (75 percent of identified events), with secondary occurrences along range fronts (10 percent) and in range interiors (15 percent). The disruption probability, E2, can be weighted for the event recurrences. This weighting

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was applied to spatial and structural models of the distribution of volcanic events in the Yucca Mountain region. A revised structural model of the Crater Flat basin has been developed in which geophysical and field mapping constraints for the Crater Flat area were incorporated. The model provides a structural framework for explaining the distribution of Miocene and Pliocene and Quaternary volcanic activity in the Yucca Mountain region. These results will be included in the final revision of "Status of Volcanism Studies for the Yucca Mountain Site Characterization Project" (Crowe et al.).

Activity 8.3.1.8.1.1.3 - Presence of magma bodies in the vicinity of the site. An assessment of geophysical data needs for the Project volcanism study began. Geophysical data for the Crater Flat basin was assessed and will be used to determine if magma bodies could be present in the Yucca Mountain region and invalidate the probabilistic estimates of repository disruption by a future volcanic event.

A presentation was made on the structural setting of the Crater Flat basin at the USGS meeting on tectonics in Colorado. Concepts concerning integration of rates of basin extension and rates of injection of basaltic volcanic dikes were presented.

Activity 8.3.1.8.1.1.4 - Probability calculations and assessment. Volcanism staff attended a one-week training course on the computer code FRACMAN; this code will be used to generate stochastic models of the probability of dike intersection of the potential repository.

Revised simulation modeling was completed for E1, the recurrence rate of volcanic events, and E2, the disruption probability and the probability of magmatic disruption of the repository. Cumulative probability distributions were constructed using simulation modeling (Latin hypercube sampling, 10,000 iterations). The results, which were presented to the NWTRB, indicated that the E1 is relatively insensitive to mid-point estimates and is more sensitive to boundary assumptions. The expected values of E1 vary by only a factor of 2 or 3, and this variation is not significant in risk assessment. It was found that the E2 is more variable. Alternative structural and spatial models gave similar expected values, but the uncertainty of the cumulative probability distributions varied considerably. Relatively high probability values were obtained for a small subset of spatial models that have a low likelihood of including the potential repository site. Careful examination of simulation results for E2 indicated that there was an interdependency between E2 and E1. Spatially restricted models of E2 exclude volcanic events. If the influence of E2 is not considered on E1, the results overestimate the probability of magmatic disruption of the potential repository. The revised updates of E1, E2, and E2, given E1, are significant for those assessing the risk of future volcanism at Yucca Mountain and will be used in performance assessment.

Planning discussions were held concerning the application of formal methods of expert judgment to the occurrence probability of volcanic events. This work began in FY 1994 and will be closely coordinated with performance assessment studies.

Forecast: Using constraint probability ranges of E2, staff will focus on the development of alternative structural models for the distribution of past basaltic centers. Data from field geologic studies, and from some aspects of the tectonics programs will be used to

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determine these models. Staff will review geophysical data for the Yucca Mountain region to determine if it is sufficiently comprehensive to allow adequate evaluation of the presence of magma bodies in the region and if there is evidence of the presence of subsurface magma in the Yucca Mountain region. Staff will develop plans for evaluating the existence and location of magma using geophysical data combined with studies of the isotopic composition of helium in groundwater. Staff will use iterative alteration models to establish the recurrence rate of volcanic events (E1). They will refine volume calculations and add these data to the data matrix. The volume refinements will use digital terrain data and the computer code Surface Display System for the calculations. Volume calculations will be completed for the Sleeping Butte, and the 1.2 and 3.7 Ma centers of Crater Flat. Interactions with external organizations reviewing the Volcanism Issue Resolution Report will be supported.

2.2.6.2 Study 8.3.1.8.1.2 - Physical Processes of Magmatism and Effects on the Repository

Activity 8.3.1.8.1.2.1 - Eruptive effects. Deposits from strombolian and hydrovolcanic eruptions were examined at Alkali Buttes, New Mexico, an analog site for eruption effects studies. Analysis of field data from this site was nearly completed. Petrographic analysis was initiated.

Activity 8.3.1.8.1.2.2 - Subsurface effects of magmatic activity. Field work was conducted at Scarp Canyon to study dike geometry and effects of dikes on wall rocks. Samples were collected from both dikes and wall rock. Wall rocks were sampled at two localities in the Paiute Ridge intrusive complex for the purpose of constraining the nature and spatial extent of rock alteration processes in small hydrothermal systems.

An abstract titled "Use of Natural Analog and Modeling Studies to Constrain the effects of Magmatic Activity on Long-Term Geologic Repositories" (Valentine et al.) was prepared for the 8th International Symposium on the Scientific Basis for Nuclear Waste Management, to be held in Kyoto, Japan, October 22-28, 1994. The abstract discussed examples and methods for applying magmatic analog studies to geologic repositories. The data are not mature enough for an assessment of significance at this time.

Activity 8.3.1.8.1.2.3 - Magma system dynamics. Literature review of documented, historical small-volume basaltic eruptions continued.

Forecast: Staff will attempt to establish the probability of direct magmatic disruption of the repository resulting in dispersal of significant quantities of radioactive waste surface to exceed the regulatory requirements for licensing of a repository. If the component of the repository inventory released at the surface is sufficiently small ($<0.1 R$ where R is the maximum radiological releases allowed under regulatory requirements), they will terminate studies on the direct effects of future volcanic activity. If the released inventory is $>0.1 R$, they will perform eruption modeling to attempt to determine the partitioning of the waste inventory in surface eruptions and the percentage of the waste that is released in the accessible environment in 10,000 years. Staff will continue to determine the potential

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subsurface effects of intrusion of magma into a repository, topographically below or above the repository, or in the waste isolation system. They will examine individual dikes, dike swarms, and sills. The analysis will focus on the effects of mechanical emplacement of the intrusions, on the thermal perturbations from the intrusions and the effects of volatile degassing on the unsaturated and saturated zone hydrology.

2.2.6.3 Study 8.3.1.8.2.1 - Analysis of Waste Package Rupture Due to Tectonic Processes and Events

A study plan was prepared to combine Investigations 8.3.1.8.2, 8.3.1.8.3, and 8.3.1.8.4 into one investigation (8.3.1.8.2, Studies to provide information required to evaluate changes in the natural and engineered barrier systems resulting from tectonic processes and events), one study, (8.3.1.8.2.1), and five activities (listed below, corresponding to the five studies formerly included in the three investigations). The reason for this consolidation is that much of the work assigned in the Site Characterization Plan to these investigations duplicates ongoing work in other studies, and the remaining work is sufficiently closely related and limited in scope to the extent that the planned work elements and the designated objectives and parameters can logically and appropriately be integrated.

Activity 8.3.1.8.2.1.1 - Analysis of waste package rupture due to tectonic processes and events. One of the tectonic processes evaluated to assess the possibility of rupturing of the potential repository is that of basaltic volcanism. The cluster of basaltic centers in nearby Crater Flat was studied for this purpose. New geologic mapping and geophysical data indicate that these and similar clusters elsewhere in the Southwest Nevada Volcanic Field are preferentially localized along strike-slip shear zones, axes of tensional strain, and major caldera faults. Based on these data, it was concluded that for magma to penetrate the potential repository site, the volcanism would have to recur along a minor transtensional zone that forms the northern boundary of Yucca Mountain where there is a small cluster of 10 Ma basaltic dikes. This zone has evidently been inactive since the late Miocene. A paper, "Structural Control of Basaltic Volcanism in the southwest Nevada Volcanic Field, and Implications for Volcanic Hazards at Yucca Mountain" (Fridrich et al.), was being prepared to present the results and conclusions of this work.

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

Activity 8.3.1.8.2.1.3 - Analysis of the effects of tectonic processes and events on changes in water-table elevation. Discussions on the possible occurrence of perched water in Drillholes USW UZ-1 and USW UZ-14 were held with the Hydrology Integration Task Force; perched water in the Topopah Spring Tuff could be a significant issue with respect to tectonic disruption of the hydrologic system.

Activity 8.3.1.8.2.1.4 - Analysis of the effects of tectonic processes and events on local fracture permeability and effective porosity. The configuration of the southward-sloping

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water table under Yucca Mountain is dominated by an abrupt decline of 300 m over a distance of less than 2 km. This zone of large hydraulic gradient (of 0.15 or more) separates an area of moderate gradient (of about 0.015) to the north from an area of very small gradient (0.0001) to the south. The position of the large gradient does not correlate well with any evident geologic feature in the upper 0.5 km of the mountain, but buried geologic features are present that may explain the geohydrologic observations. A detailed discussion is given in a paper, "Hydrogeologic Analysis of the Saturated-Zone Ground-Water System under Yucca Mountain, Nevada" (Fridrich et al., 1994).

Activity 8.3.1.8.2.1.5 - Analysis of the effects of tectonic processes and events on rock geochemical properties. No progress during the reporting period; this was an unfunded activity.

Forecast: Review of Study Plan 8.3.1.8.2.1 will be completed. Discussions regarding computer modeling of tectonic effects on the Yucca Mountain hydrologic system with potential contractors will continue, as will discussion concerning supporting paleomagnetic studies.

Discussions are beginning with performance assessment specialists to coordinate efforts.

2.2.6.4 Study 8.3.1.8.3.1 - Analysis of the Effects of Tectonic Processes and Events on Average Percolation Flux Rates Over the Repository

This study has been combined with Study 8.3.1.8.2.1.

2.2.6.5 Study 8.3.1.8.3.2 - Analysis of the Effects of Tectonic Processes and Events on Changes in Water-Table Elevation

This study has been combined with Study 8.3.1.8.2.1.

2.2.6.6 Study 8.3.1.8.3.3 - Analysis of the Effects of Tectonic Processes and Events on Local Fracture Permeability and Effective Porosity

This study has been combined with Study 8.3.1.8.2.1.

2.2.6.7 Study 8.3.1.8.4.1 - Analysis of the Effects of Tectonic Processes and Events on Rock Geochemical Properties

This study has been combined with Study 8.3.1.8.2.1.

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2.2.6.8 Study 8.3.1.8.5.1 - Characterization of Volcanic Features

A presentation titled "Update on Volcanism Investigations" (Perry et al.) summarizing progress in geochronology, field, and geochemical studies" was made to the Structural Geology and Geoengineering Panel of the NWTRB in San Francisco, California, March 8-9, 1994.

Activity 8.3.1.8.5.1.1 - Volcanism drillholes. No progress during the reporting period; this was an unfunded activity.

Activity 8.3.1.8.5.1.2 - Geochronology studies. Samples of basalt from Buckboard Mesa, Red Cone, and Little Cones were collected for $^{40}\text{Ar}/^{39}\text{Ar}$ dating. Tuff xenoliths from lava flows and scoria deposits at Lathrop Wells and Little Cones were collected for $^{40}\text{Ar}/^{39}\text{Ar}$ dating of thermally reset sanidines. A sample was identified and was being prepared for Ra/Th disequilibrium dating to verify previously obtained Holocene thermoluminescence ages for tephra deposits at Lathrop Wells. Samples for ^3He surface exposure dating were collected to refine the ^3He chronology at Lathrop Wells.

Data collection was completed on new ^3He ages obtained from eruptive units at the Lathrop Wells center. This was significant because ages of the four disruptive events at Lathrop Wells are converging to strengthen the polycyclic observations. An abstract entitled " ^3He Surface Exposure Ages at the Lathrop Wells, NV, Volcanic Center" (Poeths et al.) was submitted to the International Conference on Geochronology, Cosmochronology, and Isotope Geology, to be held in Berkeley, California, June 5-11, 1994.

Activity 8.3.1.8.5.1.3 - Field geologic studies. Field, geomorphic and-soil relationships were examined at Red Cone and Little Cones. Stratigraphic relationships of eruptive units were systematically reviewed at Lathrop Wells, resulting in the conclusion, presented to the NWTRB, that the Lathrop Wells center was formed during four main eruptive episodes, separated by time breaks of tens of thousands of years, and the geologic map of the Lathrop Wells center was revised to reflect this new conclusion. Distributions of distal ashes erupted from the Lathrop Wells center were examined in deposits west and north of the center. Test pits were constructed north of the Lathrop Wells cone to examine the relationship of scoria-fall sheets to deposits of the Lathrop Wells cone.

Activity 8.3.1.8.5.1.4 - Geochemistry of scoria sequences. Geochemical samples were collected from Buckboard Mesa, Red Cone, and Little Cones. Results of 61 instrumental neutron activation analyses for samples from Lathrop Wells, the Sleeping Butte centers, and the 3.7 Ma Crater Flat centers were received from Washington University. Spidergrams, normalized to an average Lathrop Wells composition, were constructed for all Lathrop Wells eruptive units in order to assess geochemical differences between units. Differences in incompatible-element ratios were assessed to establish the number of magma intrusions involved in the formation of the Lathrop Wells center. These data suggest that identification of unique incompatible element ratios for different eruptive episodes will be useful in correlating ashes in fault trenches near Yucca Mountain with individual eruptive episodes at Lathrop Wells.

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A spreadsheet to calculate the trace-element and major-element evolution of a magma undergoing continuous fractionation, recharge, assimilation and eruption was completed. The spreadsheet will be used to test whether geochemical variations of eruptive units at Lathrop Wells were caused by the evolution of a single magma affected by multiple, complex magmatic processes, or are due to the presence of multiple, independent magma bodies.

A talk titled "Identification and Age of Distal Ashes from the Lathrop Wells Volcanic Center in Fault Exposures Near Yucca Mountain" (Perry and Crowe) was presented at the Yucca Mountain Tectonics Workshop in Estes Park, Colorado, January 24-26, 1994. Constraints on the ages of distal ashes from Lathrop Wells found in fault trenches and methods for geochemically correlating these ashes to eruptive events at Lathrop Wells were discussed.

Activity 8.3.1.8.5.1.5 - Geochemical cycles of basaltic volcanic fields. Geochronologic, volume, and geochemical patterns of post-Miocene basaltic volcanic fields in the Great Basin and marginal areas were evaluated.

Forecast: Staff will make final assessments of U-Th disequilibrium, the cosmogenic He, and the thermoluminescence methods for establishing the ages of Late Pleistocene and Holocene volcanic centers. Age determinations using the $^{40}\text{Ar}/^{39}\text{Ar}$ method will be obtained for the various basalts in the Yucca Mountain region. Exploratory paleomagnetic work will be extended to the basalt Sleeping Butte and the basalt units of Crater Flat. Geologic mapping of the basalt of Buckboard Mesa, Lathrop Wells, Sleeping Butte, and basalt units of Crater Flat will be compiled and completed. Staff will conduct petrological and isotopic studies of the basalt of Lathrop Wells, Sleeping Butte, and the 1 Ma and 3.7 Ma basalt of Crater Flat. Isotopic analyses of Sr, Nd, and Pb will be obtained for these units. Staff will evaluate the data on evolutionary cycles of basaltic volcanic fields to attempt to constrain, by analogy, the stage of evolution of the basalt centers of the Yucca Mountain region.

Staff will attempt to bound E3, the probability of magmatic activity carrying significant quantities of waste radionuclides to the surface through direct eruption, and to evaluate subsurface effects of magma activity through formation of dikes or sills in or below the waste isolation system. The processes of magmatic activity, from generation of magma at depth, through segregation and ascent, storage within chambers in the crust or mantle, and eruption at the surface will also be examined.

2.2.6.9 Study 8.3.1.8.5.2 - Characterization of Igneous Intrusive Features

Activity 8.3.1.8.5.2.1 - Evaluation of depth of curie temperature isotherm. No progress during the reporting period; this was an unfunded activity.

Activity 8.3.1.8.5.2.2 - Chemical and physical changes around dikes. No progress during the reporting period; this was an unfunded activity.

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Activity 8.3.1.8.5.2.3 - Heat flow at Yucca Mountain and evaluation of regional ambient heat flow and local heat flow anomalies. Plans for horizontal temperature-logging of a geothermal test hole drilled from the Bow Ridge fault alcove was considered. Because the alcove is so near the surface and close to other excavations which could potentially corrupt any thermal results, and because of the priority attached to the tunnel boring machine work, it was decided to forego these measurements. A major revision and update of the heat-flow chapter of the Geophysics White Paper was in review.

Forecast: Presently, available drilling plans make it unlikely that new drillholes will be available for temperature measurements during the next reporting period. However, reconfiguration of three of the existing water table wells is likely, in which case, high-resolution temperature logs will be obtained from them. Temperature measurements may be possible in reconfigured H-series, G-series, and ramp-alignment boreholes to improve baseline data before in situ conditions are disturbed by ramp construction. Measurements in USW UZ-14 are also being considered, if results of drilling and hydrologic testing indicate that thermal studies can contribute to an understanding of the occurrence and stability of apparent perched fluids. A summary and analysis of existing heat-flow and temperature data in the Yucca Mountain area will be prepared. Input to plans for horizontal temperature-profiling off the Exploratory Studies Facility tunnels will continue.

Heat flow work planned for FY 1994 includes resolving final comments on the study plan and transmitting the plan to NRC. Precision temperature logs will be done as opportunities arise to collect data. This may happen in FY 1994 at USW UZ-14, UE-25 UZ-16, and selected water table holes.

2.2.6.10 Study 8.3.1.8.5.3 - Investigation of Folds in Miocene and Younger Rocks of the Region

Activity 8.3.1.8.5.3.1 - Evaluation of folds in Neogene rocks of the region. No progress during the reporting period; this was an out-year activity.

Forecast: This activity is not funded in FY 1994; work is planned to start in FY 1995.

2.2.7 Human Interference (SCP Section 8.3.1.9)

2.2.7.1 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

Activity 8.3.1.9.1.1.1 - Synthesis of tectonic, seismic, and volcanic hazards data from other site characterization activities. No progress during the reporting period; this was an out-year activity.

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

Forecast: No activity is planned for FY 1994.

2.2.7.2 Study 8.3.1.9.2.1 - Natural Resource Assessment of Yucca Mountain, Nye County, Nevada

Activity 8.3.1.9.2.1.1 - Geochemical assessment of Yucca Mountain in relation to the potential for mineralization. The Isotope Geochemistry Support Group continued work in support of Rock Characteristics by compiling radiometric data from known mineral occurrences. The staff fabricated new x-ray fluorescence sample cups containing rock powders from all carbonates in the Isotope Geology Support Group collection. The new cups permitted analysis of light elements used to quantify the extent of dolomitization in Paleozoic carbonates. A plan was developed for systematic sampling of the caprock of the Tiva Canyon Tuff for oxygen isotope analyses and plotted sample sites of the unit within the framework of outcrops. A sampling grid for systematic collection of samples of Tiva Canyon Tuff across Yucca Mountain was prepared to analyze samples for stable isotope compositions and to look for cryptic patterns of incipient water-rock interaction. Oxygen isotopic data were obtained and analyzed from samples from a vertical section of Tiva Canyon Tuff at Antler Ridge.

Strontium isotopic analyses of barren and mineralized Paleozoic carbonate rocks show that hydrothermal fluids added radiogenic strontium (^{87}Sr) to the mineralized zones. This relationship, detailed in a paper "Isotopic Tracers of Gold Deposition in Paleozoic Limestones, Southern Nevada" (Peterman et al.), to be presented at the 1994 High-Level Waste Conference, provides a useful technique for assessing the mineral potential of the Paleozoic rocks underlying Yucca Mountain.

Activity 8.3.1.9.2.1.2 - Geophysical/geological appraisal of the site relative to mineral resources. No progress during reporting period; this activity was unfunded.

Activity 8.3.1.9.2.1.3 - Assessment of the potential for geothermal energy at Yucca Mountain, Nevada. No progress during reporting period; this activity was unfunded.

Activity 8.3.1.9.2.1.4 - Assessment of hydrocarbon resources at and near the site. Activity was unfunded during reporting period. However, a report was prepared from previous work for presentation at the 1994 High-Level Waste Conference, "Oil and Gas Exploration Near Yucca Mountain" (Grow et al.). This report discusses results for analyses of conodont samples for color alteration indices from two oil exploration wells drilled within 20 km of Yucca Mountain and from numerous other nearby wells. The color alteration indices of the samples, which were collected from Paleozoic and lower Mesozoic sedimentary rocks are a measure of their thermal maturity. These analyses, combined with analyses of organic geochemical samples from the most likely petroleum source rocks in the area,

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indicate that the entire Paleozoic and lower Mesozoic (through the Triassic) sedimentary sequence is unfavorable as oil source rocks.

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. No progress during reporting period; activity was unfunded.

Forecast: The Tiva Canyon Tuff will be sampled systematically from natural exposures on the east side of Yucca Crest. Samples will be analyzed for whole-rock oxygen isotopes, and trace elements will be determined by x-ray fluorescence. The resulting data should provide definitive evidence for the presence or absence of significant water-rock interaction which may result in geochemical patterns typical of regional hydrothermal mineralization.

2.2.7.3 Study 8.3.1.9.2.2 - Water Resource Assessment of Yucca Mountain, Nevada

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

Forecast: No funding has been identified for FY 1994.

2.2.7.4 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

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

Forecast: No activity is planned for FY 1994.

2.2.7.5 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

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

Forecast: No activity is planned for FY 1994.

2.2.8 Meteorology (SCP Section 8.3.1.12)

2.2.8.1 Study 8.3.1.12.1.1 - Characterization of the Regional Meteorological Conditions

Three Site Characterization Plan studies in the Meteorology Program (8.3.1.12) included work to describe current regional meteorological conditions: Study 8.3.1.12.1.1,

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"Characterization of the Regional Meteorological Conditions;" Study 8.3.1.12.1.2, "Plan for Synthesis of Yucca Mountain Site Characterization Project Meteorological Monitoring;" and Study 8.3.1.12.4.1, "Characterize the Potential Extreme Weather Phenomena and Their Recurrence Intervals." These three studies are being combined into this study. Initial planning for this study plan began during this reporting period. A meeting of the primary groups that collect and use meteorological data is being planned.

Forecast: The meeting between meteorological data collectors and data users is planned for mid-1994. Work to prepare any necessary changes to the Site Characterization Program Baseline and preparation of the study plan itself will proceed during the remainder of FY 1994 and into FY 1995.

2.2.8.2 Study 8.3.1.12.1.2 - Plan for Synthesis of Yucca Mountain Site Characterization Project Meteorological Monitoring

The work in this study is intended to be combined into Study 8.3.1.12.1.1. See Section 2.2.8.1 of this Progress Report.

2.2.8.3 Study 8.3.1.12.2.1 - Meteorological Data Collection at the Yucca Mountain Site

Activity 8.3.1.12.2.1.1 - Site meteorological monitoring program. The ongoing meteorological monitoring program continued at nine active sites. This program is currently focused on data collection. Information gathered is intended for future site suitability and licensing work in estimating potential radiological dosage related to repository operations. One current application of the data from the network was during planning, execution, and analysis of the nighttime downslope wind intensity study, which is described in Section 2.2.8.4 of this Progress Report.

The Meteorological Monitoring Summary Report (SAIC) covering the period January-December 1992 was received by YMSCO during this reporting period. Data from the network were also included in the two quarterly ambient air monitoring reports submitted to the State of Nevada during this reporting period. These reports fulfill requirements of State Air Quality Permit No. 2693, regarding site characterization surface-disturbing activities.

Activity 8.3.1.12.2.1.2 - Data summary for input to dose assessments. No progress during the reporting period; this was an out-year activity. This work cannot proceed effectively until the type of atmospheric dispersion model is chosen.

Forecast: Data collection will continue at the nine sites during FY 1994 and into the first half of FY 1995.

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2.2.8.4 Study 8.3.1.12.3 - Studies to Provide Data on the Location of Population Centers Relative to Wind Patterns in the General Region of the Site

Population density and community characteristics information are intended for inclusion in the final report of this study. The latest information available on population centers will be utilized during preparation of the final report.

An intensive field study program was performed during late-October and early-November with participation from the National Oceanic and Atmospheric Administration's Atmospheric Turbulence and Diffusion Division in Oak Ridge, Tennessee, and the National Weather Service's Nuclear Support Office in Las Vegas and Mercury, Nevada. The purpose of the study was to characterize nighttime downslope airflow related to the west and east sides of the main Yucca Mountain ridge. These conditions may be the "worst-case" atmospheric dispersion related to possible releases of airborne radioactive material in terms of impact on the public.

Forecast: The analyses from the study will be completed during FY 1994, and a report will be written.

2.2.8.5 Study 8.3.1.12.4.1 - Characterize the Potential Extreme Weather Phenomena and Their Recurrence Intervals

The work in this study is intended to be combined into Study 8.3.1.12.1.1. See Section 2.2.8.1 of this Progress Report.

2.2.9 Offsite Installations and Operations (SCP Section 8.3.1.13)

The radiological environmental monitoring program will provide the background radiological information needed to respond to the objectives of the various SCP 8.3.1.13 activities. Sampling under a qualified quality assurance program began in 1990. Summary program activities are being reported annually in the Site Environmental Report by calendar year for the Project. Sample collection and analysis continued for air particulate radionuclide concentrations, ambient gamma radiation, ambient radon concentrations, and radionuclide concentrations in surface soil at a limited number of locations. Biota samples collected in FY 1993 were being prepared for analysis. Data validation and reduction was in process.

Forecast: Sample collection and analysis will continue through FY 1994 with the exception of biota. No biota samples will be collected for analysis in FY 1994. Site Environmental Report for calendar year 1993 will be available in June 1994.

2.2.10 Surface Characteristics (SCP Section 8.3.1.14)

The transition plan discussed in Progress Report #9 was implemented and successfully completed.

2.2.10.1 Study 8.3.1.14.2.1 - Exploration Program

Activity 8.3.1.14.2.1.1 - Site reconnaissance. The purpose of this activity, which began in October 1991 and was essentially completed in March 1992, was to identify the locations for a series of soil test pits.

Activity 8.3.1.14.2.1.2 - Preliminary and detailed exploration. Criteria for the Exile Hill investigations were developed and submitted for inclusion in Job Package 94-02, "Trenching on the West Side of Exile Hill." The expanded investigation of the nonlithified zone of the Rainier Mesa Member of the Timber Mountain Tuff on the west side of Exile Hill included:

- High-resolution seismic surveys
- A trench to expose and perform in situ testing of the nonlithified material
- Two boreholes to be drilled with a hollow-stem auger system with soil-sampling capability
- Laboratory material properties tests on soil samples.

High-resolution seismic surveys were completed on the west side of Exile Hill. Data from these surveys were being analyzed. Trench NRT-1 was excavated to a depth of 10 m and the geologic units of interest were exposed. The final version of the Exile Hill cross section was released; a preliminary version of the full North Ramp cross section was completed; and the location for USW SD-7 was identified.

Forecast: Additional borehole locations will be identified for the South Ramp, as well as the appropriate soils tests and locations for sampling and in situ testing to support Exploratory Studies Facility design.

A two-dimensional section for the South Ramp and the main drift will be developed.

A report that documents the activities and results of testing associated with the NRG drillholes will be completed and submitted for review.

2.2.10.2 Study 8.3.1.14.2.2 - Laboratory Tests and Material Property Measurements

Mechanical properties tests were completed on core samples from the North Ramp boreholes (except USW NRG-7/7A). Laboratory tests on the soil samples from UE-25 NRG-2A were completed. Thermal properties testing was initiated on core samples from Boreholes UE-25 NRG-5 and USW NRG-6 (see Section 2.2.11.1).

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Forecast: Laboratory mechanical and thermal properties tests will be completed for core samples from Drillholes USW SD-7, 9, 12, and USW NRG-7/7A. Soil properties tests will be completed for samples from Trench NRT-1 and Boreholes UE-25 NRG-2C and 2D.

2.2.10.3 Study 8.3.1.14.2.3 - Field Tests and Characterization Measurements

Preliminary results from the tests conducted in Trench NRT-1 were presented in a January 1994 meeting with design personnel. The geologic units of interest were exposed and in situ mechanical properties tests were conducted. Some additional tests were requested to support more detailed modeling of the behavior of the nonlithified materials; these tests are in progress.

Geologic and Rock Structural Logs for USW NRG-7/7A and UE-25 NRG-2B were completed and transmitted for technical review.

Rock structural data summaries, Schmidt Hammer rebound hardness logs, and Rock Mass Quality summary logs were issued for the NRG boreholes.

Forecast: Structural and geologic logs will be completed for USW SD-7, 9, and 12. A structural log will be completed for USW UZ-14 and a geologic log will be completed for UE-25 NRG-2C and 2D.

2.2.11 Thermal and Mechanical Rock Properties (SCP Section 8.3.1.15)

2.2.11.1 Study 8.3.1.15.1.1 - Laboratory Thermal Properties

The study plan for this study addresses Site Characterization Analysis Comment 55.

Activity 8.3.1.15.1.1.1 - Density and porosity characterization. Data transmittals for average grain densities, dry bulk densities, and matrix porosities were completed and will support interpretation of thermal and mechanical properties data being collected under SCP Activities 8.3.1.14.2.2 (Section 2.2.10), 8.3.1.15.1.1, and 8.3.1.15.1.2.

Dry bulk density and saturated bulk density measurements were obtained for thermal conductivity and thermal expansion test samples (SCP Activities 8.3.1.15.1.1.3 and 8.3.1.15.1.2). These data, along with grain densities, will be used to calculate matrix porosities and to investigate correlations between thermal properties and other rock characteristics.

Activity 8.3.1.15.1.1.2 - Volumetric heat capacity characterization. Equipment and software for a thermogravimetric analysis measuring instrument were designed. Assembly of the instrument was in process. The thermogravimetric analysis measuring instrument will be used in experiments to establish water content and develop dehydration profiles for different types of tuff samples. Dehydration profiles are needed to (1) develop testing procedures for

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determining heat capacity by adiabatic calorimetry, (2) compare calculated and measured values for heat capacity, and (3) interpret results from thermal properties testing.

Preparation of the technical procedure for measuring volumetric heat capacities using adiabatic calorimetry began. The sample container was fabricated and samples were machined for procedure development and for a study to determine baseline testing conditions. Synthetic sapphire, which was recently approved and is the only available National Institute of Standards and Testing standard for heat capacity, was ordered for developing calibration procedures.

Activity 8.3.1.15.1.1.3 - Thermal conductivity characterization. Three samples of welded devitrified tuff and three samples of nonwelded zeolitic tuff were selected to study the effects of saturation on thermal conductivity. The thermal conductivity of each sample was measured at nominal temperatures of 30°, 50°, and 70°C, at five different saturation states (fully saturated, oven dry, air dry, and two other intermediate states). Testing of the samples that were air dry, vacuum saturated, and in the two intermediate states (approximately 2/3 and 1/3 saturated) was completed. The data show that, for a given saturation state, there is little difference in thermal conductivities at the three test temperatures. However, thermal conductivity is significantly influenced by sample porosity and saturation level.

Thermal conductivity measurements were made on samples from the USW NRG-6 drillhole to support the Soil and Rock Properties Study (Section 2.2.10). Test results were used in the rock mass analyses (Section 2.3.1) and design analyses (Section 2.4) for the Exploratory Studies Facility/repository design.

Tests were completed on USW NRG-6 samples at eleven depths at or above 126.9 meters at nominal temperatures of 30°, 50°, and 70°C at three saturation states (fully saturated, air dry, and oven dry) and at nominal temperatures of 110°, 155°, 200°, 245°, and 290°C at oven dry saturation. An interim data submittal was transmitted for the acquired data. Preliminary data analysis indicates that:

- The thermal conductivity of samples of the nonwelded bedded tuff (PTn) unit is significantly less than that of samples from the Tiva Canyon and Topopah Spring members, regardless of saturation level.
- Thermal conductivity values are greater for fully saturated samples than for oven dried and air dried samples, especially for samples from the nonwelded bedded tuff (PTn) unit.
- There is no significant difference in the thermal conductivity of the air dry and oven dried samples.
- On samples containing cristobalite, the thermal conductivity decreases over the temperature range at which the alpha to beta transformation takes place; it is speculated that this decrease in thermal conductivity is due to water being released during the silica phase transformation.

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Samples taken from USW NRG-6 at 14 different depths below 126.9 m were machined and conditioned. Testing began on air dry and saturated samples at 30°, 50°, and 70°C.

Samples to support the bench-scale backfill thermal properties experiments (Section 2.4.1.5) were machined. Fourteen samples (depths of 238.4 m to 274.4 m) from UE-25 NRG-5 were machined and conditioned for testing. Machining began on samples from UE-25 NRG-4. Samples from USW NRG-7/7A were requested from the Sample Management Facility.

Analyses of 17 samples from USW NRG-6 above 126.9 m were made for mineralogical, petrologic, and chemical properties. Photographing of thin sections, hand sample (mesoscopic) descriptions, and whole rock chemical analyses were completed. Preliminary examination of whole rock chemical data from the nonwelded interval between the welded Tiva Canyon and Topopah Spring members clearly indicate secondary mineralization involving more than just simple hydration of volcanic glass. Total water is typically between 5 and 10 percent. This is considerably higher than the upper limit of about 3 percent permissible for perlitization of glass and less than typical for highly zeolitized rocks at deeper levels at Yucca Mountain. Examination of thin sections indicates that clay probably dominates the hydrated phases, but some sections appear to contain some zeolites as well. X-ray diffraction data for the 17 samples was acquired, but not yet analyzed. When analyzed, the x-ray diffraction should conclusively establish the presence or absence of zeolites and/or clay and silica polymorphs.

Forecast: Characterization will continue for samples from NRG and SD holes to support the soil and rock properties study and design of the main Exploratory Studies Facility/repository drifts. This characterization will include:

- Measurement of saturated bulk density, dry bulk density and grain density
- Calculation of matrix porosity
- Mineralogic, petrologic, petrographic, and whole rock chemical analyses.

Development of testing procedures to determine baseline testing conditions and to determine heat capacities will be completed. Measurement of heat capacities of the Topopah Spring Member of the NRG and/or SD holes will be initiated.

Studies on effects of sample saturation on thermal conductivity will be completed and results reported.

The thermal conductivity of samples from NRG holes (UE-25 NRG-4, and 5; USW NRG-6, and 7/7A) will be measured to develop Exploratory Studies Facility/repository design input. Sample testing will be limited to the Topopah Spring Member. A data report on the thermal conductivity of the samples tested will be completed.

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Testing requirements for the study on the effects of a fracture on thermal conductivity will be re-evaluated to determine if the tests can be integrated with other studies. Testing will be initiated upon completion of this evaluation.

Hand sample descriptions are being made for all depths from USW NRG-6, UE-25 NRG-2, 2A, 2B, 3, and 5 from which thermal or mechanical properties data will be acquired. Additional analyses will be conducted on selected samples. These data will be categorized so the information can be used to investigate correlations between thermal properties, mechanical properties and other rock characteristics.

If sufficient data are available, analyses of data will be initiated to:

- Examine potential correlations between thermal properties and other sample characteristics
- Begin development of geostatistical models for thermal conductivity and heat capacity
- Calculate the heat capacity of the solid components as a function of temperature using measured values of heat capacity heat, matrix porosity and reference values for the heat capacity of water and air
- Calculate the heat capacity of the solid components as a function of temperature based on bulk chemistry and mineralogy and compare with values derived from measured heat capacities
- Calculate the thermal conductivity of the solid components as a function of temperature using measured values of thermal conductivity, matrix porosity and reference values for thermal conductivity of water and air.

Thermal conductivity and heat capacity measurements being conducted to support the bench-scale backfill thermal conductivity test will be completed.

Interim data transmittals for thermal conductivity and heat capacity data will be completed. INGRES data base tables will be developed for thermal conductivity and heat capacity data. Available data will be input into the data base for direct transfer to the Project Technical Data Base.

2.2.11.2 Study 8.3.1.15.1.2 - Laboratory Thermal Expansion Testing

Activity 8.3.1.15.1.2.1 - Thermal expansion characterization. Thermal expansion measurement tests were completed on samples from USW NRG-6 (nine depths at or above 126.9 m), and interim data submittals were transmitted for the acquired data (temperature vs. displacement). The acquired data included displacements at three saturation states (fully

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saturated, air dry, and oven dry) to approximately 110°C, and displacements to approximately 300°C for oven dry samples.

Plots of the mean coefficient of thermal expansion at 25-degree intervals and the instantaneous coefficient at 5-degree intervals were generated from these data. Preliminary data analysis indicates that:

- The thermal-expansion behavior is nonlinear and may be affected by thermal cycling.
- Samples containing zeolites and/or clays have unique expansion curves with significant hysteresis.
- There is significant variability among samples, especially at temperatures above 200°C.

Representative thermal strain curves were generated from these data and were incorporated into the far-field thermal strain calculations for Exploratory Studies Facility Design Package 2C.

Pre- and post-test velocity measurements were made on six USW NRG-6 samples to examine potential micro-cracking. For those samples containing silica polymorphs, the post-test velocities were significantly (up to 20 percent) slower than the pre-test velocities, indicating an alteration in the sample due to the thermal cycling. The data generated from these tests are needed for the Exploratory Studies Facility North Ramp design calculations in order to predict thermal stresses.

Thermal expansion testing is in process for USW NRG-6 samples from 126.9 m to 329.8 m (20 different depths). Twelve samples (depths 237.8 m to 274.4 m) were machined and conditioned for testing. Samples from UE-25 NRG-4 are being machined and available samples from USW NRG-7/7A were requested.

The study to examine the effects of sample size on thermal-expansion behavior was initiated. For this study, five samples of each of four different lithologies (welded devitrified, welded vitric, nonwelded vitric, and nonwelded zeolitic) were selected for testing using nominal sample sizes of 2.54-cm diameter by 10.15-cm long and 0.64-cm diameter by 1.54-cm long.

Forecast: Studies will continue to:

- Examine potential correlations between thermal expansion, and other thermal properties and characteristics
- Conduct preliminary statistical analyses to examine the spatial variability of thermal expansion

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- Develop preliminary three dimensional model for thermal expansion
- Develop graphical interface for integrity to test locations and thermal and mechanical properties data.

Studies will also continue in determining baseline test conditions by completing the study on the effects of sample size on thermal expansion behavior and the study on the effects of sample saturation on thermal expansion behavior.

Thermal expansion measurements will continue on samples from NRG and SD holes in support of the soil and rock properties study and Exploratory Studies Facility design.

The study on the effects of sample size on thermal-expansion behavior will be completed. The study on the effects of sample saturation on thermal-expansion behavior will be initiated.

The thermal expansion of samples from NRG holes (UE-25 NRG-4, and 5; USW NRG-6, and 7/7A) will continue to be measured for Exploratory Studies Facility/ repository design and for input to performance assessment calculations. Interim data transmittals and a data report on the thermal expansion of samples will be completed.

If sufficient data are available, data analysis will be initiated to examine potential correlations between thermal expansion and other rock characteristics and to continue development of geostatistical models for thermal expansion (see Section 2.2.3.7).

INGRES data base tables will be developed for thermal expansion. Available data will be input into this data base for transfer into the Project Technical Data Base.

2.2.11.3 Study 8.3.1.15.1.3 - Laboratory Determination of Mechanical Properties of Intact Rock

Activity 8.3.1.15.1.3.1 - Compressive mechanical properties of intact rock at baseline experiment conditions. Samples were collected from core taken in the NRG drillholes for intact mechanical properties testing. During the reporting period, samples from seven holes were prepared and tested: UE-25 NRG-2A, 2B, 3, 4, and 5; USW NRG-6, and 7/7A. The tests performed were unconfined compression, confined compression, and indirect tension (Brazil).

Prior to the experiments, a series of procedures were performed to aid the characterization of the pre-test samples and the analysis of the resultant data. The samples were machined to the appropriate dimensions for the test, dried, and saturated for the determination of dry and saturated bulk densities. A computerized tomography x-ray scan and P- and S-wave velocities (both dry and saturated) were taken on each sample tested in the unconfined compression condition. An average grain density was determined from a piece of

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each core taken next to the end of a test specimen during the machining process. The bulk and grain densities were then used to calculate a porosity for each test specimen.

The results from a total of 59 unconfined compression, 24 confined compression, and 52 Brazil experiments were reported on ten Technical Data Information Forms. In addition, the average grain density was determined and reported for 101 samples.

Preliminary interpretation of the results indicated that the properties generally correlate with the thermalmechanical stratigraphic units. In addition, the P- and S-wave velocities, unconfined elastic and strength properties, and the indirect tensile strengths are all highly dependent on porosity. The trends of these relationships were similar to those determined on smaller samples of tuff several years ago. These relationships are powerful tools that will allow the evaluation of the mechanical properties over the entire stratigraphic section. This evaluation can be performed from the large base of porosity data collected from drillhole logs or from bulk property measurements. Both of the porosity techniques are low-cost, relative to measuring many additional mechanical properties directly.

Activity 8.3.1.15.1.3.2 - Effects of variable environmental conditions on mechanical properties. This study investigates time-dependent deformation through high-temperature experiments at creep and low strain rate conditions. The most recent series of experiments consisted of at least six samples of TSw2 tested at a pore pressure of 4.5 MPa, a confining pressure of 5 MPa, and a maximum constant differential stress of 80 MPa. Initially, the experiments were performed with a series of stress steps at room temperature and then at 250°C. A fourth creep experiment was initiated, and all of the results on time-dependent properties will be presented in a report late this year.

A new model, developed by combining two empirical models, allows for the prediction of ultimate strength of tuff under a standard set of conditions, when the sample size and porosity is known. This model is described in "Strength-Size-Porosity Empirical Model for Yucca Mountain Tuff" (Price, 1993), which was presented at the Fall '93 American Geophysical Union Meeting.

Description of the investigation of appropriate techniques for measuring and/or calculating bulk properties is included in the report, "Experimental Comparison of Laboratory Techniques in Determining Bulk Properties of Tuffaceous Rocks" (Boyd et al.), which was approved by DOE in February 1994.

The report, "Bulk and Mechanical Properties of the Paintbrush Tuff Recovered from Borehole USW NRG-6: Data Report" (Martin et al.), was in DOE review. This report presents mechanical properties and supporting bulk properties collected on samples from core taken in Drillhole USW NRG-6.

Discussion of all of the mechanical property data collected to date on NRG drillhole samples, as well as the supporting bulk property information and interpretation of the data, is included in a paper entitled "Mechanical and Bulk Properties in Support of Exploratory

Studies Facility Design Issues" (Price et al.). The paper was prepared for presentation at the 1994 High-Level Waste Conference.

A discussion of the relationship between elastic properties calculated from data collected in quasistatic experiments and velocity measurements on NRG drillhole samples is presented in the paper entitled "Relation Between Static and Dynamic Rock Properties in Welded and Nonwelded Tuff" (Price et al.), which was prepared for presentation at the 1st North American Rock Mechanics Symposium to be held in Austin, Texas, June 1-3, 1994.

Forecast: Experiments will continue on samples from NRG, SD, and SRG drillhole core. The data will be reduced, analyzed, and reported to support Exploratory Studies Facility design activities. Creep experiments to investigate time dependent mechanical properties will continue.

2.2.11.4 Study 8.3.1.15.1.4 - Laboratory Determination of the Mechanical Properties of Fractures

Activity 8.3.1.15.1.4.1 - Mechanical properties of fractures at baseline experiment conditions. Receipt of samples began for this testing effort. In addition, studies continued to define the baseline-condition test technique and the approach for future characterization of fracture topography.

Rotary friction (axial compression-torsion) and direct shear have been chosen as the test techniques for gathering the majority of the data on the mechanical properties of fractures. In the rotary friction procedure, thin-walled cylinders with a fracture oriented perpendicular to the cylinder axis are tested. Normal and shear forces are independently applied to the fracture surface in the desired order and proportions to create the desired load path. A Standard Test Method for the rotary shear technique was drafted and submitted to the American Society for Testing and Materials Committee D-18 on Soil and Rock Properties.

Detailed characterization and analysis of fracture surfaces will aid in the interpretation of mechanical properties (e.g., stiffness and shear strength) and transport properties. To accomplish this, a laser profilometer was designed, built, tested, and used to characterize the topography of all samples used in this study. The data from the fracture topographies were analyzed to quantify the roughness of each surface, the scaling properties, and the degree of mismatch between the two opposing surfaces. The ultimate goal is to use the surface characterizations as a predictor of the mechanical properties.

A paper entitled "Simple Mathematical Model of a Rough Fracture Using the Concepts of Fractal Geometry" (Brown, 1993) presents a model which predicts normal-closure fracture behavior when the fracture roughness is known. The paper was presented at the Geological Society of America Annual Meeting.

Activity 8.3.1.15.1.4.2 - Effects of variable environmental conditions on mechanical properties of fractures. Natural fracture samples were collected from core taken from

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Drillhole USW NRG-6 for mechanical properties testing. The samples have been tested room dry, at ambient temperature, and at a normal stress of 5 MPa. The results were analyzed and reported on Technical Data Information Forms for design use. A preliminary evaluation of the results have shown very little difference between the peak and residual shear strength. The nature of the normal compression and shear stress experiment curves are very similar to previous data gathered on natural, replicated, and artificial fractures in tuff.

Work continued on the development of a computer program to model the dilation, normal stiffness, and shear stiffness of single fractures in rock. An early version of the code is being used to study the changes in the aperture of a fracture under normal stress.

Several studies produced data relating to the time-dependent mechanical properties of fractures and to the effect of roughness on the mechanical properties. The studies included experiments on artificial (i.e., relatively smooth) fractures in rate-stepping tests and a creep experiment in triaxial compression. The data were being analyzed and future reports were being considered.

Preliminary results of creep experiments conducted to analyze the time-dependent behavior of fractures are included in the paper, "Joint Creep in Yucca Mountain Tuff" (Olsson, 1993). This study was the first attempt to analyze the time-dependent behavior of fractures. The initial experiments have shown no creep strain at stresses up to 95 percent of the sliding stress. The results of several normal compression and rotary shear experiments, which were part of an investigation of the effect of normal stress, rock strength and roughness on mechanical properties, were published in "Effect of Roughness and Material Strength on the Mechanical Properties of Fracture Replicas" (Wibowo et al., 1993a). The study indicated that fracture shear strength is strongly dependent on normal stress and roughness, but only weakly dependent on rock strength. Both papers were presented and published at the Fall '93 American Geophysical Union Meeting.

The effect of changing the rate a fractured sample is sheared in determining time-dependent mechanical behavior of fractures is presented in a report entitled "The Effect of Sliding Velocity on the Mechanical Response of an Artificial Joint in Topopah Spring Member Tuff" (Olsson, 1994). One result of this investigation was the determination that the friction is higher for wet joints than for dry ones.

The results from a study of mechanical properties of replicas of natural fractures from Yucca Mountain were presented in a report entitled "Effect of Boundary Conditions on the Strength and Deformability of Replicas of Natural Fractures in Welded Tuff: Data Analysis" (Wibowo et al.), which was in DOE review. Presented in the report are constitutive models that are variations of those presented in the open literature for shear strength, dilatancy, and surface damage.

Forecast: Experiments will continue on samples from NRG and SRG drillhole core. Data will be reduced, analyzed, and reported to support Exploratory Studies Facility design activities.

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2.2.11.5 Study 8.3.1.15.1.5 - Excavation Investigations

The excavation investigations experiments are designed to provide data for assessing the validity of the rock mass constitutive models that will be used in the repository design process and that will support the License Application, and to demonstrate constructibility and long-term stability of full-scale underground openings. The first of three excavation investigations experiments, the access convergence experiment, will occur at locations along the North Ramp shortly after the locations are excavated by the tunnel boring machine.

Activity 8.3.1.15.1.5.1 - Access convergence experiment. In the access convergence measurement experiment, two types of measurements are proposed: stress changes and displacements resulting from excavation, and the displacement of the tunnel wall resulting from the application of the gripper pads of the tunnel boring machine. The load-displacement curves generated from this second type of measurement will be used to determine the rock-mass deformation modulus and the rock-mass compliance, and will be made available for use in the repository design. Planning for the experiment began with meetings held among testing, design, and tunnel boring machine personnel. The purpose of these meetings was for testing personnel to obtain details of the North Ramp design and tunnel boring machine operation in order to perform detailed experiment design, and to learn what data are needed by the design team to verify their design methodology for Exploratory Studies Facility construction.

Activities 8.3.1.15.1.5.2 and 8.3.1.15.1.5.3. No progress during the reporting period; these are out-year activities.

Forecast: Detailed experimental plans will be completed for the access convergence test in the North Ramp. These plans will form the basis for the Test Planning Package. Fielding of the access convergence experiment will begin in FY 1994 when the tunnel boring machine begins excavation.

2.2.11.6 Study 8.3.1.15.1.6 - In Situ Thermomechanical Properties

Development of the draft study plan continued. The experiments in the study plan are designed to obtain the experimental data needed to develop and validate computational tools that will be used to predict the response of underground openings at Yucca Mountain to the elevated temperatures and stresses expected in a high-level nuclear waste repository.

Analyses were conducted to determine the boundaries of the thermal zones around the experiments to avoid test interference between experiments, and to facilitate the planning of the in situ thermomechanical experiments.

Activities 8.3.1.15.1.6.1 through 8.3.1.15.1.6.5. No progress during the reporting period; these were out-year activities.

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Forecast: The draft study plan will be completed. Results of the analyses mentioned above will be presented in a report.

2.2.11.7 Study 8.3.1.15.1.7 - In Situ Mechanical Properties

A rough draft of the study plan has been completed.

Activities 8.3.1.15.1.7.1 and 8.3.1.15.1.7.2. No progress during the reporting period; these were unfunded activities.

Forecast: No activity is planned for FY 1994.

2.2.11.8 Study 8.3.1.15.1.8 - In Situ Design Verification

Geotechnical activities were conducted in the North Ramp Starter Tunnel to confirm adequacy of design, construction, and long-term performance for the purpose of performance confirmation. To support these activities, a data acquisition system was designed and installed.

Detailed test plans were completed for the study activities to be conducted in the North Ramp. Several meetings were held with testing, design, and tunnel boring machine personnel. The purpose of these meetings was to obtain details of the North Ramp design and tunnel boring machine operation, to perform detailed experiment design and to learn what data are needed by the design team to validate the Exploratory Studies Facility design methodology.

Activity 8.3.1.15.1.8.1 - Evaluation of mining methods. Seismic monitoring of blasting in the Starter Tunnel alcove was conducted. The data obtained, combined with the seismic data obtained during the construction of the rest of the Starter Tunnel, will be used to construct a site-specific curve of peak particle velocity vs. blast charge for design use. Because peak particle velocity has been correlated with extent of blast damage in other studies, these data also will be available for use in blast damage assessments.

Rock mass classification results for the North Ramp Starter Tunnel alcove were received by YMSCO. The data were collected as the alcove was being excavated, and will be used for validating the design input.

Activity 8.3.1.15.1.8.2 - Monitoring of ground-support systems. Load cells installed on 15 of the rock bolts that form part of the permanent support of the Starter Tunnel were monitored. The cells were installed in groups of three each at five different tunnel cross sections. Six additional rock bolt load cells were installed in two cross sections in the Starter Tunnel alcove, and monitoring of these bolts was started. The load histories measured by the cells will be used to validate the design of the ground support, and enhance the safety of the tunnel. Data records of the load carried by each of the instrumented rock bolts vs. time were provided biweekly to the Field Construction Manager.

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Activity 8.3.1.15.1.8.3 - Monitoring drift stability. Closure pins were installed at the locations in the Starter Tunnel and tunnel alcove where the rock bolt load cells were installed. At each of the tunnel cross sections, five pins were installed around the perimeter of the tunnel. At each of the alcove cross sections, four pins were installed. Convergence measurements were made at each of these locations. At the two deepest convergence stations in the Starter Tunnel, multipoint extensometers were installed to monitor the rock mass movement. Three additional multipoint extensometers were installed in the alcove. The displacement measurements being made will be used to validate the design methodology used to construct the tunnel and to enhance tunnel safety.

Activity 8.3.1.15.1.8.4 - Air quality and ventilation experiment. Meetings were held among responsible organizations to identify information needs and to begin developing plans to collect air quality and ventilation parameters.

Forecast: Regular readings will be taken from the rock bolt load cells, cross-drift convergence pins, and multipoint extensometers, and the results summarized in a report that will be transmitted to the Field Construction Manager.

2.2.11.9 Study 8.3.1.15.2.1 - Characterization of the Site Ambient Stress Conditions

Activity 8.3.1.15.2.1.1 - Anelastic strain recovery experiments in core holes. No progress during the reporting period; this was an out-year activity.

Forecast: No activity is planned for FY 1994.

Activity 8.3.1.15.2.1.2 - Overcore stress experiments in the Exploratory Studies Facility. No progress during the reporting period; this was an out-year activity.

Forecast: No activity is planned for FY 1994.

2.2.11.10 Study 8.3.1.15.2.2 - Characterization of the Site Ambient Thermal Conditions

The study plan was prepared and reviewed. Much of the basic data to be analyzed in this study is being collected in Study 8.3.1.8.5.2 (see Section 2.2.6.9).

Forecast: No other activity is planned for FY 1994.

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2.2.12 Preclosure Hydrology (SCP Section 8.3.1.16)

2.2.12.1 Study 8.3.1.16.1.1 - Characterization of Flood Potential of the Yucca Mountain Site

Activity 8.3.1.16.1.1.1 - Site flood and debris hazards studies. No progress during the reporting period; this was an unfunded activity.

Forecast: No activity is planned for FY 1994.

2.2.12.2 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

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

Forecast: No activity is planned for FY 1994.

2.2.12.3 Study 8.3.1.16.3.1 - Determination of the Preclosure Hydrologic Conditions of the Unsaturated Zone at Yucca Mountain, Nevada

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

Forecast: No activity is planned for FY 1994.

2.2.13 Preclosure Tectonics (SCP Section 8.3.1.17)

Key activities within the Preclosure Tectonics program during the reporting period included development of the topical report, "Methodology to Assess Fault Displacement and Vibratory Ground Motion Hazard at Yucca Mountain" (CRWMS M&O) and a Tectonics Workshop to integrate the preliminary results of the tectonics investigations. The topical report was prepared to provide an updated, state-of-the-practice methodology to assess seismic hazards at Yucca Mountain. It represents a change from the approach discussed in the Site Characterization Plan in that the concept of a 10,000-year cumulative slip earthquake will no longer be employed. Also, while the Site Characterization Plan described both deterministic and probabilistic approaches, the current methodology relies solely on a probabilistic approach that incorporates the frequency with which earthquakes occur and uncertainties in input values to provide the annual probability that various levels of ground motion or fault displacement will be exceeded. The topical report is discussed further in Section 2.1.2.

On January 24-26, 1994, a Tectonics Workshop was held in Estes Park, Colorado to facilitate the integration of preliminary results from the tectonics program. The status of each

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study was presented so that all investigators would have a common understanding of each others preliminary findings.

2.2.13.1 Study 8.3.1.17.1.1 - Potential for Ash Fall at the Site

Activities 8.3.1.17.1.1.1 through 8.3.1.17.1.1.3. No progress during the reporting period; these were unfunded activities.

Forecast: No activity is planned for FY 1994.

2.2.13.2 Study 8.3.1.17.2.1 - Faulting Potential at the Repository

Activities 8.3.1.17.2.1.1 and 8.3.1.17.2.1.2. No progress during the reporting period; these were unfunded activities.

Forecast: A study plan will be developed to describe how faulting potential at the repository will be probabilistically assessed. This study plan may be developed independently or incorporated into the study plan on probabilistic seismic hazard assessment (see Section 2.2.13.8).

2.2.13.3 Study 8.3.1.17.3.1 - Relevant Earthquake Sources

The study plan was revised to address comments by NRC and the State of Nevada concerning the seismic hazard methodology proposed in the Site Characterization Plan. The principal revision involves a change from using the concept of the 10,000-year cumulative slip earthquake as a basis for characterizing the magnitudes of relevant earthquake sources (as presented in Study Plan 8.3.1.17.3.1, Revision 0) to a methodology that relies on a variety of geologic, seismologic, and geophysical data in efforts to characterize the locations, geometries, maximum magnitudes, and recurrence rates of relevant earthquake sources.

Activity 8.3.1.17.3.1.1 - Identify relevant earthquake sources. A preliminary compilation of potentially relevant seismic sources was evaluated with respect to a criterion specified in the NRC NUREG-1451 (NRC, 1992) for Type I faults that may be important in the consideration of vibratory ground motion for design. Faults subject to earthquakes that can produce 0.1 g within the controlled area may be important according to this criterion. Maximum magnitudes based on an evaluation of rupture parameters for potentially relevant faults were used in combination with available attenuation relations to determine which faults might produce a ground acceleration of 0.1 g within the controlled area. The effect of attenuation uncertainty was also investigated by examining the calculated ground motions at one standard deviation. This work was presented at the Committee for the Advancement of Science at Yucca Mountain Symposium in Denver, Colorado, December 1993, the American Geophysical Union Annual Meeting in San Francisco, California, December 1993, the Yucca Mountain Tectonics Workshop in Estes Park, Colorado, January 1994, the Project Technical

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Program Review in Las Vegas, Nevada, February 1994, and the NWTRB Structural Geology and Geoengineering Panel in San Francisco, California, March 1994. Work is currently focusing on the effect of different attenuation relations, including those developed specifically for normal-faulting earthquakes.

Activity 8.3.1.17.3.1.2 - Characterize 10,000-year cumulative slip earthquakes for relevant seismogenic sources. Design and performance parameters were studied to arrive at specifications for ground motions that will result from a "controlling" earthquake; preliminary conclusions were presented at the Committee for the Advancement of Science at Yucca Mountain Symposium, American Geophysical Union Annual Meeting, and the Project Technical Program Review. Scoping studies to develop a suitable technical basis for estimating earthquake magnitude were continued. The Yucca Mountain Tectonics Workshop was held to gather new information on tectonic models of Yucca Mountain and fault lengths, geometries, and downdip extents that control maximum earthquake magnitudes. Methods were formulated to establish magnitudes, once the tectonic models are determined. Portions of the topical report, "Methodology to Assess Fault Displacement and Vibratory Ground Motion Hazards of Yucca Mountain," (CRWMS M&O) were revised to incorporate and resolve comments from reviewers.

Forecast: New and existing data on the activity, magnitudes, and recurrence intervals of known or suspected seismic sources will be synthesized. The next update (Version IV) of the preliminary table of Quaternary fault and seismic-source parameters will be completed in July 1994. Potential earthquake sources associated with volcanoes; locating hidden seismogenic structures; characterizing the magnitudes and recurrence parameters for these sources; and estimating impacts of alternative tectonic models on uncertainties in the seismic-source parameters will be addressed.

Methods to estimate maximum magnitudes will continue to be developed, emphasizing updated paleoseismic information and alternative models of fault segmentation and fault geometries. Potential earthquake magnitudes will be refined and the uncertainties will be described.

2.2.13.4 Study 8.3.1.17.3.2 - Underground Nuclear Explosion Sources

Activities 8.3.1.17.3.2.1 and 8.3.1.17.3.2.2. No progress during the reporting period; these were out-year activities.

Forecast: No activity is planned for FY 1994. At the present time there are no plans for developing a study plan for this study. Available information is adequate for characterizing underground nuclear explosion seismic sources.

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2.2.13.5 Study 8.3.1.17.3.3 - Ground Motion From Regional Earthquakes and Underground Nuclear Explosions

Ground motion studies are divided into two activities: one addressing ground motion from earthquakes (Activity 8.3.1.17.3.3.1), the other from underground nuclear explosions (Activity 8.3.1.17.3.3.2). Ground motion evaluations for the probabilistic seismic hazard assessment will be developed within Activity 8.3.1.17.3.3.1, taking into account results from Activity 8.3.1.17.3.3.2.

Activity 8.3.1.17.3.3.1 - Select or develop empirical models for earthquake ground motions. A study plan was written to describe the methodology for empirically determining earthquake ground motion. A theoretical evaluation was begun of probabilistic vs. deterministic ground motion assessments to support future development of a methodology to determine seismic design inputs from the results of the probabilistic seismic hazard assessment.

Activity 8.3.1.17.3.3.2 - Select or develop empirical models for ground motion from underground nuclear explosions. A study plan was prepared and was in DOE review. A summary of analyses of ground motion from underground nuclear explosions entitled "Underground Nuclear Explosion Ground Motions Recorded at Yucca Mountain" (Walck) was prepared for presentation at the Seismological Society of America Meeting, to be held in Pasadena, California, April 5-7, 1994. These analyses evaluate ground motion at Yucca Mountain from explosions at Pahute Mesa and Yucca Flat, and also the geology-based transfer functions for the uppermost 350 m of Yucca Mountain using data from three pairs of surface and downhole instruments.

Forecast: For ground motion from earthquakes, study plan review comments will be addressed and the study plan will be finalized by the end of FY 1994. Planning will begin for a ground motion conference to address ground motion issues relevant to seismic hazard assessment at Yucca Mountain. Preliminary ground motion models for Yucca Mountain will be developed.

For ground motion from underground nuclear explosions, development of empirical ground motion models based on data collected in the 1980s will be completed.

2.2.13.6 Study 8.3.1.17.3.4 - Effects of Local Site Geology on Surface and Subsurface Motions

Activity 8.3.1.17.3.4.1 - Determine site effects from ground-motion recordings. Analyses of results of Field Experiment #1, using both direct S waves and coda waves, were completed. Data from Midway Valley, obtained during October and November 1993, were analyzed. The results of each analysis agreed well for estimating site amplification. In order to characterize the substrate at Yucca Mountain, geological information from 12 sites, including Midway Valley, and geophysical information from Midway Valley were collected. A study of site responses from the Little Skull Mountain earthquakes at 12 stations was

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completed, and the results of the study presented at the American Geophysical Union Annual Meeting.

Forecast: The University of Nevada, Reno Seismic Laboratory will compile a bibliography containing available reports on velocity structure and other data relevant to site effects. It will define the standard ground-motion model, which depends on the composite source model itself, based on regional velocity structure. Site effects will be calculated by multiplying the spectrum by the "site effect spectrum" which has been determined. To determine how well this standard model works, synthetics for stations that recorded Little Skull Mountain aftershocks will be computed and compared with observations in time and frequency domain. The level of agreement will define the uncertainty in the computations. To analyze site effects from the Midway Valley experiment, the Seismic Laboratory will determine the spectral ratios compared to reference sites for all other sites in the experiment, and will check on the stability of sites in several parts of Midway Valley. The final report on site effects will be completed.

2.2.13.7 Study 8.3.1.17.3.5 - Ground Motion at the Site From Controlling Seismic Events

Activity 8.3.1.17.3.5.1 - Identify controlling seismic hazard. No progress during the reporting period; this was an out-year activity.

Forecast: This activity was not funded in FY 1994; it is planned to start in FY 1995.

2.2.13.8 Study 8.3.1.17.3.6 - Probabilistic Seismic Hazards Analyses

Activities 8.3.1.17.3.6.1 through 8.3.1.17.3.6.2. No progress during the reporting period; these were unfunded during the first half of FY 1994.

Forecast: Preparation of the study plan will begin.

2.2.13.9 Study 8.3.1.17.4.1 - Historical and Current Seismicity

A revision of Study Plan 8.3.1.17.4.1 was in YMSCO review. The revision was prompted by a change in the configuration and number of stations comprising the Southern Great Basin Seismic Network and by modifications of some of the methods being applied in the study.

Activity 8.3.1.17.4.1.1 - Compile historical earthquake record. Field testing of the forces required to topple precariously balanced rocks continued. A field test was conducted using both physical modeling and computer modeling techniques to analyze one particular precariously balanced rock at Yucca Mountain. Precarious rocks in Fortymile Wash, Nevada; Victorville, California; Pinnacles National Monument, California; and Pyramid Lake, Nevada

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were surveyed and photographed. To continue compiling historical earthquake records, additional records at California Institute of Technology, including those made during the 1948 earthquakes near Yucca Mountain, were copied and photographed. Work began to collate previous catalogs of events in the southern Great Basin and to refine parameters for these events.

Activity 8.3.1.17.4.1.2 - Monitor current seismicity. The University of Nevada, Reno Seismic Laboratory completed the catalog of seismic events for January-September 1993. Work continued to analyze the backlog of 1993 events accumulated from the Eureka Valley, California sequence in May 1993.

Seismic data were continuously recorded using the California Institute of Technology-USGS Seismic Processing (CUSP) software. Several new procedures or pieces of equipment were installed. These included: a real-time process to produce automated event magnitudes and location, two strong-motion portable sites near Yucca Mountain, hot-switchover radios for the Angel Peak to Sober Peak sites, hardware needed to replace developocorders by on-line continuous recording using CUSP software, and new disks to handle data more efficiently. Calibration of the discriminators and analog to digital convertor was completed.

All data sources for first motions and first arrivals for June-December 1992, were merged and all Little Skull Mountain earthquakes relocated using the "master event" technique. About 700 focal mechanisms were determined using the merged data set. Analysis of the Little Skull Mountain earthquake sequence was completed in January 1994. Data from the Rock Valley fault earthquakes were analyzed. Papers based on studies of both these earthquakes were presented at American Geophysical Union Annual Meeting; the published abstracts are entitled "A Sequence of Very Shallow Earthquakes in the Rock Valley Fault Zone, Southern Nevada Test Site" (Smith and Brune, 1993) and "Site Response in the Yucca Mountain area Determined from Aftershocks of the Little Skull Mountain Earthquake" (Su et al., 1993). The nonproliferation experiment/Ryan shots were also analyzed for information on geologic structures under the Yucca Mountain region.

Activity 8.3.1.17.4.1.3 - Evaluate potential for induced seismicity at the site. No progress during the reporting period; this was an out-year study.

Forecast: The University of Nevada, Reno Seismic Laboratory will complete the historical earthquake study by compiling a definitive event catalog for the southern Great Basin, by characterizing the largest events within 100-200 km of Yucca Mountain, and by producing earthquake statistics useful for seismic hazard assessment. A report analyzing the overall seismic record of the southern Great Basin using precarious rock data (pre-1852), the information on historical events (pre-1978) and the modern instrumental catalog (post-1978), will be prepared.

The Seismic Laboratory will complete the 1993 catalog of events in the southern Great Basin and analyze the events of that year for significance. Selection of 1994 events will be kept current, barring another major earthquake in the region. Several improvements to the on-line system will be implemented, including an improved near-real-time event location

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method, a digital backup system to replace the old develocorders, and an uninterruptible power supply.

The Seismic Laboratory will proceed with the upgrade to a digital seismic network. Siting, and perhaps installation, for as many as 18 new sites will be completed. Two additional telemetry-gathering nodes will be installed. The computing hardware necessary to process the digital network will be installed, and recording of the continuous data will be implemented. Recording and processing of triggered events will also be implemented.

Analysis reports of the nonproliferation experiment/Ryan refraction experiments and on the Rock Valley earthquakes will be prepared.

2.2.13.10 Study 8.3.1.17.4.2 - Location and Recency of Faulting Near the Prospective Surface Facilities

Activity 8.3.1.17.4.2.1 - Identify appropriate trench locations in Midway Valley. This activity is complete. The final map and report on the surficial geology of Midway Valley entitled "Surficial Geologic Map of the Midway Valley Area" (Wesling et al.) was being prepared for open-file publication.

Activity 8.3.1.17.4.2.2 - Conduct exploratory trenching in Midway Valley. Analysis of data from Trenches MWV-T5, T6, and T7 occupied much of the first half of FY 1994. Linework on the Exploratory Studies Facility trench logs was prepared describing deposits and soils exposed in the trench, and parts of the manuscript and appendices were completed. Completed appendices are those that contain drafted trench logs, compiled numerical ages, soil profile descriptions, and a revised report on Trench MWV-T3. The report on these trenches will be included in the Draft Summary Report on Midway Valley.

Six samples of pedogenic carbonate and rhyzoliths were collected from trench MWV-T4, for uranium-series analyses to provide additional age control on paleoseismic events identified in the trench. On a field trip in November 1993, trenches across the Solitario Canyon, Stagecoach Road, and Bare Mountain faults were examined, and the adequacy of numerical age control for determining the timing and recurrence of paleoseismic events was discussed.

Forecast: Completion of the final report on the geology of Midway Valley will occur during FY 1994, but at this time no further work is scheduled.

2.2.13.11 Study 8.3.1.17.4.3 Quaternary Faulting Within 100 km of Yucca Mountain, Including the Walker Lane

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

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Activity 8.3.1.17.4.3.2 - Evaluate Quaternary faults within 100 km of Yucca Mountain.

Faults that have known or suspected Quaternary activity, and that are within about 100 km of the potential repository site, have been compiled from the available geologic literature. These data were included in a proposed open-file report, "Compilation of Known and Suspected Quaternary Faults Within 100 km of Yucca Mountain" (Piety), and will be used in Study 8.3.1.17.3.1, "Relevant Earthquake Sources," to assist in determining the likely locations, timing, and magnitudes of future faulting and seismic events that could affect repository design or performance. The data will also be utilized in Study 8.3.1.17.4.12, "Tectonic Models and Synthesis." The faults are shown on a topographic base map at a scale of 1:250,000, and the data set was based on both regional and local studies that identify and evaluate faults, lineaments, scarps, and other tectonic landforms of possible Quaternary age. Data on each fault that was considered pertinent to the assessment of future faulting and seismic events were compiled on description sheets and summarized on tables.

Data on faults and lineaments resulting from interpretation of air photos and field reconnaissance in the southern Amargosa Desert and Death Valley areas are given in an interim report, entitled "Preliminary Evaluation of Known and Suspected Quaternary Faults South and West of Yucca Mountain in the Death Valley and Southern Amargosa Desert" (Piety et al.). The findings were also presented at the Yucca Mountain Tectonics Workshop.

Origin of the Beatty scarp, whether by faulting or other processes, is of considerable interest to site characterization. Early interpretations favored a tectonic origin, but more recent interpretations based on geophysical studies, observations in trenches, scarp morphology, longitudinal profiles of the Amargosa River and its relationship to the elevation of the scarp, and the basic surficial geologic relations are all supportive of a nontectonic origin. Hence, the feature is not considered to be a likely source for future seismic activity. The evidence for this interpretation is the subject of a paper being prepared for an open-file report, "Fluvial Origin of the Beatty Scarp" (Anderson), and was also presented at the Yucca Mountain Tectonics Workshop.

A detailed evaluation of the Death Valley-Furnace Creek fault system is under way. Available data have been reviewed and reconnaissance field studies conducted. Preliminary conclusions about slip rates and recurrence intervals of large earthquakes on this fault system have been made. Investigators were in the field in mid-February and in early-March to select sites where additional information on slip rate and age of most recent faulting may be obtained.

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

Activity 8.3.1.17.4.3.4 - Evaluate the Bare Mountain Fault Zone. A preliminary analysis of Trenches BMT-1 (excavated September 1993) and BMT-2 (re-excavated July 1993) was completed in November 1993 and preliminary trench logs were completed in January 1994; excavation of additional trenches across the Bare Mountain fault await required permits. Preliminary interpretations regarding the age and activity of this fault zone were

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presented at the Yucca Mountain Tectonics Workshop. As part of the effort to evaluate the Quaternary activity of the Bare Mountain fault, topographic profiles of four major alluvial fans along the flanks of Bare Mountain were measured. Those fans, located on the east side of the mountain and which cross the Bare Mountain fault, exhibit flatter concave-upward shapes and considerably lower gradients than do the fans on the west side. The latter do not cross a fault, and their shape and steeper gradient are attributed to the development of a fluvial scarp caused by latest Pleistocene incision by the Amargosa River. Based on a comparison of fan profiles, the late Quaternary slip rate of the Bare Mountain fault appears to be very low and the age of the most recent movement is estimated to be ≥ 100 ka. These findings are published in an abstract, "Topographic Profiles and Their Implications for Late Quaternary Activity on the Bare Mountain Fault, Nye County, Nevada" (Klinger and Anderson, 1994) in the 1994 Abstracts with Programs, Geological Society of America Cordilleran Meeting.

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

Activity 8.3.1.17.4.3.6 - Analyze rotation (drag) of bedrock along or over suspected wrench faults based on rotation of paleomagnetic declinations. No progress during the reporting period; this was an out-year activity.

Forecast: A review draft of a report outlining the results of the seismotectonic evaluation of the Death Valley-Furnace Creek fault zone will be completed by September 1994. Assuming that permits are obtained and the required trenches are excavated this spring, a review draft of a report on the age and activity of the Bare Mountain fault zone will be prepared by September 1994.

2.2.13.12 Study 8.3.1.17.4.4 - Quaternary Faulting Proximal to the Site Within Northeast-Trending Fault Zones

Activity 8.3.1.17.4.4.1 - Evaluate the Rock Valley fault system. Air photos at a scale of 1:24,000 were analyzed and preliminary choices of fault traces that were candidates for trenches were made; two of the traces were identified and staked in the field in November 1993. In December the field area was visited by DOE personnel to evaluate trenching logistics, including access, site needs, and means of excavation. The evaluation is presented in a letter report entitled "Proposal to Excavate Trenches in the Rock Valley Fault Zone, NTS" (O'Leary, 1993).

Activity 8.3.1.17.4.4.2 - Evaluate the Mine Mountain fault system. Air photos and remote sensor images of the Mine Mountain fault zone were reviewed in preparation for spring and summer field surveys.

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Activity 8.3.1.17.4.4.3 - Evaluate the Stagecoach Road fault zone. The Stagecoach Road fault evaluation has been transferred to Study Plan 8.3.1.17.4.6, "Quaternary Faulting in the Site Area." (See Section 2.2.13.14)

Activity 8.3.1.17.4.4.4 - Evaluate the Cane Spring fault system. No progress during the reporting period; this was an out-year activity.

Forecast: Field work in April-June 1994 will evaluate the Mine Mountain fault and determine its maximum southwestern extent. It is anticipated that sufficient data will be acquired and analyses completed for preparation of a report on the structural history of the Mine Mountain fault zone. Logging of trenches in Rock Valley is expected to begin in July 1994. The scheduled excavation of the planned trenches has been delayed owing to procedural difficulties because the trench site is located outside Area 25. Any remaining time in FY 1994 available for field work will be dedicated to evaluating the easternmost and westernmost extent of the Rock Valley fault zone; the structural terminations of the zone are imperfectly known and should be determined for an adequate tectonic analysis.

2.2.13.13 Study 8.3.1.17.4.5 - Detachment Faults at or Proximal to Yucca Mountain

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. Geologic mapping and detailed studies of the hydrothermally altered tuffs and of associated breccias and conglomeratic deposits were being conducted in efforts to determine the true relationships of the contact between the Paleozoic rocks and the overlying Miocene volcanic sequence. The results will be reported in a forthcoming USGS Circular Paper, "The Miocene/Paleozoic Contact at the Calico Hills" (Simonds), in which the conclusion is drawn that the Paleozoic rocks are not structurally detached from the overlying Miocene rocks, thus eliminating the possibility that a detachment fault at that horizon constitutes a source of seismicity for consideration in repository design. A second report, "Geology and Hydrothermal Alteration at the Calico Hills, Nye County, Nevada" (Simonds), was also being prepared, and includes a 1:12,000 geologic map. Fault data collected during the mapping were digitized, and fossils to determine the age of the Paleozoic strata were identified. This map and report contain the data that are needed to assess the possibility of a detachment fault east of Yucca Mountain.

Activity 8.3.1.17.4.5.2 - Evaluate postulated detachment faults in the Beatty-Bare Mountain area. Detachment faulting has been identified, or is postulated to occur, in the Beatty-Bare Mountain area, which lies west and northwest of Yucca Mountain. In addition to geologic mapping and related field studies to determine Paleozoic/Precambrian and Paleozoic/Miocene contact relationships, study was also done to ascertain the age of uplift of core complexes that may have been closely related in time and space to suspected detachment faulting. The acquisition of microprobe data from metamorphic minerals from the core complex rocks continued, and the data were used to constrain mineral geobarometry and thermometry to determine when the last high-pressure, high-temperature event occurred that may have affected the particular sample being analyzed. This determination may, in turn, help to determine the age and original geometry of the proposed detachment fault in the Bare

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Mountain area. The results of parts of this work were presented as "Structural Domain Boundaries and Time/Space Variations in Extension in the Yucca Mountain Region 14 Ma to Present" (Fridrich) at the Yucca Mountain Tectonics Workshop.

Activity 8.3.1.17.4.5.3 - Evaluate potential relationship of breccia within and south of Crater Flat to detachment faulting. Breccia deposits in south, central, and northern Crater Flat, and core from Drillhole USW VH-2 were examined and sections containing breccias were described. Information on the distribution and relative ages of megabreccia deposits was compiled, and the literature researched for reports of large-scale landslides and rock-avalanche breccias. Maps were prepared showing the locations of breccias and a log of core from Drillhole USW VH-2. These studies showed that the megabreccias are related to tectonic deformation which produced sufficient topographic relief to produce landslides. These results are the subject of a report in preparation, entitled "Rock-Avalanche Breccia Deposits of the Yucca Mountain Region, Nevada, and Their Tectonic Significance" (Simonds and Fridrich).

Activity 8.3.1.17.4.5.4 - Evaluate postulated detachment faults in the Specter Range and Camp Desert Rock areas. Reconnaissance of the Camp Desert Rock area was conducted. Preliminary analysis of the postulated detachment at the base of the Horse Spring Formation indicates that the contact is depositional and not tectonic, as had been previously thought.

Activity 8.3.1.17.4.5.5 - Evaluate the age of detachment faults using radiometric ages. Rock-age determinations were used to date the uplift of Bare Mountain and to constrain the timing of extension in the Crater Flat basin and adjacent structural domains. Mineral separates, which will be analyzed for age determinations, were completed in February 1994.

Forecast: Final revisions of the map and associated report, "Geology and Hydrothermal Alteration of the Calico Hills" (Simonds and Scott), will be completed in the next reporting period. A field review of the work is planned, and the report will be submitted for technical review. Field work will continue in the Beatty-Bare Mountain areas. Mapping of the Big Dune quadrangle, southern Crater Flat will be completed, and a preliminary map will be readied for technical review. Work will continue to evaluate the geothermometry and geobarometry of the lower-plate rocks at Bare Mountain and a report will be prepared. Geologic mapping in the Beatty-Bare Mountain areas will contribute to the evaluation of the megabreccia deposits. The report, "Rock-Avalanche Breccia Deposits of the Yucca Mountain Region, Nevada, and Their Tectonic Significance" (Simonds and Fridrich), will be revised and submitted for technical review. Field work will be conducted in the Specter Range and Camp Desert Rock areas to evaluate postulated detachments. A report on the results of field work will be prepared by the end of the fiscal year.

2.2.13.14 Study 8.3.1.17.4.6 - Quaternary Faulting Within the Site Area

Activity 8.3.1.17.4.6.1 - Evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain. The map of known and suspected Quaternary faults and the accompanying text were revised in response to comments from technical reviewers. A digital version of the

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map was prepared by digitizing station locations and translating them to the computer-aided design format, so that changes to it could be made more readily. The revised map and text have been submitted for USGS Director's approval. Results of this project were presented at the Yucca Mountain Tectonics Workshop in January 1994.

Activity 8.3.1.17.4.6.2 - Evaluate age and recurrence of movement on suspected and known Quaternary faults. The preliminary photogrammetric logs of Wall 4 at Busted Butte and of Trench 14 on the Paintbrush Canyon fault were prepared. New thermoluminescence and uranium-series dates for Wall 4 and new age data on the Lathrop Wells ashes were incorporated, along with a revised estimate of recurrence and slip rates. Walls 1 and 2 at Busted Butte were cleaned and mapped. Stratigraphic and structural markers were flagged in preparation for photography, and the preliminary tectonic interpretations for these walls were developed. A talk reviewing information about slip rates and recurrence intervals of faulting on faults exposed in the trench walls was prepared and presented at the Yucca Mountain Tectonics Workshop in January 1994.

The paleoseismic studies completed to date have provided valuable preliminary data on the amounts and rates of Quaternary activity on the Paintbrush Canyon, Bow Ridge, and Stagecoach Road faults over time spans of <700 ka to <150 ka. Stratigraphic interpretations at the fault traces at all sites studied indicate multiple surface ruptures with small-to-moderate vertical separations ranging from 5 cm to 1 m and commonly in the range of 20 to 60 cm. The limited timing data suggest fairly long recurrence intervals (10^4 to 10^5 years), which when combined with small offsets, suggest low slip rates of 0.001 mm/yr to 0.03 mm/yr. The ages of the most recent ruptures appear significantly younger on the Stagecoach Road fault relative to the Paintbrush Canyon fault. Thus surface ruptures on these two faults do not appear to be linked persistently, at least in late-Quaternary time, which reduces the maximum length of rupture, and hence earthquake size, on the Paintbrush Canyon fault. The above information is the subject of a report, "Paleoseismic Investigations of Quaternary Faults on Eastern Yucca Mountain, Nevada" (Menges et al.), prepared for publication in the Proceedings of the 1994 High-Level Waste Conference.

Logs for Trenches SCR-T1 and SCR-T3 on the Stagecoach Road fault were completed, as were descriptions of stratigraphic units and soils. Reports were being prepared to incorporate new data on the ages of Lathrop Wells ash in paleoseismic interpretations. Work on these trenches took priority because the trench walls are more fragile and thus more easily degraded.

Remaining work on Trench 14D, across the Bow Ridge fault, was delayed while work on Stagecoach Road faults was completed. Descriptions of stratigraphic units and soils were compiled. New age dates (thermoluminescence, U-series, and those derived from a new Lathrop Wells ash chronology) were incorporated into revised paleoseismic interpretations. Topographic profiles across the base of Exile Hill to the other side of Trench 14 were measured.

Collection, analysis, and interpretation of all geophysical data for Windy Wash were completed, and a first draft of the report was begun.

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Stratigraphic contacts and structures in Trenches CF-1 and CF-1A on Fatigue Wash fault were cleaned, mapped, and flagged in February 1994. Walls were rephotographed prior to compiling preliminary trench logs, and the topographic profiles across the fault scarp adjoining the trenches were measured. Several sites for additional trenches north of Trench CF-1 were identified.

Excavation of a new trench, MWV-T3, and deepening and extension of Trench A1, were completed in December 1993. Only Trench A1 was found to cross the Paintbrush Canyon fault (at Alice Ridge); the trench was examined, logging began, and samples were collected for U-series dating.

Logging of Trench SCR-T3 and newly modified ancillary pit SCR-T14 across the Solitario Canyon fault began. Contacts and faults were measured with total-station surveying equipment in SCR-T3 and soils and stratigraphic units were described. The drafting or revision of trench logs for Trenches SCF-T1, SCR-T4, Trench 8, Trench SCF-1A, and SCF-T3 continued. The first draft of a report on the Stagecoach Road fault was written.

A two-day field trip to Crater Flat was conducted with technical experts to discuss problems and methods for dating carbonate sediments in trenches at Yucca Mountain. Samples collected for U-series analysis and thermoluminescence dating from Trench SCR-T2 were processed, and ages were determined for two samples from Trench SCR-T1.

Forecast: Final reports on the Stagecoach Road fault and Bow Ridge fault and in-progress ("provisional results") reports describing trench logging on the Solitario Canyon fault, Paintbrush Canyon fault on Alice Ridge, and Trench CF-1 on the Fatigue Wash fault will be completed. Reports and technical data information forms on trench logging activities at Busted Butte and Windy Wash will also be completed.

2.2.13.15 Study 8.3.1.17.4.7 - Subsurface Geometry and Concealed Extensions of Quaternary Faults at Yucca Mountain

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

Forecast: No activity is planned for FY 1994.

2.2.13.16 Study 8.3.1.17.4.8 - Stress Field Within and Proximal to the Site Area

Activity 8.3.1.17.4.8.1 through 8.3.1.17.4.8.4. No progress during the reporting period; these were out-year activities.

Forecast: No activity is planned for FY 1994.

2.2.13.17 Study 8.3.1.17.4.9 - Tectonic Geomorphology of the Yucca Mountain Region

Activities 8.3.1.17.4.9.1 through 8.3.1.17.4.9.3. No progress during the reporting period; these were out-year activities.

Forecast: No activity is planned for FY 1994.

2.2.13.18 Study 8.3.1.17.4.10 - Geodetic Leveling

Activity 8.3.1.17.4.10.1 - Relevel base-station network, Yucca Mountain and vicinity. Data continued to be processed for the Little Skull Mountain earthquake to assess surficial changes induced by the earthquake. The planned quadrilateral survey at Yucca Mountain was delayed pending completion of arrangements to perform the work.

Activity 8.3.1.17.4.10.2 - Survey selected base stations, Yucca Mountain and vicinity, using global positioning satellite.

Activity 8.3.1.17.4.10.3 - Analyze existing releveled data, Yucca Mountain and vicinity.

Forecast: Assessment of the geodetic data related to the Little Skull Mountain earthquake will continue. It is anticipated that the quadrilateral survey will be completed by July 1, 1994 and the data submitted for review by the end of FY 1994.

2.2.13.19 Study 8.3.1.17.4.11 - Characterization of Regional Lateral Crustal Movement

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

Forecast: No activity is planned for FY 1994.

2.2.13.20 Study 8.3.1.17.4.12 - Tectonic Models and Synthesis

Activity 8.3.1.17.4.12.1 - Evaluate tectonic processes and tectonic stability at the site. Geologic, tectonic, magnetic, and gravity data for the activity were integrated and synthesized. Enhanced remote sensor image data, which includes Yucca Mountain and its larger geologic setting, were received from the Jet Propulsion Laboratory. Methods to integrate digital versions of the data with other geophysical data to facilitate interactive visualization, analysis, and tectonic interpretation were determined.

Activity 8.3.1.17.4.12.2 - Evaluate tectonic models. Work continued to develop a fundamental scheme for evaluating tectonic models and tectonic data, and to develop a preliminary tectonic model for Yucca Mountain that is congruent with plausible tectonic scenarios. A computer code was modified that will provide three-dimensional modeling of

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deformation at Yucca Mountain, and three-dimensional models were tested against two-dimensional models derived using other techniques. The first complete Yucca Mountain model was completed and described in a presentation at the Yucca Mountain Tectonics Workshop.

Northeast-trending fault data are being interpreted to determine: (1) the stress configurations within and adjacent to Rock Valley, (2) genetic relationships of fault sets in the fault zone, and (3) discrete slip events along faults that display no clear offsets in datable markers. A field trip was conducted to Rock Valley in November 1993 for USGS participants in the tectonics program, to aid in evaluating field data and interpreting the seismic and tectonic significance of the Rock Valley fault zone. A discussion of this fault zone was presented at the Yucca Mountain Tectonics Workshop in January 1994.

Activity 8.3.1.17.4.12.3 - Evaluate tectonic disruption sequences. No progress during the reporting period; this was an out-year activity.

Forecast: Reports on preliminary results of the boundary element modeling scoping study and on a preliminary tectonic model are expected this spring. The balance of FY 1994 will be dedicated to: (1) interpretation and analysis of regional small-scale data sets, including remote sensor data, aerial photos, and geophysical data; (2) synthesis and compilation of results of on-going site characterization studies; and (3) re-evaluation of tectonic models with the goal of converging on a final, unified model.

2.2.14 Study 8.3.1.20.1.1 - Altered Zone Characterization

A new Work Breakdown Structure element has been established to cover this activity. The Site Characterization Program Baseline section will be written in the next reporting period and the study plan number that will probably be assigned is 8.3.1.20.1.1. The study plan for this Work Breakdown Structure is now being written and completion is projected for the next reporting period.

Preliminary activities were initiated to begin experiments to evaluate the effect of relative humidity on reaction products and rates in vitric material. The sample material was characterized prior to loading into reaction vessels. The high-temperature experiments were successfully concluded. The samples were retrieved and water analyses completed. The products appear to be predominately zeolites, and the reaction appears to have gone to completion, although more thorough characterization of the samples is required before this can be concluded. The reaction products will be provided to Los Alamos National Laboratory for use in studies of dehydration/rehydration effects in single phases.

Discussions concerning the use of the HFEM code in coupled code efforts were initiated. The types of modifications that would be required, data inputs that could be developed using EQ3/6 output files, and methods for evaluating the effects of mineralogical changes on hydrological properties were discussed. Additional existing codes that couple hydrological and geochemical processes were obtained, installed, and tested. Initial work

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concentrated on the 1Dreact code. Subsequent work on general test cases for use in all of the codes, as well as design of experiments to test the codes, has begun.

Consultations concerning coordination of activities regarding the stability of mineral assemblages took place in Albuquerque, New Mexico, and discussion of study design occurred. The results of that meeting were being documented.

Plans for the first reaction precipitation studies were developed and existing equipment was deemed suitable. The first efforts focused on silica precipitation kinetics and began in February 1994.

Forecast: Experiments and code coupling activities will continue. The study plan will be completed.

SECTION 2.3 REPOSITORY OVERVIEW

2.3.1 Geomechanical Analyses (SCP Section 8.3.2.1.4.1)

A collaborative effort has begun on a series of laboratory scale tests of small, layered polycarbonate models of layered rock structures. These tests will be extremely useful for validating numerical analysis tools. Agreement was reached on the scope of the effort and a contract was initiated.

A report on the FY 1993 layered plate experiments entitled "Laboratory Measurements of Frictional Slip on Interfaces in a Polycarbonate Model" (Brown) was received by YMSCO for review. The experimental technique of measuring slip on interfaces is documented in a report entitled "Geometric Moire Method of Strain Analysis with Displacement Discontinuities" (Brown and Hardy) and was also received by YMSCO. The layered plate tests consisted of a far-field view of loading normal to the plates, a close-up view of loading normal to the plate, a far-field view of loading at 10° to the plate, and a close-up view of loading at 10° to the plate. The results showed significant joint sliding along the interfaces adjacent to the central hole in the model, demonstrating that this test model could be used to validate numerical jointed-rock material representations. Although valuable data were obtained, one of the conclusions reached was that the data-reduction process for deducing the joint slips is much too time consuming and laborious. The experimental procedure was reviewed to explore ways of either accelerating the data reduction or modifying the tests before any further tests are conducted. A number of suggestions were made and a reasonable new approach to the problem was identified. The new approach involves changing the experimental technique from a Moire method to a holographic method.

Study of surface characteristics of natural fractures and how to relate these to the frictional data gathered on replicas of the surfaces continued. The study emphasizes determining whether the fitting parameters in the so-called "Barton Model" for frictional behavior have physical significance. This is being accomplished by investigating the effect on fracture shear strength and dilation with variation in three parameters: normal stress, roughness, and the strength of the rock material.

In 1992, a series of experiments were conducted to study the effects of nonstandard loading conditions on frictional properties. The details of the experiment and data were published in "Effect of Boundary Conditions on the Strength and Deformability of Replicas of Natural Fractures in Welded Tuff: Data Report" (Wibowo et al., 1993b). The first of two analysis reports, "Effect of Boundary Conditions on the Strength and Deformability of Replicas of Natural Fractures in Welded Tuff: Comparison Between Predicted and Observed Behavior" (Wibowo et al., 1993c) was also published. The second report, "Effect of Boundary Conditions on the Strength and Deformability of Replicas of Natural Fractures in Welded Tuff: Data Analysis" (Wibowo et al.), was in YMSCO review. This work documents basic joint mechanical behavior that is essential for understanding their roles in the rock-mass deformations. These data are also important from a numerical modeling viewpoint, because they provide critical information for developing and calibrating numerical rock-mass models.

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A work agreement was prepared to prescribe the work for investigating the effects of silica phase transformations on the stresses in the proposed repository. These phase transformations dramatically increase the thermal expansion coefficients of the rock and have the potential of significantly increasing the stresses. Preliminary analyses showed that increases of the stresses on the order of a factor of two could be expected. The results will be studied and new plans will be formulated. The planning addresses how the spatial variability of this material can be incorporated in a meaningful way and what waste streams should be considered for the study.

Discrete block models are needed to predict and study the rock behavior in the near field. Specifically, near-field rock stability questions cannot be modeled well using continuum approaches. Therefore, discrete block modeling techniques are used. A paper was received by YMSCO that describes a new approach to discrete block modeling. The paper, entitled "Using an Augmented Lagrangian Method and Block Fracturing in the DDA Method" (Lin et al.), was submitted for presentation at the Eighth International Conference on Computer Methods and Advances in Geomechanics to be held in May 1994. This paper covers the procedure developed to tie sub-blocks together to form larger blocks and also introduces block fracturing capabilities. The paper represents the first major publication outlining the advances that have been made in discrete block modeling, which is probably the only technique that will be able to address local rock stability questions.

Work was done on the sub-blocking approach to discrete element analyses using an Augmented Lagrangian Method and rock block fracturing work. The approach worked well, and a number of successful test problems were run. These problems dealt with rock fall, underground excavation of jointed rock, and uniaxial compression of blocky rock samples. "Modeling Fracturing of Rock Masses with the DDA Method" (Jung et al.), a paper prepared for the North American Rock Mechanics Symposium in Austin, Texas, was received by YMSCO. The limitations of the Augmented Lagrangian Method and the convergence of the method using different measures, such as a norm of the residual vs. a displacement increment norm, were explored. Future work will include adding more general joint constitutive modeling capabilities, investigating the pathologies of the method, and using the method to perform backward analyses (a limited amount of experimental data is used as input to examine how the entire system behaves).

Improvements to the continuum joint model continued. A single joint set, three-dimensional version of the successful two-dimensional model was implemented. The principal effort in this work was to develop new generalized models. The objectives were for increased numerical robustness, more joint sets at arbitrary angles, and modifiable joint-slip curves. More capabilities of the new formulation were examined. The report entitled "A Computational Model for Three-Dimensional Jointed Media with a Single Joint Set" (Koteris, 1994) was published.

In November 1993, a constitutive model was examined in a dynamic code, PRONTO, that has the proper form for the development effort being taken. In December 1993, the model was moved to a three-dimensional static code, JAS. In January 1994, a capability to treat the intact rock as a Drucker-Prager material was exercised with limited success. One

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element test problem was successfully performed but larger problems failed, perhaps due to an error(s) in the coding. The model was able to obtain solutions for problems involving 2, 3, and 4 joint sets in a three-dimensional solid composed of 729 elements.

A report entitled "JAC2D - A Two-Dimensional Finite-Element Computer Program for the Nonlinear Quasi-Static Response of Solids with the Conjugate Gradient Method" (Biffle and Blanford) was received by YMSCO for review. JAC2D is the primary mechanical two-dimensional finite-element analysis tool for performing linear and nonlinear rock-mass response calculations. This report documents the theory and inputs to the code developed in FY 1993.

Work continued on the hybrid boundary element-finite element numerical method. The last two-dimensional coupling cases using different nonlinear models progressed. In the next few months, the two-dimensional work will be completed and a report issued that documents coupling of boundary elements with finite element models using a variety of constitutive models, including elastic, elastic-plastic, visco-elastic, and jointed rock.

Forecast: The significance of rock mass creep on the stability of underground openings affiliated with the Exploratory Studies Facility and repository will be evaluated by analyzing site-specific data and published information. This topic will be discussed with external experts and decisions made to either incorporate specific concerns into Exploratory Studies Facility/repository analyses and testing programs or to document that no further work is required.

Laboratory-scale experiments on rock joints and simulated rock masses for development, verification, and validation of Exploratory Studies Facility rock-mass design models will be performed. These ongoing tests are conducted under controlled conditions to obtain the quality of data necessary to properly validate analysis models. With laboratory-scale experiments, researchers can control critical properties (e.g., joint geometries and roughness) and obtain higher quality full-field data.

Further development of continuum joint models will continue. This is necessary to perform repository scale modeling that will include physically important phenomena (such as joint dilation), increased numerical robustness, and added generality.

Development of discrete joint and block modeling capabilities for use in the design of the Exploratory Studies Facility and repository will continue. These models will be used in the validation analyses along with the continuum joint models. Deliverables will include reports detailing developmental efforts.

SECTION 2.4 REPOSITORY DESIGN

Advanced Conceptual Design for the repository continued during the reporting period. To avoid proliferation of designs and unnecessary duplication of effort, repository design moved into the focused Advanced Conceptual Design concept late in the reporting period. This approach to Advanced Conceptual Design relies on identifying assumptions to be verified as site characterization progresses. Key assumptions identified during the reporting period include horizontal in-drift emplacement of multipurpose canister-based waste packages, integrated rail transport for subsurface transport of waste packages, 100-year retrievability period, and a subsurface standoff distance of 60 m from the main trace of a fault at the repository level. Progress in repository design relative to these and other Advanced Conceptual Design concepts is discussed in this section.

2.4.1 Configuration of Underground Facilities (Postclosure) (SCP Section 8.3.2.2)

Section 2.1.9.3 in Progress Report #9 (DOE, 1994f) provided a detailed description of the enhancements, which have now been approved, to the Exploratory Studies Facility configuration, including related changes to the proposed repository layout. In brief, the change:

- Results in grades less than 3.0 percent in the ramps and through the repository, thus maintaining the option for conventional rail haulage
- Realigns the Exploratory Studies Facility main drift so it parallels the Ghost Dance fault instead of crossing it
- Eliminates exploratory cross-drifting through the middle of the potential repository block, instead it proposed cross-drifts at each end
- Allows emplacement drifts to be placed higher above the water table
- Allows more flexibility for consideration of alternative repository layout concepts
- Provides a layout that is more conducive to the majority of the repository excavation being performed by the tunnel boring machine.

Development of revised repository layout concepts continued during the current reporting period, and was summarized in a report to DOE (CRWMS M&O, 1993d). A draft set of six drawings showing Exploratory Studies Facility/Repository interfaces was also submitted to DOE (CRWMS M&O, 1994b).

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2.4.1.1 Design Activity 1.11.1.1 - Compile a Comprehensive List of All the Information Required From Site Characterization to Resolve This Issue

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

Forecast: Compilation of this list will begin in FY 1994.

2.4.1.2 Design Activity 1.11.1.2 - Determine Adequacy of Existing Site Data

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

Forecast: No activity is planned for FY 1994.

2.4.1.3 Design Activity 1.11.1.3 - Document Reference Three-Dimensional Thermal/Mechanical Stratigraphy of Yucca Mountain

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

Forecast: No activity is planned for FY 1994.

2.4.1.4 Design Activity 1.11.1.4 - Preparation of Reference Properties for the Reference Information Base

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

Forecast: No activity is planned for FY 1994.

2.4.1.5 Design Activity 1.11.2.1 - Compile Waste Package Information Needed for Repository Design

Several features of the waste package will affect Mined Geologic Disposal System design including the capacities of various types of waste packages, whether they are for bare fuel or multipurpose canister, their height and diameter, lifting and handling features, mass of the empty waste package, lids and full sealed waste package, closure method, and time for closure welding and inspection.

This information was compiled for seven types of waste package: disposal containers for the 125-ton (113.5-metric-ton) and 75-ton (68.1-metric-ton) multipurpose canister, waste packages for 21 and 12 bare pressurized-water reactor assemblies, waste packages for 40 and 24 bare boiling water reactor assemblies, and a disposal container for four Savannah River high-level waste canisters. The most demanding of these is the disposal container for a

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125-ton (113.5-metric-ton) multipurpose canister, which has the largest diameter, length, and mass.

To assess the impacts of backfill on the near-field thermal environment, the first of a series of tests designed to help quantify the effective thermal properties of a crushed tuff backfill was conducted. Pre-test analyses of the experiment were conducted using nonlinear heat conduction codes and approximations of effective thermal properties obtained from the literature. Parameter estimation techniques were used to assess the effects of the test apparatus on the thermal performance of the test bed (i.e., the crushed rock), as well as to optimize sensor placement. The environmental, safety, and health requirements necessary for the conduct of the experiment were evaluated and implemented. Data were also taken on the moisture content and physical dimensions of the crushed tuff particles. Tuff samples were provided for mineralogy, thermal conductivity, heat capacitance, and abrasivity testing.

Forecast: Efforts will continue to assess the impacts of various backfill scenarios on near-field internal waste package temperatures.

2.4.1.6 Design Activity 1.11.3.1 - Area Needed Determination

The emplacement area needed is determined by dividing the total initial thermal output of the waste inventory by the local, or unit, thermal load. The lower the thermal load, the greater the area needed for emplacement. A design basis thermal load has not yet been selected by the Project. Some of the considerations in selecting a thermal load are size and initial thermal output of individual waste packages, allowable waste package cladding temperature, waste package and drift spacing, maximum allowable excavation extraction ratio, allowable rock surface temperature in the drift, and allowable temperature at the ground surface and at the TSw2/TSw3 contact below the repository.

The current working concept for a repository layout can accommodate a thermal load of 181 kW/ha (73 kW/acre) or greater within the primary emplacement area located west of the Ghost Dance fault. Thermal loads as low as 63 kW/ha (25 kW/acre) may be accommodated by also utilizing the primary area east of the Ghost Dance fault and one or more expansion areas as shown on Figure 2.4-1.

The primary emplacement area lying east of Ghost Dance fault and south of the Exploratory Studies Facility main test area is within the currently baselined repository footprint. The other potential emplacement blocks are included in areas designated as potentially usable areas 2 and 4 as identified in "Preliminary Evaluation of the Subsurface Area Available for a Potential Repository at Yucca Mountain" (Mansure and Ortiz, 1984). The expanded areas are roughly bounded by the Pagany Wash fault on the north side, the Fatigue Wash fault on the west side, and the Solitario Canyon fault on the east side. Optional Areas A through D comprise four different emplacement horizons to maintain main drift gradients below 2 percent, emplacement drifts at flat/horizontal gradients, and to stay within the TSw2 unit. The potential storage horizon with the highest elevation is Area B, followed by C, A, and D.

Figure 2.4-1. Potential Repository Expansion Areas

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Forecast: Work will continue throughout FY 1994.

2.4.1.7 Design Activity 1.11.3.2 - Usable Area and Flexibility Evaluation

As discussed in 2.4.1.6, potential expansion areas have been identified. Very limited geologic information is available for Optional areas A through D. Additional site characterization activities and studies must be performed to confirm that these areas are usable. Generic subsurface layouts for various repository thermal loadings are proceeding on the assumption that the optional areas are usable.

Current repository and waste package studies are focusing on in-drift emplacement of multipurpose canister-based waste packages instead of placement in horizontal or vertical boreholes as in the current baseline. In-drift emplacement appears to be better suited to emplacement of the larger, 21 pressurized-water reactor assembly packages in terms of handling and heat transfer considerations. This concept is also discussed in Section 2.4.1.8.

Forecast: Work will continue throughout FY 1994. Reports summarizing the progress of this work will be issued during the next reporting period.

2.4.1.8 Design Activity 1.11.3.3 - Vertical and Horizontal Emplacement Orientation Decision

This activity is being addressed by the waste package performance allocation/ emplacement mode system study and repository design trade studies and is discussed in more detail in Section 2.4.1.17.

Forecast: Work will continue throughout FY 1994. Reports summarizing the progress of this work will be issued during the next reporting period.

2.4.1.9 Design Activity 1.11.3.4 - Drainage and Moisture Control Plan

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

Forecast: No activity is planned for FY 1994.

2.4.1.10 Design Activity 1.11.3.5 - Criteria for Contingency Plan

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

Forecast: No activity is planned for FY 1994.

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2.4.1.11 Design Activity 1.11.4.1 - Chemical Changes Resulting From the Use of Construction Materials

No progress during the reporting period; this was an unfunded activity. Related work is also discussed under the appropriate activities of Section 2.6.2.2, "Characterize Chemical and Mineralogical Changes in the Postemplacement Environment" and Section 2.6.2.6, "Characterize the Effects of Man-Made Materials on Water Chemistry in the Postemplacement Environment."

Forecast: No activity is planned for FY 1994.

2.4.1.12 Design Activity 1.11.4.2 - Material Inventory Criteria

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

Forecast: No activity is planned for FY 1994.

2.4.1.13 Design Activity 1.11.4.3 - Water Management Criteria

All current recommended controls for water use on the surface and for excavation of the Exploratory Studies Facility Starter Tunnel have been based on the fundamental concept that water migrating downward from the surface or near-surface will eventually enter the PTn hydrogeologic unit, which is a relatively porous unit compared to the overlying TCw hydrogeologic unit and the underlying Topopah Spring welded hydrogeologic unit. The PTn hydrogeologic unit is also believed to be relatively unfractured and have pore sizes that are intermediate between the very small pore sizes of welded tuffs and the much larger fracture apertures. Water migrating in the welded tuff matrix is not expected to be able to penetrate to potential waste package emplacement zones over a 10,000-year time frame. If one assumes that the natural rainfall, runoff, evaporation, and infiltration are in a steady-state, a conservative limit for additional water discharge to any area of ground is the volume of gas-filled pore space available in the underlying PTn hydrogeologic unit.

This criterion has been applied to various specific situations for controlling water use. Water controls issued for construction of the Exploratory Studies Facility Starter Tunnel and Alcove #1 (CRWMS M&O, 1994c) are based on a straightforward application of the criterion using the tunnel and alcove plan view cross-sections and the estimated volume available for holding water in the underlying, partially saturated PTn hydrogeologic unit. Other uses of this criterion include controls for enhanced natural infiltration and infiltration testing in the Bow Ridge fault Trench NRT-1 (CRWMS M&O, 1994d), infiltration testing in Pagany Wash at Neutron Borehole UE-25 UZN-7 (CRWMS M&O, 1994e), discharge of pump test water at boreholes USW G-2, USW WT-1, UE- 25 WT-12, and UE-25 WT-17 (CRWMS M&O, 1993e).

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Exploratory Studies Facility Performance Assessment Analysis #14 will investigate the sensitivity of previous hydrologic performance assessment analyses to variability in hydrologic properties, the effects of underground ventilation, and the use of different computational and conceptual models. The analysis will provide an iterative assessment of surface and underground water management requirements determined by earlier analyses. In support of this analysis, four activities were initiated: (1) the submittal of the hydrological code FEHM to software configuration management and its implementation in the above analysis, (2) the simulation of underground water movement in the Exploratory Studies Facility tunnel (TSw2 section) using the hydrology code TOUGH2 and implementing a vapor-phase diffusion model for the removal of in situ moisture by ventilating air, (3) calculations using NORIA-SP to test the sensitivity of previous performance assessment analyses to various sets of hydrological parameters used for the PTn hydrogeologic unit, and (4) the calculations to produce realizations of heterogeneous geohydrological properties.

A presentation on underground water analysis (Exploratory Studies Facility Performance Assessment Analysis #13) relating to fire suppression was made at the DOE-NRC Technical Exchange on the Exploratory Studies Facility Title II Design in October 1993.

Forecast: The next significant challenge for water management is the use of construction water during excavation of the Exploratory Studies Facility North Ramp. The development of different criteria and analysis methods will be required because the North Ramp will penetrate the PTn hydrogeologic unit and place water directly into the Topopah Spring welded hydrogeologic unit. Some assessments have been completed, including a model study of water migration following discharge into Exploratory Studies Facility excavations in the Topopah Spring welded and PTn hydrogeologic units. The results of this study are discussed in the report "Evaluation of the Effects of Underground Water Usage and Spillage in the Exploratory Studies Facility" (Dunn and Sobolik, 1993). Additional work is required to determine potential repository performance impacts of water discharge in Exploratory Studies Facility construction and testing. The initial step in this process will be the completion of the sensitivity studies of previous analyses to uncertainty in the hydrologic properties, to the effects of underground ventilation, and to the usage of different computational and conceptual models (Exploratory Studies Facility Performance Assessment Analysis #14). Results will be included in a report to DOE summarizing results and recommendations regarding the Exploratory Studies Facility design. Discussions have been held on expanding the scope of the integrated subsystem/total system analysis to a validation exercise using the Exploratory Studies Facility construction as a large-scale site characterization experiment. To begin this work, an integrated subsystem/total system analysis will be defined and initiated.

2.4.1.14 Design Activity 1.11.5.1 - Excavation Methods Criteria

The objective of this design activity is to identify any constraints to be placed on excavation because of postclosure performance considerations. The concern is to limit excavation induced changes to rock mass permeability. It is generally accepted that use of a

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tunnel boring machine results in the least amount of change due to the excavation process. Properly controlled drill-and-blast excavation may result in damage equivalent to that from a tunnel boring machine, but any lesser control will result in greater change.

The repository layout in the Site Characterization Plan assumes mostly drill-and-blast excavation. The layout in the current baseline assumes mostly tunnel boring machine excavation, but the layout does not permit efficient use of a tunnel boring machine. A revised repository layout was being developed which allows most, if not all, of the excavation to be performed by mechanical methods.

Research is being conducted by the Colorado School of Mines (under a Project contract) involving adaptation/modification of current cutter disc technology to roadheader machines. They are also developing a specially configured alcove miner which can be transported on a rail car to the alcove location and set up to excavate alcoves of various dimensions by initially working in a 7.6-m-drift. These developments may offer the flexibility necessary to create custom excavation profiles. It is assumed that these concepts and equipment will be fully developed and tested and will be available for repository construction, thereby eliminating the need to utilize drill and blast techniques to perform secondary excavation tasks.

The above discussion suggests that constraints need be placed only on drill-and-blast excavation. Because the design is now assuming the majority of the repository excavation will be done using a tunnel boring machine and the remainder using other mechanical methods, blasting constraints are unnecessary. However, there may still be a need to assess the changes caused by the excavation itself, irrespective of the excavation method, to assess postclosure performance.

Forecast: Tracking of progress in equipment development by the Colorado School of Mines will continue throughout FY 1994.

2.4.1.15 Design Activity 1.11.5.2 - Long-Term Subsidence Control Strategy

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

Forecast: No activity is planned for FY 1994.

2.4.1.16 Design Activity 1.11.6.1 - Thermal Loading for Underground Facility

An FY 1993 Thermal Loading Systems Study was completed during the period. The study was undertaken to evaluate the implications of thermal loading on postclosure performance, operability, and cost and to begin developing the technical basis for ultimately making a thermal loading decision. Although the Site Characterization Plan reference case is 141 kW/ha (57 kW/acre), other thermal loading strategies (different areal mass loadings) have been proposed which possess other advantages or disadvantages. The draft final report

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(CRWMS M&O) describing the study and the results was written and both a technical and management review of the document were performed. The report was in DOE review, and a broader technical peer review among the participants was being conducted.

The objectives of the FY 1993 Thermal Loading Study were to (1) place bounds on the thermal loading which would establish the loading regime that is "too hot" and the loading regime that is "too cold," (2) evaluate the performance, as a function of thermal loading, of the repository to contain high-level wastes against performance criteria, and (3) evaluate the performance of the various options with respect to cost, safety, and operability. Additionally, the study was to identify important uncertainties that need to be resolved by tests and/or analyses in order to complete a performance assessment on the effects of thermal loading.

The study utilized and integrated the efforts of the design groups and three of the national laboratories.

Two series of three-dimensional near-field thermal analyses for the thermal loading systems study were completed. In the first series, the specific layouts were selected based on a mined-volume cost-minimization approach in which canister spacing was held constant and drift spacings changed to alter areal mass loading. For the second series, the drift spacings were held constant (consistent with a 30 percent extraction ratio) and the canister spacings adjusted to alter areal mass loadings. Waste packages designed to hold 6, 12, and 21 pressurized-water reactor assemblies were analyzed for loadings ranging from 60 MTU/ha to 275 MTU/ha and an in-drift emplacement mode.

Temperature histories at selected points were generated, and the full three-dimensional output from the models were made available for use in structural evaluations.

Heat conduction calculations were performed to evaluate near-field, preclosure performance. Hydrothermal calculations were also done to evaluate postclosure performance due to changes in temperature and water movement on a mountain scale. The calculations were used to evaluate whether or not geochemical alterations might occur. The ability to monitor the repository under heated conditions was also evaluated. The results of the analyses were examined to evaluate performance at the various thermal loads in part by comparing the thermal predictions against thermal goals.

Several major conclusions were established in the course of the study. Some of those conclusions are:

1. Thermal loads greater than 248 MTU/ha are "too hot" and should be avoided.
2. Below boiling (bulk average) loadings produces negligible mountain-scale hydrologic perturbation for bulk permeabilities below about 1 darcy.
3. Equivalent continuum model predictions for above boiling strategies appear to result in large scale water redistribution.

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4. Cost does not appear to vary significantly (less than 15 percent) between hot (above boiling) and below boiling strategies. Thus, it does not appear that cost is a useful discriminator between thermal loading options based on our current understanding. However, uncertainties remain in the costs and are being investigated as information develops.
5. Electronic components exhibit high failure rates above about 160°C. Therefore, monitoring may not be feasible at areal mass loadings above 248 MTU/ha because of drift temperatures well in excess of 160°C.
6. High thermal loads appear to significantly increase the uncertainty of geochemical alterations.

In summary, the study provided a compelling technical basis to conclude that thermal loads above 248 MTU/ha are "too hot." Additionally, the evaluations indicated that the uncertainties in waste package corrosion, geochemical alterations, mountain-scale water movement, and thermomechanical and operational aspects were all found to increase with increasing thermal load. A significant challenge of the program will be a measurement of water movement and bulk permeability through thermal testing. Both mountain-scale and drift-scale water movement must be understood regardless of whether an above boiling or below boiling (bulk average) repository is ultimately selected.

The study also identified a number of the uncertainties important to waste isolation that must be reduced to adequately evaluate performance. An evaluation of whether or not these issues are adequately represented in the testing program needs to be done. It was recommended that, until the uncertainties are reduced by further tests and/or analyses, no final decisions be made between either the above boiling, hot regime, or the below boiling regime.

Forecast: A follow-up study in the area of thermal loading is planned to investigate many of the issues identified above, such as fuel variability and uncertainties in parameters. The systems studies are developing the technical basis for making a final thermal loading decision. However, laboratory and underground data from a variety of sources, especially the heater tests, are needed to provide necessary input for that decision process. Those tests are to be conducted over the next several years.

Investigation of the influence of nonisothermal conditions on processes governing flow and transport through fractured and unfractured porous media will continue. This activity represents the modeling interface with lab-scale experiments (Subactivity 1.6.2.2.2). Evaluations of geostatistical bulk-property models will be formulated based on combined numerical and experimental results.

Thermal simulations will be performed and evaluated utilizing two-dimensional geostatistical maps of the spatial heterogeneity of thermal properties. This is the first step in establishing the importance of spatial heterogeneity on heat transfer at the site and will provide feedback to the sampling strategies incorporated in the data collection activities described in Section 2.2.

2.4.1.17 Design Activity 1.11.6.2 - Borehole Spacing Strategy

This activity deals with thermal loading, one component of which is waste package spacing. This activity was planned while it was assumed that waste packages would be placed in horizontal or vertical boreholes. As mentioned in Section 2.4.1.7, current repository and waste package studies are focusing on in-drift emplacement of waste packages instead of placement in horizontal or vertical boreholes.

The term "borehole spacing" used while planning this activity is not strictly applicable to in-drift emplacement; the applicable terms are waste package spacing and drift spacing. Heat transfer along a drift without backfill is rapid because of radiation, but heat transfer between drifts occurs only by conduction and convection, so it is much slower. Accordingly, short-term thermal behavior is controlled by the thermal output of a waste package and waste package spacing, but longer-term thermal behavior is controlled by areal power density and areal mass loading. A more complete discussion of this is found in Section 2.6.1.3.

The needed information regarding repository thermal loading and thermomechanical response of the host rock is being addressed via the thermal loading systems study and the waste package performance allocation and emplacement mode study. The analysis includes the in-drift emplacement mode which lends itself to larger waste packages more suitable to the conceptual design of the multipurpose canister. Analyses have shown that waste package spacing is a very strong determinant of the waste package peak surface temperatures and the drift wall peak temperatures. The thermal studies are also discussed in Sections 2.4.1.16 and 2.4.1.18.

This activity is ongoing and is related to the determination of repository layout and thermal loading.

Forecast: Activity will continue during FY 1994.

2.4.1.18 Design Activity 1.11.6.3 - Sensitivity Studies

Sensitivity studies were being performed to evaluate the effects of uncertainties in the description of the waste form, the geologic setting, and the geologic response to the thermal perturbation of waste emplacement. These studies support the thermal loading system study (Section 2.4.1.16) and the Total System Performance Assessment analyses.

The exercises being performed in the near-field thermohydrological area focus on predicting temperature and saturation conditions in the immediate vicinity of the waste packages. Two different modeling approaches are being followed to predict the near-field environmental conditions. One of these approaches assumes that the hydrothermal conditions far from the waste packages are known a priori, through certain subrepository scale hydrothermal calculations (TOUGH2). These average repository conditions are provided as boundary conditions for the near-field model. In the second approach, the modeling domain

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is considered to be the entire unsaturated zone, with local refinement near the waste packages. Thus, the boundary conditions for this approach are specified at the top and bottom of the unsaturated zone.

A near-field thermal model has been developed to determine the temperatures of the waste package and of the surrounding host rock as a function of time after waste emplacement. This model can be used for in-drift emplacement mode and it accounts for the effects of backfill. This model calculates near-field thermal profiles based on the average repository temperatures obtained from a subrepository scale hydrothermal model.

This model was used by CRWMS M&O to perform supporting calculations for the exercise for Total System Performance Assessment. The effects of waste emplacement characteristics such as drift diameter, waste package spacing, number of fuel assemblies and the backfill were analyzed using this model. These analyses performed in support of Total System Performance Assessment-1993 will be described at the 1994 High-Level Waste Conference in the presentation, "Near-Field Thermal Calculations for Individual Waste Package Placement" (Lingineni).

Forecast: Hydrothermal calculations in the near field are being performed using a finite element heat and mass transfer code (FEHM) using both of the approaches mentioned above. Results from these analysis will indicate the relative importance of convective processes occurring in the near field in predicting the conditions around the waste package. A comparison of the results from both approaches will also indicate the validity and accuracy of the predictions made by simplified near-field models. The results of these studies will be described in two documents to be prepared in August 1994: (1) a sensitivity analysis describing the alternate conceptual models and parameters, and (2) a benchmarking of the near-field thermohydrological analyses using TOUGH2 and FEHM.

2.4.1.19 Design Activity 1.11.6.4 - Strategy for Containment Enhancement

Progress in strategy for containment enhancement is described in Sections 2.6.1.3 and 2.6.1.4.

2.4.1.20 Design Activity 1.11.6.5 - Reference Calculations

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

Forecast: No activity is planned for FY 1994.

2.4.1.21 Design Activity 1.11.7.1 - Reference Postclosure Repository Design

The approach previously used to arrive at an Advanced Conceptual Design was to develop multiple design concepts in parallel until sufficient scientific basis is available to

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support the selection of a single concept. The selection of a single concept was planned to occur at the completion of the Advanced Conceptual Design activities. Due to considerations such as limited availability of resources (resulting from past funding shortfalls and anticipated future funding limitations), the pending incorporation of the multipurpose canister in the program baseline, and the availability of increased scientific knowledge since publication of the Site Characterization Plan-Conceptual Design Report, a new process to help expedite repository/waste package design progress was necessary.

The new process developed is referred to as the focused Advanced Conceptual Design approach. The essence of the process is based on the selection of a single primary design concept that meets the repository/waste package requirements. The selection of the primary concept is based on management decisions/assumptions that utilize the available technical data to support the decision. Each decision/assumption made that is not supported by sufficient technical data will generate a substantiation activity to attempt to validate the decision. As the design and substantiation activities progress, the decisions/assumptions will be modified as necessary. However, the designs will not be optimized technically (i.e., meeting the requirements is considered adequate, but the designs will be optimized from a cost and schedule point of view).

This focused Advanced Conceptual Design process will expedite the development of an Advanced Conceptual Design with the fundamental objectives of: (1) developing a Project scope that satisfies program needs, (2) assuring and/or validating Project feasibility and attainable technical performance levels, (3) identifying and quantifying any Project risks, and (4) developing a reliable cost estimate and a realistic performance schedule.

Finally, the focused Advanced Conceptual Design approach requires the identification and development of alternatives to features of the primary design concept that are important to waste isolation, as required by NRC Regulation 10 CFR 60.21(c)(1)(ii)(D).

Forecast: The development of the focused Advanced Conceptual Design approach will continue.

2.4.1.22 Design Activity 1.11.7.2 - Documentation of Compliance

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

Forecast: No activity is planned for FY 1994.

2.4.2 Repository Design Criteria for Radiological Safety (SCP 8.3.2.3)

2.4.2.1 Design Activity 2.7.1.1 - Design Evaluation for Compliance with Radiological Safety Design Criteria and Performance Goals

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

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Forecast: No activity is planned for FY 1994.

2.4.3 Nonradiological Health and Safety (SCP Section 8.3.2.4)

2.4.3.1 Design Activity 8.3.2.4.1.1 - Design Activity to Verify Access and Drift Usability

Thermomechanical analyses in support of North Ramp Design Package 2C were completed. Cross sections along the North Ramp subject to combinations of in situ, seismic, and thermal loads were evaluated. Thermal stresses were computed along the North Ramp using the output from a 248 kW/ha (100 kW/acre) repository scale thermal model as input into a layered three-dimensional elastic model. The latest available site data were used in the mechanical model. Seismic loads were estimated primarily using a quasistatic approach based on a 0.4-g earthquake. A limited set of dynamic seismic analyses using scaled downhole earthquake logs were also completed. Documentation of this work will be incorporated into the report, "Design Support Analyses: North Ramp Design Package 2C" (Jung and Ryder).

Extensions to the mechanical model are being pursued and an additional thermal loading equivalent to 198 kW/ha (80 kW/acre) has been analyzed. The results will be included in modifications to the draft report on North Ramp Design Package 2C.

Forecast: Thermal and mechanical analyses to assess the impacts of various thermal loading scenarios on waste containment and isolation will continue. The primary emphasis for the remainder of FY 1994 will be to establish a dynamic seismic analysis methodology for use in future design evaluations.

2.4.3.2 Design Activity 8.3.2.4.1.2 - Design Activity to Verify Air Quality and Ventilation

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

Forecast: No activity is planned for FY 1994.

2.4.4 Preclosure Design and Technical Feasibility (SCP Section 8.3.2.5)

2.4.4.1 Design Activity 4.4.3.1 - Operations Plan to Accompany the Advanced Conceptual Design

Preliminary work under this activity is a part of all repository studies. Assumptions regarding repository operations are being assembled as part of the focused Advanced Conceptual Design effort.

Forecast: A preliminary Operations Concepts document will be written as part of the focused Advanced Conceptual Design effort during FY 1994.

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2.4.4.2 Design Activity 4.4.3.2 - Operations Plan to Accompany the License Application Design

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

Forecast: No activity is planned for FY 1994.

2.4.4.3 Design Activity 4.4.4.1 - Repository Design Requirements for License Application Design

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

Forecast: No activity is planned for FY 1994.

SECTION 2.5 SEALS SYSTEM DESIGN

2.5.1 Shaft and Borehole Seals Characteristics (SCP Section 8.3.3.2)

2.5.1.1 Study 1.12.2.1 - Seal Material Properties Development

Activities 1.12.2.1.1 and 1.12.2.1.2. No progress during the reporting period; these were unfunded activities.

Forecast: No activity is planned for FY 1994.

2.5.1.2 Design Activity 1.12.2.2 - A Degradation Model for Cementitious Materials Emplaced in a Tuffaceous Environment

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

Forecast: No activity is planned for FY 1994.

2.5.1.3 Study 1.12.2.3 - In Situ Testing of Seal Components

Work agreements were prepared that prescribe the activities associated with developing strategies for sealing the potential repository, and developing concepts for sealing the Exploratory Studies Facility/repository openings currently planned. Evaluations of sealing concepts were started, paying specific attention to their application for the current Exploratory Studies Facility/repository layouts and concepts. An evaluation was begun of repository design/performance constraints for seal systems as related to the current facility design. The report entitled "A Review of the Available Technologies for Sealing a Potential Underground Nuclear Waste Repository at Yucca Mountain, Nevada" (Fernandez and Richardson) was received by YMSCO for review.

A study plan for sealing testing was initiated, which will outline the rationale, concepts, and basic test concepts for in situ sealing tests. The completion of this document will allow early-FY 1995 field evaluations of borehole seal tests along with other critical seal evaluations such as the fracture grouting tests.

Forecast: Field-scale tests will begin to validate borehole sealing concepts and strategy. Activities include conducting limited field and laboratory testing and evaluations of borehole sealing concepts. Simple tests will be performed that will evaluate the performance of suggested cementitious sealing materials along with evaluations of the adequacy of standard emplacement techniques.

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2.5.1.4 Design Activity 1.12.4.1 - Development of the Advanced Conceptual Design for Sealing

Design Subactivity 1.12.4.1.1 - Define subsystem design requirements. Plans were developed for conducting laboratory tests and limited field demonstrations. Test concepts were based on those identified in "A Strategy to Seal Exploratory Boreholes in Unsaturated Tuff" (Fernandez et al., 1993). The laboratory tests are necessary prior to full-scale tests to establish confidence in material fluid flow and mechanical performance. Also, proven and demonstrated laboratory test techniques are necessary to evaluate sealing materials that are used for field demonstrations. These sealing tests will ultimately be integrated into the performance assessments of Yucca Mountain.

A limited laboratory evaluation of the Y-7 grout mix that is intended for use in the UE-25 UZ-16 instrumentation emplacement and characterization activities was completed. The evaluation was limited to the grout supplied, along with an assessment of mechanical property data. The mechanical properties of the Y-7 mix suggest that it could be removed from boreholes after emplacement; however, it is uncertain how the material will perform as a plugging and sealing material over longer time periods.

A report entitled "Sealing and Backfilling Strategy for the Proposed Repository" (Case et al.) that outlines the strategy for sealing and backfilling the Exploratory Studies Facility/repository openings was being prepared. The strategy for sealing attempts to isolate water from all sources entering shafts/ramps or the underground from the waste packages by infiltration and diversion. The report will provide sealing concepts based on the current proposed designs and describe sealing issues, such as where, how, and when to seal; some of which may be impacted by the currently proposed "in-drift" emplacement concepts. This impact is largely related to the timing of seal components such as fracture grouting and construction of engineered dams, when necessary, within the emplacement drifts themselves.

Design Subactivity 1.12.4.1.2 - Perform trade-off studies to support advanced design development. No progress during the reporting period. The emphasis in this reporting period was in support of Design Subactivity 1.12.4.1.1.

Design Subactivity 1.12.4.1.3 - Develop advanced conceptual design for seals. No progress during the reporting period; this was an unfunded activity.

Forecast: A sealing design strategy will continue to be developed for sealing the Exploratory Studies Facility/repository openings in support of the Exploratory Studies Facility design and construction process. The strategy will include design and performance analyses that address various sealing issues and requirements and will entail close cooperation with Exploratory Studies Facility design engineers using an iterative process.

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2.5.1.5 Design Activity 1.12.4.2 - Development of the License Application Design for Sealing

Design Subactivities 1.12.4.2.1 through 1.12.4.2.3. No progress during the reporting period; these were out-year activities.

Forecast: No activity is planned for FY 1994.

SECTION 2.6 WASTE PACKAGE

The waste package consists of the waste form and the container in which the waste form is placed. The waste package design program includes the development of waste package design bases, design analysis, container materials testing, the development of a reference design, waste form testing, and characterization of the waste package emplacement environment. Progress of the waste package program is described in this section.

Advanced Conceptual Design for the waste package continued during the reporting period. To avoid proliferation of designs and unnecessary duplication of effort, repository design moved into the focused Advanced Conceptual Design concept late in the reporting period. This approach to Advanced Conceptual Design relies on identifying assumptions to be verified as site characterization progresses. Key assumptions identified during the reporting period include horizontal in-drift emplacement of multipurpose canister-based waste packages, use of burnup credit and partial neutron absorber for nuclear criticality control, integrated rail transport for subsurface transport of waste package, 100-year retrievability period, and a mean waste package lifetime in excess of 1000 years. Progress in waste package design relative to these and other Advanced Conceptual Design concepts is discussed in this section.

2.6.1 Waste Package Design (SCP Section 8.3.4.2)

The design activities discussed in this section are closely related to the activities discussed in Sections 2.6.2, "Postemplacement Near-Field Environment" and 2.6.6, "Waste Package Performance."

2.6.1.1 Design Activity 1.10.2.1 - Concept Development

The Project held a waste package workshop in Las Vegas, Nevada, September 20-23, 1993. Objectives of the workshop were to allow outside organizations to present their ideas on waste packages, to provide a forum for the discussion of waste package concepts, and to solicit opinions from experts outside the program regarding waste packages.

Activity 1.10.2.1.1 - Advanced Conceptual Design concepts. To avoid proliferation of designs and unnecessary duplication of efforts, waste package development has moved into focused Advanced Conceptual Design. In light of current understanding of anticipated and unanticipated repository environments, the most promising concepts have been selected for further study.

Two types of containers for spent fuel are under consideration, one for uncanistered fuel and one for fuel in multipurpose canisters. Both are metallic with a relatively thin corrosion resistant barrier surrounded by a thicker corrosion allowance barrier. Both are intended for horizontal emplacement. The primary difference is that the container for uncanistered fuel will contain a basket to provide mechanical support, criticality control, and

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conduction of heat to the surface of the package, functions the multipurpose canister provides for the other container. Waste packages will be developed with several capacities. While current efforts are focused on pressurized-water reactor fuel, a metallic multibarrier container will be developed for disposal of defense high-level waste glass canisters.

No further development of the Site Characterization Plan container design has occurred. Increased understanding of the repository environment and waste package performance indicate that the austenitic stainless steel specified for this design will be subject to stress corrosion cracking. As a result, this design will not meet the containment requirements of 10 CFR Part 60.

Activity 1.10.2.1.2 - Design basis fuel. The parameters for the design basis fuel were refined. Age, burnup, and criticality potential were determined for both the waste package and the multipurpose canister. These values must be sufficiently conservative to ensure that the packages will meet requirements on external radiation, fuel temperature, and criticality. Shielding, package size, and neutron absorber materials will be chosen to accommodate the design basis fuel. The relatively few assemblies having more stressing parameter values may be handled by de-rating the standard package or by using a more conservative waste package.

Statistics on pressurized-water reactor fuel from the Energy Information Administration forecast data base have been analyzed. Analyses were performed for those discharges expected before 2003 and for the full 86,000 MTU to be discharged. The former is appropriate for the design of an initial phase waste package or multipurpose canister; the latter is closer to what is expected for the entire repository.

The current conservative assumption is that fuel will be emplaced five years after discharge. The actual age of the spent nuclear fuel being emplaced will depend on the order of delivery by the utilities. For any reasonable scenario the average age will be upwards of 20 years, particularly if the utilities follow a strategy that minimizes worker exposure to radiation.

Forecast: Total system performance analyses relating the waste package period of containment to the overall containment performance of the geologic setting will be conducted.

More accurate Monte Carlo transport codes and more realistic isotope cross sections have become available. These will be used to produce a new set of points to further refine the choice of design basis fuels.

Further insight is expected regarding the delivery strategies which will be agreed upon between the utilities and DOE. It may then be appropriate to relax the very conservative assumption of five-year age for all fuel and use something consistent with both the utility plans and the ages in the Energy Information Administration data base.

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2.6.1.2 Design Activity 1.10.2.2 - Design Tools

Verification and validation have been completed for three design tools: ANSYS 5.0A, MCNP4.2, and FIDAP. These codes and their verification and validation are discussed below.

ANSYS 5.0A is the most recent revision of this commercial finite element code for thermal and structural analysis. Since the previous version had been installed and verified and validated, this installation required only a reverification of the original test cases and a limited set of new verification and validation documentation for Quality Assurance and records. In addition, nine representative test cases were hand checked to independently verify the answers supplied in the vendor's verification manual.

MCNP4.2 is a Monte Carlo neutron and photon diffusion code. It was developed by Los Alamos National Laboratory and is used to support design for shielding and criticality. The verification and validation process consisted primarily of executing the developer's test cases and verifying the test results. All of these cases were too complex to hand check, so a simplified example with spherical symmetry was defined. It was verified that MCNP4.2 gave the same answer as the analytic hand calculation.

FIDAP is a standard commercial finite element code for heat and mass transfer. It is able to directly model convective cooling of the waste package. The code was installed and several cases of a simplified waste package geometry were analyzed. The results were comparable with those of ANSYS.

2.6.1.3 Design Activity 1.10.2.3 - Design Evaluations

Activity 1.10.2.3.1 - Thermal. Limits on thermal loading due to the use of large multipurpose canisters have been studied. For repository disposal, there are two thermal criteria that constrain the use of the multipurpose canister: the fuel cladding temperature must not exceed 350°C (to preserve the fuel cladding) and the drift wall temperature must not exceed 200°C (to avoid rock instability due to the cristobalite phase transformation). Current analyses indicate that internal temperature goals can be achieved with large multipurpose canisters at thermal loadings of up to 247 kW/ha (100 kW/acre) (corresponding to a mass loading of 222 MTU/ha). If a low thermal load is chosen instead, a possible requirement is that waste package surface temperatures remain below the boiling point of water. With suitable fuel aging, this requirement can be met. The multipurpose canister is thus considered thermally compatible with repository emplacement even though repository thermal decisions have not been made.

Backfilling has not been considered. Analyses of possible thermal transients at the time of backfilling will be performed when better properties are available.

The key parameters in determining near-field and internal temperatures are waste package capacity, fuel age, and waste package spacing. The repository must still be designed

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to maintain the thermal environment specified in the requirements. For low thermal loads, the fuel will require aging if surface temperatures are to be kept below boiling.

Peak fuel temperatures typically occur within a few years, but peak rock surface temperatures are typically reached only after tens of years. Since the peak fuel temperature occurs early, waste package spacing is more important than drift spacing in determining peak fuel temperatures. In an open drift, the waste packages will interact by radiating heat down the length of the drift. Larger waste package spacings result in a larger heat sink area and lower near-field temperatures, but the heat moves into the rock slowly and drift-to-drift thermal interaction will not occur until ten years or more, even for small drift spacings.

Temperature histories were calculated for three different thermal loads at constant waste package spacing. The early thermal behavior is identical for vastly different thermal loads, but long-term temperatures depend on areal mass loading. Because of the importance of the first few years to the fuel cladding, a minimum waste package spacing for a given package capacity and thermal output could be derived that is otherwise independent of thermal loading.

Thermal requirements for multipurpose canister design will effectively divorce multipurpose canister vendors from repository thermal loading concerns. The requirements are, in general, a 225°C-canister-wall temperature, total package heat load of 14.2 kW, and a maximum cladding temperature of 350°C. These requirements should ensure multipurpose canister compatibility with repository emplacement provided the eventual emplacement scheme is similar to the one used to derive the requirements. The 225°C-canister temperature is appropriate for a 7.62-m-diameter drift. Using a smaller drift may cause excessive rock temperatures. Rock temperatures will likely be the deciding factor for an upper bound on thermal loading.

For low thermal loads, peak fuel cladding temperatures are not considered limiting. However, other requirements such as keeping the waste package surface below boiling may restrict the age of fuel that can be emplaced in a multipurpose canister. A multipurpose canister loaded with an average fuel will have surface temperatures above boiling before emplacement. Prolonged aging may be required to keep temperatures below boiling after emplacement. For low thermal loads, boiling temperatures on the surfaces of some of the packages are considered undesirable from a corrosion perspective.

Activity 1.10.2.3.2 - Structural. Structural analyses for impact of falling rocks and for drop testing were performed. Advances in these areas are described here.

Studies have been performed to determine the size and weight of a rock that will result in permanent plastic deformation of the waste package. Two-dimensional finite element analyses have been performed, and three-dimensional analyses, which will provide greater accuracy, are planned. The most recent analysis suggests that dropping a 310 kg rock 4.8 m onto a waste package may be sufficient to cause plastic deformation of the outer barrier of the waste package. Here it is assumed that the rock impacts a 58 cm² area of the waste package and does not shatter.

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Further analyses will include a three-dimensional finite element model with more accurate assumptions, including a representative modulus of elasticity for a design basis rock. More appropriate drop heights will also be simulated.

Structural calculations have been performed to support design of a waste package for uncanistered fuel. These included buckling and bending stress calculations intended to determine the appropriateness of material selections and assumptions about basket member design. Some of the calculations included steel shot as a waste package filler material. Preliminary calculations indicate that there are large factors of safety for buckling, normal loading, bending, and shearing. These safety factors will be vital for maintaining structural integrity during drop tests. Further work will include finite element analyses of waste package designs and evaluation of their performance during the tests.

Activity 1.10:2.3.3 - Criticality. Criticality evaluations have focused on burnup credit and the related topics of time phased approach, isotopics, and materials.

The criticality evaluation efforts have supported the Burnup Credit Working Group for technical exchanges with NRC on burnup credit. Burnup credit has been identified as an important tool for long term criticality control. Input to these technical exchanges has concentrated on burnup credit for long term criticality control for disposal.

Three time phases in criticality control have been defined: a preclosure/operational phase with deterministic evaluations of criticality, a postclosure/substantially complete containment phase with deterministic evaluations changing to probabilistic evaluations of radionuclide release, and a postclosure/isolation phase with probabilistic evaluations of criticality events and bounding deterministic evaluations of consequences of events. A criticality fault tree is being created for the probabilistic evaluations, and event probabilities are being calculated and assigned. The NRC has commented favorably on the three phase approach and agrees that the probabilistic approach is reasonable for long times.

Changes in isotopics are responsible for the changes in reactivity/criticality potential of the spent nuclear fuel. The isotopes that are included in the evaluations are important for burnup credit. The importance of nuclides changes with time as certain nuclides decay and others are produced. Development of a set of principal isotopes for long term criticality evaluations is under way.

The material properties of the waste package basket and spent nuclear fuel assembly are also important to long-term criticality control. The basket and fuel components determine the geometry of the system, which affects neutron leakage and moderation. The corrosion rates and modes of the various basket and fuel components are being evaluated to predict degradation conditions for the long term criticality evaluations. These evaluations are being incorporated into the development of the probabilistic fault tree and used for the deterministic bounding calculations.

The current evaluations lay the groundwork for evaluations of the requirements for a moderator displacing filler material, the amount of moderator required for a criticality event,

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the effect of low moderator density on criticality potential, the effects of axial variations in burnup, the differential loading of spent nuclear fuel assemblies, and the effects of isotopic transmutation over long times.

Activity 1.10.2.3.4 - Cost Estimation. The waste package design must be suitable for manufacturing. The Engineering Development Program augments the waste package design efforts to ensure that the proposed design can be manufactured at a reasonable cost.

The "Waste Package Engineering Development Task Plan" (CRWMS M&O, 1993f) was generated to describe the procedure for reviewing manufacturing processes and assuring fabricability. A current task is the development of waste package/multipurpose canister internal filler materials. A technical document was generated to describe the engineering tests that must be performed on filler materials and filling methods. Besides mitigating tendencies toward nuclear criticality, fillers can also act as sorption materials and capture radionuclides before they are released to the near field.

A spreadsheet has been developed to perform routine calculations of waste package cost estimation. The spreadsheet calculates sizes, material volumes, masses, and estimated costs for the various components. The spreadsheet enhances productivity and accuracy of the tradeoff studies. Design inputs may be frozen and results published at discrete times through the Advanced Conceptual Design phase, as is essential for orderly and timely disclosure of interface information.

2.6.1.4 Design Activity 1.10.2.4 - Material Selection Design Support

Activity 1.10.2.4.1 - Materials selection process. For metallic multibarrier containers, the selection criteria are essentially a composite of how a material performs within a waste package system and how well it meets the performance and design requirements. The selection criteria have been classified into two major categories: (1) those related to performance, and (2) non-performance-related aspects, such as cost, engineering experience, and availability. A weighting factor based on engineering judgment has been assigned to each selection criterion. The highest weighting factor was applied to chemical performance, which includes corrosion and oxidation. The remaining factors were, in order of importance, the ability to fabricate, predictability, mechanical performance, compatibility, cost, and previous experience. There are subtopics within the factors, each of which receives a share of the weight.

As indicated earlier, engineering judgment will be used to identify materials that have the desired properties and generally favorable attributes relative to the selection criteria. A quantitative rating will be given to each candidate material for each selection criterion. This rating will be based on available test data, the degradation mode surveys, and other relevant information. These ratings will be used to rank the candidate materials for each component.

Activity 1.10.2.4.2 - Container shell. Progress in selection of container shell materials is described under Activity 1.10.2.4.1.

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Activity 1.10.2.4.3 - Shield plug. A shield plug is a design feature of the multipurpose canister. Current designs for containers do not include shield plugs. Accordingly, no additional effort has been made in selecting shield plug materials.

Activity 1.10.2.4.4 - Spent nuclear fuel basket (structural). Progress in selection of basket materials is described under Activity 1.10.2.3.3

Activity 1.10.2.4.5 - Spent nuclear fuel basket (criticality). Progress in selection of basket materials is described under Activity 1.10.2.3.3.

Activity 1.10.2.4.6 - Filler material. Iron shot remains the first choice for filler material. Efforts to obtain information on its thermal conductivity are continuing.

Activity 1.10.2.4.7 - Fill gas. Argon was previously the primary choice for a fill gas, and helium was the secondary choice. During this reporting period, the choice of fill gases was re-examined. Helium is now recognized as being superior to argon because of its higher thermal conductivity. Helium leak specifications are so stringent and detection methods so sensitive that a negligible fraction of the helium will escape from an intact waste package during the period of substantially complete containment. If air replaces the helium fill gas, the temperature of the waste will increase, and for waste packages that fail very early, additional degradation of the cladding or fuel may result. But almost all containers must remain intact through the period of substantially complete containment, so the heat output will normally be so low at the time of breach that little temperature rise will result.

Helium will be produced in the waste package by radioactive decay, but the rate of production will be low. The production over a million years will be comparable to the initial helium inventory of a waste package. The thermal conductivity of gases is essentially independent of pressure, so pressure changes will not affect thermal performance.

2.6.1.5 Design Activity 1.10.2.5 - Performance Evaluations

Activity 1.10.2.5.1 - Container oxidation and corrosion. The question of waste package performance with respect to thermal load and container surface temperature has been raised. The performance of the waste package is critical in ensuring that radionuclides are contained within the packages during the containment period.

It has been observed over many years that the worst aqueous corrosion occurs above about 60°C. For general corrosion of steel and copper in neutral pH aqueous environments, the corrosion rate is governed principally by the availability of oxygen. As temperature increases, the diffusivity of oxygen increases and the solubility decreases. The result of these opposing factors is a maximum in the corrosion rate near 80°C. Many localized forms of corrosion and stress corrosion have a strong dependence on temperature, and these forms of corrosion usually occur above a threshold temperature, which is about 60°C. Other factors, such as pH, oxygen content, and chloride ion concentration, also influence the threshold temperature. The 60°C temperature line does not imply that localized or stress corrosion is

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impossible below this temperature, but that the incidence of their occurrence above the temperature is high, especially for corrosion-resistant materials.

Temperature profiles for several waste package and drift spacings have been generated through the use of a finite element code. A moderate thermal load, similar to that of the Site Characterization Plan, is the worst with regard to waste package integrity in that the temperature enters the aggressive zone early and remains there for a long time. At a high thermal loading the temperature does not cross into the aggressive zone until thousands of years have passed. This helps ensure that the containment requirement is met and contributes to meeting the controlled release requirement. At low thermal loadings, the temperature passes through the aggressive zone soon after emplacement. It is possible to reduce corrosion through extended cooling of the waste package before emplacement. However, the low thermal load may create conditions conducive to microbiologically influenced corrosion.

Calculations have been performed on the relative humidity of the atmosphere surrounding the waste packages as a function of temperature and time. These indicate that higher thermal loads yield dryer conditions. This has implications on the initiation of microbiologically influenced corrosion, which is most important under warm and moist conditions.

Activity 1.10.2.5.2 - Waste package degradation by mechanical stress. Analytical expressions have been used to model the impact of rocks on a waste package. There is a strong dependence on the assumptions made about the nature of the rock and the amount of damage that can be sustained by the waste package without failure. Failure occurs for a relatively small rock if the rock is rigid, the container is elastic, and failure occurs if the maximum stress in the container exceeds the yield stress. Substantially larger rocks are required if the surface of the rock is crushed upon impact with the waste package or if the waste package deforms before it fails.

Activity 1.10.2.5.3 - Thermal degradation of fuel cladding. Studies of the degradation of cladding focused on two areas: studying the possibility that fuel rods will sag during horizontal storage at high temperature and improving calculations of degradation by diffusion-controlled cavity growth. The improvements include closer correspondence of parameter values with those used by the NRC and better temperature histories for dry storage. Advances in these areas are described below.

Because of their horizontal orientation, fuel rods in a drift-emplaced waste package are subject to sagging between spacer grids. The amount of deformation due to creep was calculated. Creep displacements depend on time and temperature, but, for typical peak temperatures, displacement rates of 9 mm per year are predicted. If preventing deformation of cladding is of interest, strict limits on exposure to high temperatures are needed. However, some sources specify creep rates that are much smaller than the one used here, so the rate of sagging may be a serious overestimate. The strain rates are extremely small, so accurate measurements are difficult. Review of other information on sagging is planned.

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The treatment of storage and disposal was refined in two ways. The first refinement was to calculate temperatures for storage from the heat output of spent fuel and from thermal performance data for a CASTOR V/21 storage cask. The second refinement was to adjust the parameters of the theoretical model of diffusion-controlled cavity growth. The changed parameters now agree with those used by NRC. The model still differs from that of NRC, however, in that effects of microstructure are included, rather than being conservatively neglected.

For typical pressurized-water reactor fuel, the temperature during storage drops rapidly. As a result, cladding degradation has nearly stopped by the end of five years of dry storage. There is an abrupt increase in temperature and in degradation rate at the time of repository emplacement. As the heat output of the fuel continues to decrease, temperature also decreases, and damage accumulation has essentially stopped by 100 years after discharge.

2.6.2 Postemplacement Near-Field Environment (SCP Section 8.3.4.2)

Discussion of several factors listed in 10 CFR Part 60.135(a) may be found in Section 2.6.1. The factors discussed there include corrosion, gas generation, thermal effects, mechanical strength, mechanical stress, and thermal loads. A paper entitled "Engineered Barrier Environment, Yucca Mountain" (Wilder) was prepared for the 1994 High-Level Waste Conference. The paper is an overview of the near-field environment characterization status including the recent work on correlating rock saturation, relative humidity, and waste package corrosion and is a high-level summary of the activities in Section 2.6.2.

2.6.2.1 Design Activity 1.10.1.1 - Consideration of 10 CFR 60.135(a) Factors

In support of the thermal loading systems study, a new set of mountain-scale repository models was developed. The models consider various areal mass loadings and rock permeabilities and represent the repository area as a disk. They are appropriate for representing large-scale behavior such as mountain-scale, buoyant, gas-phase convection. A uniform fracture permeability was assumed to apply throughout the unsaturated zone. At low permeabilities, there is negligible mountain-scale, buoyant, gas-phase convection. Average repository temperature for low areal mass loadings (up to 89 MTU/ha) never exceeds the boiling point, but for higher areal mass loadings (137 MTU/ha and up) peak temperatures above boiling are seen. At higher permeabilities, mountain-scale, buoyant, gas-phase convection contributes to cooling. Significant reductions in the time spent above boiling are seen, with the cooling effect being stronger at high permeability but weaker at high areal mass loading because the large zone of above-boiling temperatures suppresses convection.

The impact of drift-scale, buoyant, gas-phase convection on hydrothermal performance near emplacement drifts was also studied. The most important observation is that the temperatures predicted by repository-scale models are substantially below those predicted by drift-scale models. Another important observation is that the peak temperature varies modestly for areal mass loadings ranging from 60 to 137 MTU/ha and is relatively insensitive

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to drift spacing. For high areal mass loadings, the drift spacing is small enough to cause the peak temperature to be sensitive to drift spacing. A third observation is that the boiling duration is insensitive to sub-repository-scale, buoyant, gas-phase convection for the low and high areal mass loadings, and modestly sensitive for intermediate loadings. The spatial extent of moisture movement (i.e., dryout and condensate buildup) is very dependent on the magnitude of sub-repository-scale, gas convection for the low areal mass loading cases and insensitive for the high areal mass loading cases.

A drift-scale model was used to evaluate whether heterogeneity at the sub-repository-scale might result in focused vapor and condensate flow in the vicinity of an emplacement drift. A 1.6 m wide, high bulk permeability (K_b) zone was aligned along the axis of the waste package and flanked by low- K_b zones. The gas-phase pressure differential between these zones drove water vapor back toward the drift and into the high- K_b zone. Water vapor flowed up the high-permeability zone until it condensed and drained back down. Enough water vapor entered and condensed in this zone to cause the condensate drainage flux to be large enough to maintain refluxing in the repository. At low areal mass loading, this heat pipe effect caused refluxing above the waste package for more than 2000 years. At high areal mass loadings, however, dryout overcomes the heat pipe effect and after a short time the effects of heterogeneous permeability virtually vanish.

Boiling conditions can persist around an emplacement drift even if the average repository temperature is well below the boiling point. Moreover, if buoyant, gas-phase convection is significant, it can drive substantial vapor and condensate fluxes whether or not boiling ever occurs. On the other hand, if buoyant gas-phase convection is insignificant, a boiling period of sufficiently limited duration will generate condensate fluxes that have only a minor impact on performance. The absence of local boiling conditions is not, in itself, an adequate indicator of whether repository heat drives significant vapor and condensate flow. Average repository temperatures are an even poorer indicator of the significance of repository-heat-driven hydrothermal flow to the performance of a low areal mass loading repository. Diagnosing whether sub-boiling conditions can be equated with the absence of significant repository-heat-driven effects will require in situ heater tests conducted under sub-boiling as well as above-boiling conditions. Fuel age has significant effects on some thermal properties but not on others. For example, increasing fuel age at emplacement from 12 to 41 years cuts peak temperatures by 40° to 60°C but reduces temperatures at 1000 years by only 2° to 3°C. Although increasing the age to 40 years resulted in eliminating the boiling period for two low areal mass loading cases, the calculations show that for sufficiently large K_b , the contribution of sub-repository-scale, buoyant, gas-phase convection to the generation of condensate is nearly as great as it was for the 12-year-old spent nuclear fuel cases that resulted in boiling conditions.

The use of variations in areal mass loading to provide a nearly uniform duration of boiling throughout the entire repository was also studied. For the 274-MTU/ha case, a uniformly loaded repository has boiling durations from 1700 to over 8100 years, depending on location. Non-uniform thermal loading can reduce that range to between 2900 and 4800 years. Another substantial benefit in optimizing the areal mass loading distribution is a more uniform distribution of the duration of subambient liquid saturation in the repository.

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A paper entitled "The Impact of Buoyant Gas-Phase Flow and Heterogeneity on Thermo-Hydrological Behavior at Yucca Mountain" (Buscheck and Nitao), and another entitled "Evaluation of Thermo-Hydrological Performance in Support of the Thermal Loading Systems Study" (Buscheck et al.), were approved for publication in the Proceedings of the 1994 High-Level Waste Conference. The above discussion summarizes material in those papers. This work is being used to determine preliminary thermal loads to be used in Advanced Conceptual Design.

Forecast: Support of waste package related systems studies will continue.

2.6.2.2 Study 1.10.4.1 - Characterize Chemical and Mineralogical Changes in the Postemplacement Environment

Activity 1.10.4.1.1 - Rock-water interactions at elevated temperatures. A report covering preliminary results of modeling downhole mineralogy at Wairakei, New Zealand, using fluid chemistries obtained from active wells, was completed. The results demonstrate that good correspondence can be achieved between downhole mineralogy and simulations, for specific choices of Fe- and Al-controlling phases. The results were presented at FOCUS '93, and at the October 14, 1993, DOE-NRC Technical Exchange.

Work on the New Zealand natural process analog site addressed the effects of uncertainties in gas analyses and mineral constraints on water chemistry. Modeling of the equilibrium state of the system requires a consistent method for back-calculating downhole water chemistry from gas and water analyses collected at the well head. Differences between various reported water chemistries focused attention on the approach to these calculations.

Use of affinity-temperature diagrams has indicated particular areas of interest where minerals that control or strongly influence water chemistry can be identified. Current work is addressing apparent discrepancies between the results of this type of analysis and observed mineral assemblages. Specific questions are being formulated to determine how best to identify the equilibrium mineral assemblages.

The formal understandings for obtaining data from the production companies on the New Zealand natural process analog site work were drafted and reviewed. Data on well waters, and mineralogy and petrology from Kawerau, Wairakei, and Champagne Pool were being collected and summarized by the New Zealand researchers. Preliminary reports summarizing the Wairakei properties were submitted. Samples from Champagne Pool have been submitted for analysis. These data will be used to model precipitation and fluid mixing. Samples from the drains at Wairakei are of interest because they represent a system in which silica precipitation from solutions of known composition is occurring. The intent is to conduct experiments in this system to evaluate current models of precipitation kinetics. X-ray diffraction of these samples has been completed, revealing that the precipitate consists of amorphous silica, albite and halite. Scanning electron microscopy is under way to further characterize these materials. Planning of field-based experiments on silica precipitation kinetics is under way.

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Activity 1.10.4.1.2 - Effect of grout, concrete, and other repository materials on water composition. This activity is reported under 1.10.4.5.1 as a result of changes to the Site Characterization Program Baseline, Revision 8.

Activity 1.10.4.1.3 - Composition of vadose water from the waste package environment. No progress during the reporting period; this was an unfunded activity.

Activity 1.10.4.1.4 - Dissolution of phases in the waste package environment. No progress during the reporting period; this was an unfunded activity.

Activity 1.10.4.1.5 - Effects of radiation on water chemistry. This activity is discussed under 1.10.4.5.3 because the activity was divided between geochemistry and man-made material activities in the Site Characterization Program Baseline, Revision 8.

Activity 1.10.4.1.6 - Effects of container and borehole liner corrosion products on water chemistry. This activity is reported under 1.10.4.5.2 as a result of changes to the Site Characterization Program Baseline, Revision 8.

Activity 1.10.4.1.7 - Numerical analysis and modeling of rock-water interaction. This activity is discussed under 1.10.4.5.4 because the activity was divided between geochemistry and man-made material activities (in the Site Characterization Program Baseline, Revision 8).

The development of three-dimensional representation techniques began for coupled thermal-hydrology code and geochemical code output. Installation of EARTH VISION software was completed, and test cases were run. Data sets for use in the three-dimensional representation of mineralogical and chemical changes associated with various waste loading scenarios and repository geometries were obtained.

Forecast: The study plan will be reviewed by YMSCO. Collaboration with the New Zealand geothermal companies will continue and a report will be completed on this work. The code coupling activity will produce a review of existing codes and a recommendation for future code development.

2.6.2.3 Study 1.10.4.2 - Hydrologic Properties of Waste Package Environment

Activity 1.10.4.2.1 - Single-phase fluid system properties. The saturated water permeability measurements on an intact sample from USW G-4 are complete.

Activity 1.10.4.2.2 - Two-phase fluid system properties. Measurement of electrical resistivity as a function of moisture content of Topopah Spring Tuff samples from the USW G-4 and USW GU-3 holes continued. The results will allow electrical resistance measurements to be used as an indicator of saturation in field and laboratory tests. Distilled and UE-25 J-13 water are being used as pore fluid. A new electrical conductivity bridge meter was introduced; this instrument increases the range of frequency of the measurement to 20×10^6 Hz enabling a better determination of the dielectric constant. Measurements of the

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USW G-4 samples at 40°C were completed; measurements included the wetting and drying cycle. Very little anisotropy in the measured electrical conductivity with respect to the core axis was found. The wetting and drying phase measurements at 65°C were completed. Several samples were broken during the continuous heating and cooling process. It is difficult to obtain data at the highest saturations. At 65°C, the highest saturation achieved was about 70 percent. It may be necessary to immerse the samples in water at the elevated temperatures to produce at least one data point near saturation. This work was described in a paper entitled "Electrical Properties of Topopah Spring Tuff as a Function of Saturation" (Roberts and Lin), which was prepared for the 1994 High-Level Waste Conference.

The experiment to determine the moisture retention curve and one-dimensional imbibition using USW G-4 core continues. The data from this experiment will be used to calculate relative permeability as a function of water saturation. Measurements have been completed of a complete imbibition-drying cycle at 25°C. Moisture retention experiments at high temperatures began in November 1993. Measurements at 95°C and up to 85 percent relative humidity are complete. Evaluation of the use of the four-electrode method on a rectangular sample continues.

A fractured Topopah Spring Tuff sample from the USW G-4 hole has been jacketed and installed in the pressure vessel for an experiment to study fracture healing at high temperature and low-confining pressure. The effect of confining pressure on fracture healing will be determined. An abstract describing this work, entitled "The Effect of Rock-Water Interaction on Permeability" (Lin et al.) was submitted to the Eighth International Congress on Rock Mechanics to be held in Makuhari, Japan, September 25-28, 1995.

Activity 1.10.4.2.3 - Numerical analysis of flow and transport in laboratory systems.

The experiments and analyses described in the other two activities of this study are not yet linked. The experiments are measuring properties and single phenomena at a small scale. The analyses are primarily for mid-to-large scale coupled effects. For this activity, each paragraph describes a separate set of calculations or analyses performed by the investigators.

Calculations show that refluxing, or the heat-pipe effect, may be important to Mined Geologic Disposal System design because it maintains local temperatures near the boiling point, making it more difficult to dry the rock out. Consequently, the relative humidity may remain high, increasing the likelihood of a liquid film on waste package surfaces. Refluxing can also bring mobile liquid water in contact with waste packages, affecting container lifetime, waste-form dissolution, and radionuclide transport.

Based on experience with geothermal systems, some have hypothesized that heat-pipe zones could cause the repository to remain at the nominal boiling point. The heat-pipe zones would function as "cooling fins," attracting heat from other locations in the repository. If this preferential heat flow from the neighboring rock into the heat-pipe zone primarily occurs as heat conduction, the thermal gradients associated with that conduction will necessitate that the temperature at other locations in the repository be elevated above the boiling point. These calculations indicate that it is very unlikely that these heat-pipe zones will cause the temperature of the entire repository to remain at the boiling point.

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Additional calculations addressed the impact of buoyant, gas-phase convection on bulk moisture movement in the unsaturated zone. The net buildup in liquid water above the repository (ΔV) as a function of bulk permeability (K_b) was examined. Because the model is an equivalent continuum formulation, nonequilibrium fracture flow (and hence much of the potential shedding of water) is not modeled; therefore, the predicted net water buildup is larger than that expected in the field. The dependence of ΔV vs. K_b is very nonlinear for the 67- to 122-MTU/ha cases. The water buildup increases abruptly at 1 darcy for the 122-MTU/ha case and at 10 darcy for the 67-MTU/ha case. Where the impact of mountain-scale, buoyant, gas-phase convection is greatest, the low-to-intermediate areal mass loading cases result in the largest ΔV . For intermediate- K_b (280 millidarcy to 1 darcy), where the impact of mountain-scale gas convection is relatively moderate, ΔV for the various areal mass loading cases generally varies by less than a factor of two.

Repository-scale unsaturated zone-saturated zone equivalent continuum models were used to analyze the sensitivity of mountain-scale, buoyant, gas-phase convection to K_b . The K_b distribution was varied vertically in consideration of the unpublished K_b data of Weeks (USGS), which indicates considerable layering of K_b . In particular, it appears that K_b may be far smaller in the nonwelded units (PTn and CHn) than in the welded units. For the uniform- K_b case, mountain-scale convection behaves as though it is in an open system with respect to the ground surface. When K_b in the PTn is reduced, this unit functions as a gas-phase flow barrier or "vapor cap," effectively isolating the convection cells from the ground surface for low areal mass loading. A reduced K_b in the CHn also reduced water buildup by half. Reducing K_b in both the PTn and CHn reduces water buildup by another factor of two relative to the case with the reduced K_b in the PTn for low areal mass loading. For the high areal mass loading cases, an open convective system results in a much more substantial loss of water vapor to the atmosphere than for a low areal mass loading repository. A reduced K_b in the CHn reduces water buildup by nearly half compared to the homogeneous system, which is similar to the effect shown for the low areal mass loading repository although both cases have only about one-third the water buildup of the corresponding low areal mass loading cases. Reducing K_b in the PTn produces a water buildup larger than the other high areal mass loading cases, and about the same as the corresponding low areal mass loading case. Reducing K_b in both the PTn and CHn for the high areal mass loading case also produces about the same water buildup as the low areal mass loading case.

A comparison of the net total liquid saturation buildup (ignoring shedding) above the repository for a range of thermal loads and K_b cases was performed. To the first order, for the above-boiling cases, the maximum total net saturation buildup is proportional to the repository area and therefore decreases with increasing areal mass loading. For 274 MTU/ha and $K_b = 10$ millidarcy, the net saturation buildup above the repository is less than zero (a net decrease in liquid saturation). For low K_b , the sub-boiling cases result in less net saturation buildup than for 274 MTU/ha. For high K_b , the sub-boiling cases result in substantially greater net saturation buildup than the 274-MTU/ha case. To first order for high K_b , the maximum total net saturation buildup is also proportional to the repository area and therefore decreases with increasing areal mass loading.

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The effect of enhanced gas-phase diffusion on repository-scale hydrothermal performance was examined. It has been observed that in soils, the movement of water vapor in the gas phase due to diffusive transport is greater under nonisothermal conditions than under isothermal conditions. Under nonisothermal conditions, the diffusive flux is affected by the diffusion enhancement factor, τ_e , which depends on the saturation and temperature. In soils, τ_e can be as large as 5. The effects of varying τ_e were considered in a calculation with an areal mass loading of 384 MTU/ha and a permeability of 280 millidarcies. Increasing τ_e from 0.2 to 2 has only a minor effect in reducing temperature and the amount of liquid water buildup above the repository.

It has been suggested that enhanced gas-phase diffusion might transport extra water to the repository from the water table at late times, well after temperatures have dropped below boiling. Because gas-phase diffusion is primarily driven by temperature gradients, it is useful to consider the temperature difference between the top of the saturated zone and the repository horizon. Because the repository is the primary source of heat flow for a long time, temperatures at the repository exceed those at the top of the saturated zone for a long time. As long as this occurs, the diffusive flux of water vapor below the repository will be downward. Eventually, the geothermal flux will again dominate the vertical temperature profile, causing it to be reversed. Thermohydrologic calculations show that the diffusive flux of water vapor from the saturated zone will be directed up toward a low areal mass loading repository long before it is for a high areal mass loading repository and that the contribution of the diffusive flux of water vapor from the saturated zone to the overall moisture balance at the repository will be greater for low areal mass loading than for high areal mass loading. This result corroborates calculations that show the net effect of enhanced vapor diffusion on the moisture balance at the repository is to make it drier rather than wetter.

A paper entitled "The Impact of Buoyant, Gas-Phase Flow and Heterogeneity on Thermo-Hydrological Behavior at Yucca Mountain" (Buscheck and Nitao) was prepared for the 1994 High-Level Waste Conference. Another paper entitled "Repository-Heat-Driven Hydrothermal Flow at Yucca Mountain, Part I: Modeling and Analysis" (Buscheck and Nitao, 1993a), was published in Nuclear Technology. These papers provide more detail about the work described in this section.

A paper entitled "Dispersivity in Heterogeneous Permeable Media" (Chesnut) was prepared for the 1994 High-Level Waste Conference. This paper addresses the impact of heterogeneity on early breakthrough of radionuclides to the saturated zone. The results of this paper and subsequent work indicate that a robust engineered barrier system may be required. A preliminary application of the results to radionuclide transport was included in a paper presented at the Project Technical Program Review.

A paper published in Nuclear Technology, "Implications of Episodic Nonequilibrium Fracture-Matrix Flow on Repository Performance" (Nitao et al., 1993), was a combination of numerical and analytical treatments of nonequilibrium fracture flow. It indicated that simple analytical expressions for approximating nonequilibrium transport were corroborated by the results from the numerical models. The analytical expressions illustrate the relative

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contributions of various retardation mechanisms, including matrix imbibition, matrix diffusion, and chemical adsorption in the fractures and in the matrix.

Forecast: Verification of the V-TOUGH code, including benchmarking against similar codes, will be emphasized. Effort will also focus on the development of three-dimensional models of the near-field and altered zones. Development of coupling geochemistry with hydrothermal flow will continue, primarily with the NUFT code. The analysis of the thermo-hydrological conditions around waste packages will continue with emphasis on the gas-phase conditions (i.e., relative humidity and air mass fraction).

2.6.2.4 Study 1.10.4.3 - Characterization of the Geomechanical Attributes of the Waste Package Environment

A draft activity plan for geomechanical investigations is in technical review and will be issued during the next reporting period.

Assessment of instrumentation for the laboratory and field block tests continued. Staff visited a potential vendor to evaluate a frequency modulated laser ranging system for use in the measurement of displacements in laboratory and field tests. The frequency modulated system would circumvent many of the limitations of the conventional multiple borehole extensometer systems. However, it currently does not provide the required precision and needs more development.

Activity 1.10.4.3.1 - Block stability analysis. Preparation of the laboratory facilities for characterization of material from the Large Block Test site continued. This includes repair and modification of the 360 ton press, and procurement and/or assembly of measurement and data acquisition systems. Progress was made on the fabrication of a pressure control system for the laboratory block tests and purchase of a conventional multiple-point borehole extensometer for the Large Block Test. Materials were received for a prototype guard heater for the Large Block Test, which is being assembled for testing. Samples for geomechanics testing were selected from the Large Block Test core holes and were requested from the Sample Management Facility.

Activity 1.10.4.3.2 - Borehole damage analysis. No progress during the reporting period; this was an unfunded activity.

Activity 1.10.4.3.3 - Geomechanical properties analysis. Staff continued design and planning of the acoustic measurements to be made on the laboratory and main large block tests. These include assessment of acoustic sources and receivers, design of experiment geometry, and interfaces with other experiments on the Large Block Test.

Work on the numerical modeling subtask includes initiation of efforts to simulate the geomechanical response of the Large Block Test during the heat-up phase; this simulation will be coupled to the hydrologic analysis. Stress and temperature boundary conditions prescribed for the Large Block Test will be incorporated along with isotherms for various

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times after the start of heating. The rock block response will be evaluated using different constitutive models to estimate stress and displacement fields at different stages of the heat-up phase. To assist in evaluation of options for design of the Large Block Test loading system, three different loading geometries were simulated to determine the nature of stress fields and stress gradients for each.

A design was developed for the initial laboratory block experiments in support of the Large Block Test. The purpose of these experiments is to evaluate techniques and equipment to be used in the Large Block Test and in the laboratory scale block tests. The following test geometry and boundary conditions are proposed. A cubic sample will be prepared from material excavated from the site. The cube will be loaded in uniaxial compression, with load applied to the top and bottom faces. A thermal gradient will be imposed between the bottom and top faces by heating the bottom face with a guard heater assembly. The sides of the cube will be insulated. The following parameters will be measured at several locations on or in the block: temperature, displacement, acoustic velocity, and internal stress. This one-dimensional thermomechanical test will allow evaluation of guard heater assemblies, and diagnostics for sensors. In addition, the temperature control system for guard heaters will be evaluated.

Forecast: The laboratory testing of thermomechanical responses of small blocks will begin. Preparation of instrumentation for geomechanics measurements on the Large Block Test will take place during the next reporting period. Preliminary coupling of geomechanical and hydrologic models for the Large Block Test will begin.

2.6.2.5 Study 1.10.4.4 - Engineered Barrier System Field Tests

A paper entitled "Repository-Heat-Driven Hydrothermal Flow at Yucca Mountain, Part II: Large Scale In Situ Heater Tests" (Buscheck and Nitao, 1993b) was published in Nuclear Technology. This paper applies the mountain-scale models to field-scale tests. The results will be used for preliminary design of the Engineered Barrier System field tests to be conducted in the Exploratory Studies Facility.

The activity plan for the Large Block Test was issued in March 1993. This plan adds details to the previously issued Scientific Investigation Plan. Both plans have been provided to NRC.

A paper on the Large Block Test entitled "The Testing of Thermal-Mechanical - Hydrological-Chemical Processes using a Large Block" (Lin et al.) was prepared for the 1994 High-Level Waste Conference. An abstract entitled "A Heated Large Block Test for High Level Nuclear Waste Management" (Lin et al.) was submitted to the Eighth International Congress on Rock Mechanics. These papers describe the planning and construction of the Large Block Test. Some of that information is summarized in the remainder of this section.

The Large Block Test Task Leader attended a meeting to discuss the possibility of using existing Nevada Test Site tunnels for thermohydrological field tests. Input was

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provided to YMSCO. Although this option was not deemed to be economically feasible at this time, it was an important alternative to the existing program, and it merited consideration.

Activity 1.10.4.4.1 - Repository horizon near-field hydrologic properties. Leveling and surface fracture mapping of the Large Block Test site was completed. The location of the block was determined based on the distribution and orientation of fractures on the surface. Drilling of vertical instrument holes in the large block was completed in December 1993. The core had fewer minerals in the fractures than was anticipated. Preliminary indications were that the block is suitable for planned tests of several thermohydrological hypotheses. A television camera was used to log all of the holes and neutron logging was conducted in four holes to estimate the current moisture content in the block. Fractures in the cores were mapped. The data collected included fracture location (in terms of depth), dip angle, aperture, mineralogical coatings and fill, and alteration zones. Some core sections were selected for determining porosity, pore size distribution, and mineralogy. A request for additional samples has been submitted to the Sample Management Facility so that measurements may be conducted in the laboratory. Air permeability measurements were conducted and the permeability at the potential heater horizon in the block ranges between 5 and 10 millidarcy. Scoping calculations indicate that the permeability level is suitable for creating a dryout zone and a condensate zone in the block by heating from internal heaters, as planned. Sawing of the large block was completed in February 1994 and excavation will be completed in the next reporting period. The fracture flow visualization experiment was completed, and fractures on the surface of the test area were mapped. Electrical resistivity tomography was conducted during the infiltration. Preliminary results indicate dominating fluid conducting zones under the ponded area.

Two meter scale blocks will be removed as part of the large block construction. These blocks will be used to support radionuclide transport tests at Los Alamos National Laboratory. Sawing required to collect the meter-size blocks was completed in February 1993. Later in the mucking process, the two blocks will be removed for testing.

Large Block Test loading frame drawings were prepared by the fabricator, approved by the design engineer, and construction of the dome portion of the load-retaining frame has been completed.

Diagnostic probes designed to measure thermal conductivity and diffusivity will be installed.

Technical progress was made in the identification and evaluation of techniques and instrumentation to be used in both laboratory tests on small blocks and the Large Block Test. Preliminary designs for laboratory tests on smaller blocks were completed. The designs are subject to revision based on the size of the small blocks available from Fran Ridge.

Activity 1.10.4.4.2 - Repository horizon rock-water interaction. No progress during the reporting period; this was an unfunded activity.

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Activity 1.10.4.4.3 - Numerical analysis of fluid flow and transport in repository horizon near-field environment. Thermohydrological calculations were performed to support the large block testing.

Forecast: Comment resolution of Study Plan 8.3.4.2.4.4 will be completed. The block isolation excavation will be completed. The large block will be characterized and instruments will be installed.

2.6.2.6 Study 1.10.4.5 - Characterize the Effects of Man-Made Materials on Water Chemistry in the Postemplacement Environment

Activity 1.10.4.5.1 - Effect of grout, concrete, and other repository materials on water composition. Progress at the New Zealand natural process analog site is discussed in part in Section 2.6.2.2. Preliminary results from the biodegraded cement cores indicate the presence of both thiobacillus and nitrifying bacteria in the cement exposed to geothermal conditions. Groundwork for a contract to address long-term biodegradation of cement has been accomplished and is in procurement. This contract is essential to determination of pH values of water in contact with cementitious materials. A paper describing the activities leading to this work entitled "Progress in Understanding the Structure and Thermodynamics of Calcium Hydrates" (Meike et al.) was prepared for the 1994 High-Level Waste Conference.

Accelerated hydrous diesel fuel pyrolysis experiments at elevated temperature continued. The first analyses of the 300°C H₂O-diesel fuel-fibercrete™ experiments are presently being assessed. This work was described in a poster session at the Project Technical Program Review and in a paper entitled "Experimental Investigation of Hydrous Pyrolysis of Diesel Fuel and the Effect of Pyrolysis Products on the Candidate Nuclear Waste Repository at Yucca Mountain" (Jackson and Carroll) that was presented at the Materials Research Society Symposium. The results will be considered in diesel vs. electric decisions by the Exploratory Studies Facility Design team.

Meetings were held to discuss the potential chemical ramifications of the presence of diesel exhaust in the Exploratory Studies Facility and the potential repository at Yucca Mountain. A proposal for the study of these effects through both historical analogs and experiments has been submitted.

A paper entitled "Introduced Materials and Colloid Formation: A Report on the Current State of Knowledge" (Meike and Wittwer) was presented at the Materials Research Society Symposium. This paper describes work done during previous reporting periods; it provides a basis for initiating performance assessment models that consider the interactions of radionuclides with colloids that may have formed from materials used in the repository.

Activity 1.10.4.5.2 - Effects of container and borehole liner corrosion products on water chemistry. No progress during the reporting period; this was an unfunded activity.

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Activity 1.10.4.5.3 - Effects of man-made materials in presence of radiation field. No progress during the reporting period; this was an unfunded activity.

Activity 1.10.4.5.4 - Numerical analysis and modeling of man-made materials/water interaction. The development of three-dimensional representation techniques began. Installation of EARTH VISION software was completed, and test cases were run. Data sets specific to Yucca Mountain were collected. These sets will be used as the basis for representing mineralogical and chemical changes associated with various waste loading scenarios and repository geometrics.

The preliminary phase of modeling downhole mineralogy at Wairakei, using fluid chemistries obtained from active wells, was completed. The results were presented at FOCUS '93, and at the October 14, 1993, DOE-NRC Technical Exchange. The results demonstrated that good correspondence can be achieved between downhole mineralogy and simulations, for specific choices of Fe- and Al-controlling phases. Work is now under way to develop guidelines for selecting the controlling phases.

Forecast: Experimental analysis of the reaction products of the hydrous pyrolysis of diesel fuel and other appropriate hydrocarbons will continue. A report on the results to date will be issued. Long-term field experiments have been initiated in conjunction with the metallic barriers and geochemistry tasks. Once the samples are emplaced, the experiments will require minimum effort for maintenance until the samples are removed and analyzed in 12-18 months. Activities related to the biodegradation of cement will also continue. In support of the August 1993 decision regarding diesel fuel usage in the Exploratory Studies Facility, the man-made materials task will conduct chemical and microbial analyses of effects related to diesel exhaust deposits in N-tunnel.

2.6.3 Characteristics and Behavior of the Waste Form (SCP Section 8.3.5.10)

2.6.3.1 Activity 1.5.1.1 - Integrate Waste Form Data and Waste Package Design Data

Subactivity 1.5.1.1.1 - Integrate spent fuel information. Resolution of comments on the Preliminary Waste Form Characteristics Report was completed.

Subactivity 1.5.1.1.2 - Integrate glass waste form information. Resolution of comments on the Preliminary Waste Form Characteristics Report was completed.

Subactivity 1.5.1.1.3 - Integrate waste package and repository design information. No progress during the reporting period; this was an unfunded activity.

Forecast: The Preliminary Waste Form Characteristics Report will be published.

2.6.3.2 Activity 1.5.2.1 - Characterization of the Spent Fuel Waste Form

Old and unusable spent fuel samples prepared by the Materials Characterization Center at Pacific Northwest Laboratory under a subcontract are being repackaged to reduce vulnerabilities. Part of the repackaging effort is physical measurement of each sample to allow calculation of Special Nuclear Material content for inventory purposes. A data base was set up to record measurements.

The liquid radioactive waste disposal holding tank for the Pacific Northwest Laboratory analytical hot cells is being replaced. Until completion near the end of March 1994, only minor amounts of radioactive liquid waste can be generated, which precludes operation of any flow-through tests.

Subactivity 1.5.2.1:1 - Dissolution and leaching of spent fuel. An activity plan was written and issued for ongoing unsaturated (dripping water) dissolution testing that will be performed at Argonne National Laboratory. The unsaturated tests were initiated at Argonne National Laboratory in FY 1993 to evaluate the long-term dissolution performance of spent fuel under unsaturated conditions at 90°C. The seven tests had 450 days of testing by the end of December 1993. Similar tests on UO_2 have been ongoing for about eight years. Transmission electron microscope samples of the leachate have been examined. Colloidal species were found in both leachates, and consisted of clay particles containing large amounts of manganese and nickel. Uranium was uniformly dispersed throughout these clay particles; no major uranium phases or rare earth elements were detected. This work was reported in three papers: (1) "Elements Present in Leach Solutions from Unsaturated Spent Fuel Tests" (Finn et al.), presented at the Materials Research Society Symposium; (2) "Colloidal Products and Actinide Species in Leachage from Spent Nuclear Fuel" (Finn et al.), presented at the Fourth International Conference on the Chemistry and Migration of Actinides and Fission Products in the Geosphere, and being reviewed for publication in *Radiochimica Acta*; and (3) "The Effect of Fuel Type in Unsaturated Spent Fuel Tests" (Finn et al.).

The following additional papers on this subject were prepared for the 1994 High-Level Waste Conference: "Rationale for Determining Spent Fuel Acquisitions" (Marschman et al.), which discussed planning for specimens to be used in future characterization, and "Comparison of Uranium Dissolution Rates from Spent Fuel and Uranium Dioxide" (Steward and Gray).

A paper entitled "In Situ Photothermal Deflection Spectroscopy of Uranium Dioxide Dissolution" (Rudnicki et al.) discussed experimental work to obtain dissolution data using state-of-the-art equipment.

A report summarizing the experimental data and analysis of the uranium dioxide dissolution rates entitled "Modeling of UO_2 Aqueous Dissolution Over a Wide Range of Conditions" (Steward and Weed, 1993) was published. The tests examined the effects of temperature and concentrations of carbonate, oxygen and hydrogen ions on aqueous dissolution of UO_2 and spent fuel. Results indicate that dissolution rates are most strongly dependent on dissolved oxygen concentration and that the oxygen dependence is sensitive to

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both sample type (spent fuel or unirradiated UO_2) and temperature. Aside from oxygen concentration, dissolution rates are most dependent on temperature followed by a lesser dependence on carbonate concentration. Changes in pH had the least effect on the dissolution rates. Both sets of data show the expected linear Arrhenius type dependence of the logarithmic dissolution rate on inverse temperature, although the activation energies are different for UO_2 and spent fuel. Increased levels of dissolved oxygen increase the dissolution rate in both, but the effects vary in magnitude. Whether the differences are significant is yet to be determined. The dissolution response to carbonate concentration seems nonlinear in both studies. Mean dissolution rates differ by less than a factor of two. Two papers entitled "Interlaboratory Comparison of UO_2 Dissolution Rates" (Gray et al.), and "The Effect of Fuel Type in Unsaturated Spent Fuel Test" (Finn et al.) were prepared for the 1994 High-Level Waste Conference.

Specimens of pressurized-water reactor and boiling water reactor spent fuel were prepared for dissolution testing as oxidized fuel. Part of the preparation involves exposing short sections of the fuel and its associated cladding to deionized water for one week. These waters will be analyzed to determine the gap inventories of ^{137}Cs , ^{129}I , and other radionuclides. Following the water exposure, portions of each fuel will be oxidized to U_3O_8 for use in flow-through dissolution tests. Other portions are ground and screened to produce specimens consisting of individual grains. These will be subjected to short-term dissolution tests designed to measure the grain-boundary inventories. The specimens will then be used in flow-through dissolution tests where the results will be compared with test results from other specimens that were oxidized to U_4O_{9+x} .

Subactivity 1.5.2.1.2 - Oxidation of spent fuel. An interim examination of drybath oxidation tests was conducted. The sample weights continued to rise in the 255°C test and are up to an oxygen-to-metal ratio as high as 2.57 in some cases. No plateau was formed at an oxygen-to-metal ratio of 2.4 as has been observed in other tests. As previously reported, these samples are primarily U_4O_9 with only a trace of U_3O_8 . The remainder of the tests showed no unusual weight gains. A suite of samples was selected from the tests in the oxygen-to-metal range of 2.4 to 2.6 for electro-optical examination for additional phases.

A new waste bucket was installed in the Pacific Northwest Laboratory hot cell. In the process, a lead feedthrough plate fell, destroying one unused drybath and displacing another. After cleanup, samples from the baths were reweighed. Significant mass losses were found only for powdered samples in the displaced bath. This loss should have no impact on the test data as it can be corrected by treating it as if a subsample had been removed. It is not thought that there was any cross contamination. In all probability, when the bath was impacted, the lid lifted off the bath and some of the fine material in the powdered samples became airborne and dispersed into the cell proper. Since it was not determined that the mishap influenced the validity of the tests, the drybaths were restarted. The tests at Pacific Northwest Laboratory have run without incident since restart. Another full interim examination is not planned until near the end of the fiscal year. The time for the next interim exam on the 255°C and 195°C tests will be determined near the end of this reporting period.

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To determine the character of the oxidation beyond an oxygen to metal ratio of 2.4, a series of drybath samples having oxygen to metal ratios from 2.4 to 2.56 was analyzed by quantitative x-ray diffractometry. Results indicate that the cubic $\text{UO}_{2.4}$ phase in oxidized spent fuel transforms to a metastable amorphous phase before it forms crystalline U_3O_8 . The x-ray results clearly demonstrate the disappearance of the $\text{UO}_{2.4}$ phase without detectable formation of U_3O_8 or higher oxides at oxygen to metal ratios as high as 2.55.

In addition to the drybath oxidation tests, spent fuel oxidation tests with a thermogravimetric apparatus are being conducted at Pacific Northwest Laboratory to address the phase stability of the U_4O_9 plateau, and the temperature-time responses as the uranium oxide of this plateau transitions to higher phases. A revision to the existing thermogravimetric apparatus test plan has been completed. Review comments are being addressed. Some preliminary thermogravimetric apparatus tests of spent fuel oxidation were run at 255°C to obtain the initial rise-to-plateau part of the oxidation curve and at 270°, 283°, and 304.5°C to obtain full oxidation curves. All of these tests have been completed. Higher temperatures produce increased oxidation and powdering of the samples.

X-ray diffraction analyses were performed on a 283°C fragment that was oxidized to a final oxygen-to-metal ratio of 2.79 and on a 325°C fragment that was oxidized to a final oxygen-to-metal ratio of 2.73. In both cases, the analysis indicates almost complete conversion to U_3O_8 with only a small amount of U_4O_9 remaining. Initial scanning electron microscope analysis of that 283°C fragment revealed large amounts of inter- and intra-granular cracking as well as crystal growth on the surfaces of many particles. Scanning electron microscope analysis of the 325°C sample revealed much finer particles with even more inter- and intra-granular cracking. There is evidence of some crystal growth; however, there is not as much growth as in the sample oxidized at 283°C.

Subactivity 1.5.2.1.3 - Corrosion of zircaloy. No progress during the reporting period; this was an unfunded activity.

Subactivity 1.5.2.1.4 - Corrosion of and radionuclide release from other materials in the spent fuel waste form. No progress during the reporting period; this was an unfunded activity.

Subactivity 1.5.2.1.5 - Evaluation of the inventory and release of carbon-14 from zircaloy cladding. A paper on ^{14}C release entitled "Behavior of Carbon-14 in Waste Packages for Spent Fuel in a Tuff Repository" (Van Konynenburg) was prepared for the 1994 High-Level Waste Conference. This paper supports the National Academy of Sciences activity mandated by the Energy Policy Act (U.S. Congress, 1992).

Subactivity 1.5.2.1.6 - Other experiments on the spent fuel waste form. No progress during the reporting period; this was an unfunded activity.

Forecast: The hot cell oxidation and dissolution activities will continue. The hot-cell, drybath oxidation testing will be augmented by the thermogravimetric analysis oxidation testing. The data obtained from these tests will address the time-temperature oxidation

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response of the UO_2 lattice and its transformation to higher oxidation phases. Of particular concern is the temperature domain between $200^\circ - 270^\circ\text{C}$, and the rate at which U_3O_8 is formed in this temperature interval. In addition to the oxidation testing, the flow-through dissolution testing will continue, with primary emphasis on the higher oxidation states of spent fuel. These tests provide an upper bound for the release rate response for the domain of water chemistries being used. Also, the unsaturated (dripping water) tests on spent fuel forms will continue. Additional characterization of the colloids from these tests will be performed.

2.6.3.3 Activity 1.5.2.2 - Characterization of the Glass Waste Form

Work is in progress on the Activity Plan for Glass Dissolution Modeling.

Subactivity 1.5.2.2.1 - Leach testing of glass. Tests on Savannah River Laboratory actinide-doped glass continued as scheduled at Argonne National Laboratory with sampling occurring December 22, 1993. These tests have been in progress for over eight years. This was the first sampling of these tests since May 3, 1990. Throughout the 3.5-year period, the test vessels have registered pressure which indicates that some water was retained in the vessel; however, there was some question as to how the sealing gasket was retaining its integrity. Tests with glass were sampled and all had retained more than 10 mL of solution. Aliquots were taken for pH, carbon anion, actinide, cation, and colloid analyses. The remaining liquid was retained in the test vessels which were sealed and stored for later analysis and use in potential tests. The glass samples were transferred to clean vessels with new gaskets and the tests were continued. A blank test was sampled, the liquid removed from the vessel, and the test continued.

The West Valley actinide-doped glass dissolution tests at Argonne National Laboratory were also sampled for the first time in nearly 3.5 years, for analysis of pH, carbon, radio-nuclides, anions, cations, and colloids. The glass had undergone significant reaction with a gray-green layer covering the top and side surfaces of the glass. There were areas on the side surfaces of the glass where the layer had broken free and had been transferred to solution. Additional analyses of these samples are reported in Subactivity 1.5.2.2.2.

A paper entitled "Results of Drip Tests on Sludge-Based and Actinide-Doped Glasses" (Bates and Buck) was approved by YMSCO and will be published in the Proceedings of the 1994 High-Level Waste Conference. This paper describes ongoing work on glass leach testing.

Sixteen parametric tests of Defense Waste Processing Facility and West Valley (New York) Demonstration Project glass are continuing; some have been in progress for up to eight years. No sampling has been done in several years and none is anticipated this year, although the solution injections will continue. Several dozen tests on glasses exposed at 70°C with 60 and 95 percent relative humidity continue. An activity plan will be written to complete the planning for continuing initially-scoping parametric studies of West Valley Demonstration Project and Defense Waste Processing Facility glass under full Quality Assurance Program

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control. No test terminations have been done for several years and none are planned for this year.

Subactivity 1.5.2.2.2 - Materials interactions affecting glass leaching. During the sampling of the Savannah River Laboratory glass tests (described in Subactivity 1.5.2.2.1), an additional reaction was observed in one of the tests, for the first time, between the glass and the metal retainer holding the glass in position. There was a strong interaction that resulted in the bottom metal component taking on a rusted appearance, and considerable particulate material in the solution. The solution was analyzed for colloids using analytical electron microscopy. The sample which showed a strong interaction between the metal holder and the glass (the metal was oxidized), exhibited a large number of iron-rich particles (some attached to clay). In another sample, a small amount of calcium thorium phosphate phase was found. The phase was buried within an iron silicate. This phase was previously identified as brockite (ideally $[\text{Ca,Th}](\text{PO}_4)_2 \cdot \text{H}_2\text{O}$), and shown through autoradiography techniques to contain actinides. The particles found in this sample were colloidal and the amount of thorium was barely detectable. Large agglomerates that produced a smectite-type diffraction pattern were also observed. The agglomerates have concentrated regions which are iron rich. A barium-lead particle, which may also contain Al and Si was observed together with the clay phases which contained a thorium calcium phosphate at trace levels. Actinides were not detected in this phase.

Subactivity 1.5.2.2.3 - Cooperative testing with waste producers. No progress during the reporting period; this was an unfunded activity.

Forecast: Additional characterization of the colloids that exist in the solutions from the unsaturated tests will be conducted. The amount of solution available is limited, and the characterization data from the glass waste form and spent fuel waste form will be compared.

2.6.3.4 Activity 1.5.3.1 - Integrate Scenarios for Release From Waste Packages

Subactivity 1.5.3.1.1 - Develop scenario identifications. Development of the YMIM code continued, including both testing and planning for code qualification. Code qualification is the verification and validation work required to certify the code for application to the YMSCO nuclear waste isolation impact assessment. A verification and validation plan for the YMIM code was drafted.

Subactivity 1.5.3.1.2 - Separate scenarios into anticipated and unanticipated categories. No progress during the reporting period; this was an unfunded activity.

Subactivity 1.5.3.1.3 - Development of parameters describing the scenarios. Information pertaining to this subactivity is provided under Subactivity 1.5.3.1.1.

Subactivity 1.5.3.1.4 - Determine adequacy of design envelope of waste package. Information pertaining to this subactivity is provided under Subactivity 1.5.3.1.1.

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Forecast: See Section 2.6.3.8. The models described in that section will be used to integrate scenarios for follow-up Total System Performance Assessment activity.

2.6.3.5 Activity 1.5.3.2 - Develop Geochemical Speciation and Reaction Model

Activity Plan D-20-54, "Actinide Solubilities: Solubility Measurements and Thermodynamic Data Determinations," was issued on December 7, 1993.

Subactivity 1.5.3.2.1 - Develop data base for geochemical modeling. A review of recently published thermodynamic data for Np, Am, Pu, and Tc species has been initiated. These data will be used to augment those already in the GEMBOCHS data base until publication of the Nuclear Energy Agency-thermochemical data base critical reviews of the chemical thermodynamics of these species. These reviews, to be published as separate volumes in the series, began with the uranium compilation (Grenthe et al., 1992) and will be available in the next few years.

Development continued of a Windows/4GL version of the JEWEL pre-processor. Several new features have been incorporated:

1. A "composite" data file for approximately 300 aqueous Np, Pu and Am species can now be generated.
2. Species whose thermodynamic properties are calculated using SUPCRT92 algorithms, but with data reported by subsequent publications, can now be referenced appropriately.
3. Both calculated and reported reference-state standard molal properties are now printed.

Development of a Windows/4GL version of the FACET data base management program has been initiated. This program facilitates interactive point-and-click review, revision, deletion, and addition of GEMBOCHS data.

Subactivity 1.5.3.2.2 - Develop geochemical modeling code. EQ3/6 Version 7.2a was completed on December 28, 1993. Principal improvements included:

1. The personal computer interface software operates correctly under straight DOS (previously it worked only in a DOS window under Windows 3.1).
2. The CHEMVAL data base is now in the package. It is unique in that it uses "e" as the redox species instead of $O_2(g)$.
3. Convergence behavior in systems containing highly concentrated aqueous solutions is much improved.

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The EQ6 run times for modeling such systems have been dramatically reduced, and convergence failures upon attempting to precipitate certain salt mineral assemblages have been eliminated.

Distribution packages of EQ3/6 Version 7.2a were prepared for all existing Project users. Packages were also prepared, at the direction of YMSCO, for a new user at Los Alamos National Laboratory and for the CHEMVAL study participants. The packages have been transmitted and all Project participants using EQ3/6 have now been updated with Version 7.2a.

Work continued on EQ3/6 Version 8.0. In FY 1993, a major rewrite of the software was completed, incorporating major changes in the data structure in order to accommodate improvements in numerical methods and the addition of new functional capabilities. The EQ6 code was modified to utilize the auxiliary basis concept, thus allowing it to make reaction path calculations incorporating specified redox disequilibria. This capability is important in treating the metastable persistence of dissolved components such as sulfate, nitrate, and organics in laboratory and field settings. In FY 1994, two additional capabilities to EQ3/6 will be added: (1) a generic ion-exchange model; and (2) correction of supporting data, mostly thermodynamic, to pressures off the 1.013 bar-steam saturation curve. Release of EQ3/6 Version 8.0 for non-quality affecting work is planned for late in FY 1994.

Forecast: The United States contribution to the Nuclear Energy Agency Am volume will be completed. Development of GEMBOCHS related software will continue. EQ3/6 Version 8.0 will be completed.

2.6.3.6 Activity 1.5.3.3 - Generate Models for Release From Spent Fuel

Subactivity 1.5.3.3.1 - Generate release for spent fuel models. No progress during the reporting period; this was an unfunded activity.

Forecast: No activity is planned for FY 1994.

2.6.3.7 Activity 1.5.3.4 - Generate Models for Release From Glass Waste Forms

Subactivity 1.5.3.4.1 - Generate release models for glass waste forms. No progress during the reporting period; this was an unfunded activity.

Forecast: No activity is planned for FY 1994.

2.6.3.8 Activity 1.5.3.5 - Waste Package Performance Assessment Model Development

Subactivity 1.5.3.5.1 - Development of system model. A paper entitled "On Integrating Modeling Software for Application to Total System Performance Assessment" (Lewis and

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Wilson) was submitted to the American Nuclear Society SPECTRUM '94 Conference, to be held in Atlanta, Georgia, August 14-18, 1994, describing methods used to integrate YMIM code modules into the computer models for the Sandia National Laboratories 1993 Total System Performance Assessment. The Total System Performance Assessment-1993 models predict waste package source term response in terms of predicted contaminant release-time profiles from the engineered barrier repository subsystem. This work incorporates temperature effects on container failure rates and contaminant release.

The final draft of "Near-Field Diffusion Through One and Two Finite Zones from a Nuclear Waste Package" (Ueng and O'Connell) was accepted for publication in the American Nuclear Society Journal Nuclear Technology.

Final borehole-emplacement hottest-fuel temperature histories were provided for Total System Performance Assessment-1993 with compromise boundary conditions imposed on the rock wall. This compromise applied the Sandia National Laboratories-calculated temperatures for the waste package surface onto the rock wall, and should represent the early time thermal transient fairly well with moderate errors at long times (perhaps 20°C high at 1000 years). The Sandia National Laboratories performance assessment team was also provided with time histories of spent fuel rod temperatures at the center of emplaced waste packages, for revised conservative boundary temperature histories. It was verified that the change in spent fuel and waste package effective thermal conductivity is small within the applicable temperature range, and hence a simple model could be used to adjust detailed calculations to the various cases.

Portions of six chapters (text and graphics) were submitted to Sandia National Laboratories for inclusion in the draft Total System Performance Assessment-1993 report: Chapter 3 "Thermal/Emplacement Configurations," Chapter 10 "Thermal Effects," Chapter 13 "Source Term: Near-field Processes," Chapter 22 "Discussion," Chapter 23 "Conclusions/Recommendations" and Chapter 24 "Future TSPA Work." The following papers were approved by YMSCO and will be published in the Proceedings of the 1994 High-Level Waste Conference: "Integrated Modeling of Near Field and Engineered Barrier System Processes" (Lamont and Gansemer), "Identifying Significant Uncertainties in Thermally Dependent Processes for Repository Performance Analysis" (Gansemer and Lamont), "Performance Assessment Model of a Single Waste Package" (O'Connell et al.), and "What Do We Mean By A Cold Repository?" (Halsey). These papers describe the work done in support of Total System Performance Assessment and thermal loading decision studies.

A paper entitled "Demands Placed on Waste Package Performance Testing and Modeling by Some General Results of Reliability Analysis" (Chesnut, 1993) was published in Nuclear Technology. The paper discusses the impact of using multiple, independent, barriers to meeting engineered barrier subsystem requirements prescribed by 10 CFR Part 60.

Pacific Northwest Laboratory submitted its final draft document, "Mathematical Formulations for AREST Upgrades." This document outlines the mathematical formulations to be implemented in the next version of the AREST code to include the data structure, chemical models and transport algorithms. The focus of the AREST upgrade is to ensure that the detailed waste package model accounts for the principal processes affecting container

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degradation, waste form alteration, and radionuclide release to the host rock. The code will be used to perform analyses at the process model level to determine the sensitivity of the radionuclide source term to various near-field parameters. The code will also be used to define and quantify the radionuclide source term for the higher level probabilistic Total System Performance Assessment analyses accomplished with codes such as RIP. A summary of the present development of the AREST code will be presented at the 1994 High-Level Waste Conference as: "Development and Feasibility of a Waste Package Coupled Reactive Transport Model (AREST-CT)" (Engel et al.).

A summary of the present performance assessment models and modelling capabilities for defense high-level waste was presented at the fall Materials Research Society meeting as: "Perspectives on Performance Assessment and High-Level Waste Glass in a Geologic Repository" (McGrail and Engel).

The definition of the status of the model of the radionuclide source term for the spent fuel portion of the waste form will be presented at the 1994 High-Level Waste Conference as: "Preliminary Spent LWR Fuel Oxidation Source Term Model" (Einziger). The paper also discusses the availability and validity of the input data required for the model.

Subactivity 1.5.3.5.2 - Development of uncertainty methodology. No progress during the reporting period; this was an unfunded activity.

Subactivity 1.5.3.5.3 - Water flow into and out of a breached container. No progress during the reporting period; this was an unfunded activity.

Forecast: Continued development of YMIM will improve models of radionuclide inventory, release mode, water contact, and corrosion. The YMIM qualification process will begin. Upgrading of the AREST code will continue. The milestone date for delivery of the draft AREST Design Document is August 1994. The purpose of the AREST Design Document is to provide for the design of new models to be implemented in the code. The document will provide a framework for allowing multiple developers to contribute to this and future upgrades.

2.6.3.9 Activity 1.5.4.1 - Deterministic Calculation of Releases From the Waste Package

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

Forecast: No activity is planned for FY 1994.

2.6.3.10 Activity 1.5.4.2 - Probabilistic Calculation of Releases from the Waste Package

Improved waste package models were developed and release calculations were performed in support of Total System Performance Assessment-1993 as described above.

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Forecast: YMIM and Total System Performance Assessment-1993 scenarios and data sets will be used to perform subsystem analyses to determine importance of information.

2.6.3.11 Activity 1.5.5.1 - Determine Radionuclide Transport Parameters

Subactivity 1.5.5.1.1 - Radionuclide distribution in tuff wafers. Work in this area that is also pertinent to determining the radionuclide distribution in tuff cores is reported under Subactivity 1.5.5.1.2. No significant activity occurred pertaining exclusively to distributions of radionuclides in tuff wafers.

Subactivity 1.5.5.1.2 - Radionuclide distribution in tuff cores. A meeting was held on October 5, 1993, to discuss and plan experiments related to radionuclide transport.

The test phase of the flow-through apparatus was completed and documented in a letter report received by YMSCO. Analysis of the preliminary flow data indicate that constant flow conditions cannot be maintained with the present pump. A piston metering pump has been ordered. The flow-through apparatus will be reassembled when the new pump and a fraction collector for sampling are received.

Forecast: Movement of the Core-Flow Apparatus will be completed and the test program will be resumed. A report on colloid characterization results will be prepared for to YMSCO.

2.6.4 Characteristics and Configurations of the Waste Packages (SCP Section 8.3.4.3)

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

Forecast: No activity is planned for FY 1994.

2.6.5 Waste Package Production Technologies (SCP Section 8.3.4.4)

The principal goal of waste package Advanced Conceptual Design is to evaluate and develop a set of waste package design concepts. As part of this process, technical feasibility and cost effectiveness of the manufacturing processes will be evaluated for each concept. Designs will be evaluated for disposal of both spent nuclear fuel and defense high-level waste. Spent nuclear fuel waste package concepts include the multipurpose canister disposal container.

Engineering development tasks involve test and evaluation of full or reduced scale sections of various waste package design concepts. The tasks will focus on key manufacturing uncertainties specific to each design concept. As the manufacturing processes are developed, and as the results of the prototype testing become available, proposed process specifications will be developed and preliminary fabrication drawings will be generated.

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The five basic areas of the plan are described in the following sections.

2.6.5.1 Design Activity 4.3.1.1- Waste Package Fabrication Process Development

The objective of the fabrication, closure, and inspection tasks is to identify and demonstrate the optimum process for container manufacturing that is consistent with the functional and performance requirements. The solution is complex because the manufacturing method affects the characteristics and properties of the product being produced. These effects must be understood and integrated into the overall program to achieve a selection of materials and manufacturing methods that meet the design requirements. Processes should be technically conservative to ensure safety and long-term performance. In this regard, cost is a concern, but not a top priority. The objective of this development task is to select and develop fabrication techniques that are technically and economically acceptable and produce minimal stresses.

2.6.5.2 Design Activity 4.3.1.2 - Waste Package Closure Process Development

The objective of this development task is to develop remote closure welding processes that are technically and economically acceptable, and will also minimize stresses. Workable methods of repairing defective closure welds must also be developed. The development of welding processes and examination techniques will be performed in concert with waste package container fabrication.

The primary objectives are to produce the lowest possible post-weld tensile stresses and to choose joint configurations that can be inspected. Various closure welding processes will be investigated for each configuration. Other considerations include the quality of the welds, time required to make them, availability of equipment, the ability to use the same equipment for both the inner and outer weld, radiation resistance of the welding equipment, and methods for repair of defective welds or container replacement.

The fabrication industry is continually making advances in development of fully automatic remote welding equipment and process control. This development task is expected to benefit greatly from welding advances. However, the complete isolation of the welding activity within a hot cell and the radiation environment are not typical of industrial welding; therefore, the adaptation of that technology to the waste package closure welds is a major endeavor of this development task.

2.6.5.3 Design Activity 4.3.1.3 - Waste Package Closure Inspection Development

The objective of this task is to develop nondestructive examination techniques that are technically and economically acceptable and can accommodate the selected waste package materials, thicknesses, and geometries. The techniques will have to prove the quality of both inner and outer closure welds.

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Potential flaws in the remotely welded joints must be well understood. Evaluation of weld test samples will provide the data necessary for characterizing the weld defects and for subsequent nondestructive examination. Weld inspection methods must be capable of detecting the types of defects potentially produced by the weld method.

Joint geometry will be a major concern. An ideal geometry would have no reflective surfaces on or near the inner portion of the weld which might interfere with interpretation of the test results. Likewise, it is desirable that the exterior surface in the vicinity of the weld be a simple shape and that there be straight line access to the weld in two orthogonal directions.

2.6.5.4 Design Activity 4.3.1.4 - Remote In-Service-Inspection Development

A performance confirmation program is required by 10 CFR 60.137. The objective of this task is to select and develop remote in-service-inspection equipment and techniques for such a program that are technically and economically acceptable, and which can withstand the radiation field and temperatures of the waste package environment. Sensors may be mounted on or around waste packages and/or sample material coupons, on and within the drift rock walls and within environmental monitoring stations that might be placed in the drifts.

2.6.5.5 Design Activity 4.3.1.5 - Internal Filler Material Process Development

Use of waste package filler materials would assist in achieving several technical objectives. Among these are minimizing the amount of water that could enter the waste package, improving heat transfer, controlling criticality, and providing chemical buffering for radionuclides. The use of fillers may, however, increase waste package or multipurpose canister weight and cost.

The purpose of this task is to perform engineering development activities with regard to use of filler material. Specific activities will include infiltration and determination of uniformity of distribution, effective thermal conductivity, and high-temperature properties. This development task will support both the waste package and multipurpose canister engineering development activities. Filler material, if used, would be remotely added at the Mined Geologic Disposal System after insertion of the spent nuclear fuel and before closure. A method of measuring the quantity of filler material would be required to establish that the proper quantity has been placed.

Internal void space may be filled with either a solid or an inert gas depending on the choice of filler material. Filler materials considered include low melting temperature metals, graded coarse granular solids such as iron shot, or fine materials such as dry cementitious mixes.

Forecast: The Waste Package Engineering Development Task will continue through conclusion of the License Application Design phase.

2.6.6 Waste Package Performance (SCP Section 8.3.5.9)

Discussions of several aspects of waste package performance are given in Sections 2.6.1.4 and 2.6.1.5. These include container oxidation and corrosion, waste package degradation by mechanical stress, thermal degradation of fuel cladding, and gas generation and release.

2.6.6.1 Activity 1.4.1.1 - Integrate Design and Materials Information (Metal Container)

The Metal Barrier Scientific Investigation Plan is being revised to incorporate changes on container material considerations corresponding to the Advanced Conceptual Design. It is anticipated that the new plan will constitute fewer main activities (degradation modes, testing, modeling, recommendations), but each main activity will be divided into several subactivities.

The preparation of the Engineered Materials Characterization Report was started. The report will cover work performed during conceptual design. It will include recommendations of materials for the waste package, and will outline important testing activities for the Advanced Conceptual Design.

The Nickel Development Institute requested information on the status of Project work on candidate barrier materials and has expressed an interest in working on the application of Ni-base alloys in multiple barrier waste package designs.

The YMSCO Design Integration Workshops were held to discuss the Advanced Conceptual Design phase of the Project, and how the efforts of all participants will be integrated. Organizations were discussed, and proposed modification of the present Work Breakdown Structure nomenclature was presented. An ongoing dialogue between organizations responsible for the repository design, the waste package design, and the performance of engineered barrier materials was established as the function of the workshop group.

Subactivity 1.4.1.1.1 - Mechanical properties. No progress during the reporting period; this was an unfunded activity.

Subactivity 1.4.1.1.2 - Microstructural properties. No progress during the reporting period; this was an unfunded activity.

Subactivity 1.4.1.1.3 - Physical properties. No progress during the reporting period; this was an unfunded activity.

Subactivity 1.4.1.1.4 - State of stress in the container. No progress during the reporting period; this was an unfunded activity.

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Subactivity 1.4.1.1.5 - Characterization and inspection of weld integrity. No progress during the reporting period; this was an unfunded activity.

Subactivity 1.4.1.1.6 - Characterization of the container surface. No progress during the reporting period; this was an unfunded activity.

Forecast: The updated Scientific Investigation Plan draft and the Engineered Materials Characterization Report will be submitted within the next two reporting periods.

2.6.6.2 Activity 1.4.1.2 - Integrate Design and Materials Information (Alternate Barriers Investigation)

The work planned for the Nonmetallic Barrier Concepts Task for FY 1994 includes preparation of a survey on possible ceramic materials that could be used in a multiple barrier design, the state of technology in fabricating ceramics of dimensions suitable for a waste package barrier, and possible degradation modes affecting ceramics used for long-term disposal. The various planning documents for this task will be updated and modified, as needed.

Subactivity 1.4.1.2.1 - Survey of alternative barrier designs, materials, and processes to determine feasibility of fabricating a satisfactory waste package.

Ceramic manufacturers were contacted to identify large scale products, and a search of ceramic literature regarding the construction and joining techniques needed to produce large, ceramic waste containment vessels was initiated. These activities seek to identify ceramic materials that could be used in a multiple barrier design, the state of technology in fabricating ceramic materials in dimensions suitable for a waste package barrier, and possible degradation modes affecting ceramics for long-term disposal. This includes systematic searches of abstracts covering the United States, European and Japanese materials literature, collection of relevant papers and paging through a random sampling of publications to find letters, news releases and advertising.

The ability of the ceramic manufacturing industry to produce large, monolithic, oxide ceramic vessels was reviewed. A few companies are capable of doing so, but there has never been a large enough market to justify the capital expenses associated with producing large numbers of such parts.

Arc plasma spray forming is a process currently used to make a small selection of net or near net-shape oxide parts such as crucibles and plates. It is likely that an adaptation of this technique could be used to produce free standing ceramic cylinders in the large sizes required for the Yucca Mountain effort; however, the cost could be prohibitive because a maximum of about 3 kg per hour can be deposited using a plasma sprayer. The current literature suggests that 10 percent or more of porosity is to be expected in a spray formed part, and that internal stresses build up rapidly as the part thickness increases. Further densification and stress relief have been demonstrated using conventional sintering and hot

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isostatic pressing after the part is already formed. A better approach to the problem could be to plasma spray a ceramic coating over and/or within a metal container, thereby protecting the structural metal from the local environment.

The search of available literature regarding the construction and joining techniques needed to produce, assemble, and seal large ceramic waste containment vessels identified several joining techniques potentially appropriate to this work. Diffusion bonding can be used to assemble large, chemically homogeneous pieces from smaller, more easily mass-produced parts. Brazing of ceramic rings approximately 1 m in diameter was accomplished at about 820°C for the Princeton Tokamak reactor. Laser or electron beam welding may be useful for lidding without raising the average temperature of the vessel beyond acceptable limits.

Subactivity 1.4.1.2.2. - Mechanical properties. No progress during the reporting period; this was an unfunded activity.

Subactivity 1.4.1.2.3. - Microstructural properties. No progress during the reporting period; this was an unfunded activity.

Subactivity 1.4.1.2.4 - Thermophysical properties. No progress during the reporting period; this was an unfunded activity.

Subactivity 1.4.1.2.5 - Nondestructive characterization of the alternate barrier investigations waste package container. No progress during the reporting period; this was an unfunded activity.

Forecast: Work will continue on determining the state of technology in fabricating nonmetallic barriers. A report will be prepared for YMSCO.

2.6.6.3 Activity 1.4.2.1 - Selection of the Container Material for the License Application Design

Subactivity 1.4.2.1.1 - Establishment of selection criteria and their weighting factors. No progress during the reporting period; this was an unfunded activity.

Subactivity 1.4.2.1.2 - Material selection. No progress during the reporting period; this was an unfunded activity.

Forecast: No activity is planned for FY 1994.

2.6.6.4 Activity 1.4.2.2 - Degradation Modes Affecting Candidate Copper-Based Container Materials

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

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Forecast: No activity is planned for FY 1994.

2.6.6.5 Activity 1.4.2.3 - Degradation Modes Affecting Candidate Austenitic Materials

Austenitic materials are part of the test matrix reported in Activity 1.4.2.4.

Subactivity 1.4.2.3.1 - Assessment of degradation modes in austenitic container. No progress during the reporting period; this was an unfunded activity. Related discussion is included under Section 2.6.6.6, Subactivity 1.4.2.4.3.

Subactivities 1.4.2.3.2 through 1.4.2.3.9. No progress during the reporting period; these were unfunded activities. The single exception is the inclusion of stainless steels in the test matrix for stress corrosion cracking (see Section 2.6.6.6, Subactivity 1.4.2.4.4).

Forecast: For Subactivity 1.4.2.3.1, the ferrous materials degradation mode survey will be prepared for YMSCO.

2.6.6.6 Activity 1.4.2.4 - Degradation Modes Affecting Ceramic-Metal, Bimetallic/Single Metal, or Coatings and Filler Systems

Subactivity 1.4.2.4.1 - Assessment of degradation modes affecting ceramic-metal systems. No progress during the reporting period; this was an unfunded activity.

Subactivity 1.4.2.4.2 - Laboratory test plan for ceramic-metal systems of the alternate barriers investigations. No progress during the reporting period; this was an unfunded activity.

Subactivity 1.4.2.4.3 - Assessment of degradation modes affecting bimetallic/single metal systems. A subcontract was initiated at Iowa State University to complete the degradation mode survey on ferrous materials (carbon steels, alloy steels, and cast irons) that are being considered in multiple-barrier concepts. Over 80 technical papers and 10 textbooks/handbooks have been obtained and are currently under review. Following completion of the review, additional relevant effects relating to galvanic corrosion, microbiologically influenced corrosion and other subjects will be evaluated. Detailed tables have been prepared for the atmospheric and aqueous corrosion data for these materials. These data represent the majority of the information identified in the literature, and in many cases represent data obtained from years of exposure.

Subactivity 1.4.2.4.4 - Laboratory test plan for bimetallic/single metal material systems. Stress corrosion crack growth test work resumed in August 1993 after a two-year hiatus during which one test cell was maintained in operation. The work is centered on measuring very slow crack propagation in pre-cracked compact tension specimens. Crack growth is determined by measuring the very small changes in electrical resistance of the specimen as the crack propagates. Thus far, more than 20,000 exposure hours have accumulated.

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Specimens of 304L and 316L stainless steels and nickel-base Alloy 825 have been tested in 90°C simulated UE-25 J-13 water under severe mechanical stress. Resolution of any crack extension corresponds to crack growth measurements on the order of 10^{-12} m/s; at this rate a crack would require more than 300 years under continuously wet conditions to penetrate a one-cm-thick container wall. Work in FY 1994 is emphasizing corrosion resistant materials that could be used in multiple barrier container designs and to test in more aggressive environmental conditions. Specimens of Hastelloy C-4, Hastelloy C-22, and Titanium Grade 12 will be added to the test matrix. New heats of types 304L and 316L stainless steel will continue to be tested as points of reference because of the abundant data and mechanistic studies available on these materials. Corrosion models have been derived from data on the stainless steels and extension of these models to the high performance alloys of interest is a key factor in predicting the performance of these materials. All six of the alloys to be tested have been purchased and received in forms suitable for the fabrication of compact tension specimens.

Work began on setting up a slow crack growth rate measuring system, similar to that being used at Argonne National Laboratory. This apparatus will be used for determining stress corrosion resistance of corrosion allowance materials, and will complement the Argonne National Laboratory work. Project staff worked with the manufacturer to update and modify the software, which was purchased with the unit. Several short term tests were run and all major software problems were resolved. Plots of crack length vs. time and vessel temperature vs. time were produced. Confidence in the ability to run long-term experiments is much improved.

A Cahn thermogravimetric analysis unit was obtained and will be used to determine the temperature-humidity relationship for formation of water layers that cause corrosion cells to initiate on a metal surface. It is expected that formation of the critical amount of water on the surface will lead to a discernible difference in weight gain due to the initial rapid kinetics of aqueous corrosion. Various specimen geometries are being considered, and a number of different corrosion-active metals are proposed for the first round of studies. It was necessary to build a remote vapor delivery system outside the thermogravimetric analysis unit system box to eliminate the possibility of condensation in the existing system. At the same time, the sophisticated gas switching system of the thermogravimetric analysis unit controller was able to be maintained. The remote electronic hook-up was completed. There was some concern with the noise level of the signal from the apparatus. Some operating conditions were changed in order to decrease the noise level. The present data thermogravimetric analysis unit acquisition software is limited to a run time of 48 hours. Cahn developed new software that allows an indefinite time for data acquisition. The longer data acquisition times will give flexibility in the type of data that can be obtained.

Some baseline tests were run on the thermogravimetric analysis unit balance to determine the drift in the system. One test was run for 48 hours, after removing the sample and the Nichrome wires that hold the samples, and turning off all the gases. The balance drifted about 150 μ g. These test data will have to be considered later during the analysis of actual test data. A presentation was made to the Nuclear Waste Technical Review Board in

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March 1994 (see Section 2.1.1.4) on the status of the thermogravimetric analysis work and its implications on discerning the transition from metal oxidation to metal corrosion.

Subactivity 1.4.2.4.5 - Assessment of degradation modes in coatings and filler systems. No progress during the reporting period; this was an unfunded activity.

Subactivity 1.4.2.4.6 - Laboratory test plan for coatings and filler systems of the alternate barriers investigations. No progress during the reporting period; this was an unfunded activity.

Forecast: Subactivity 1.4.2.4.3 - The ferrous metals degradation mode survey will be prepared for YMSCO. Subactivity 1.4.2.4.4 - Testing will continue at Argonne National Laboratory and begin at Lawrence Livermore National Laboratory on stress corrosion cracking.

Subactivities 1.4.2.4.1, 1.4.2.4.2, 1.4.2.4.5, and 1.4.2.4.6. No activity is planned for FY 1994.

2.6.6.7 Activity 1.4.3.1 - Models for Copper and Copper Alloy Degradation

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

Forecast: No activity is planned for FY 1994.

2.6.6.8 Activity 1.4.3.2 - Models for Austenitic Material Degradation

Subactivities 1.4.3.2.1 through 1.4.3.2.5. No progress during the reporting period; these were unfunded activities.

Subactivity 1.4.3.2.6 - Pitting, crevice, and other localized attack. The impact of fully implementing the Software Quality procedures on the stochastic pitting corrosion modeling effort is being assessed.

A literature review of the available experimental techniques for determining the distribution of pit sizes as a function of exposure time, alloy composition, and environment has begun. The correlation of electrochemical potential with pitting may be nonconservative because the threshold for pitting appears to decrease with "waiting time." Experiments necessarily have much shorter waiting times than will be experienced in a repository situation.

Computer simulations of the pitting potential as a function of "waiting time" and statistical variables within the stochastic model are in progress. Preliminary results indicate that the statistical input to the model has a strong influence on the predicted pitting potential and that the pitting potential decreases as the waiting time increases. The sensitivity of the predicted median pit induction time, median number of pits, and median pit depth to the

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number of "cells" used in the stochastic simulations was studied. At least several hundred cells are required to provide median values of pit quantity and depth that are independent of the number of cells used; the pit induction time appears to be less sensitive to the number of cells. Further simulations showed that using a large number of cells does not significantly affect the shape of the distribution of pit depths although it produces a smoother distribution than if a small number of cells is used. Also, as the exposure time increases, the distribution gradually decreases in height, broadens, becomes less skewed toward small depths, and moves to larger depths. Finally, decreasing the growth probability decreases the rate at which the distribution evolves but not the character of the evolution.

Subactivities 1.4.3.2.7 and 1.4.3.2.8. No progress during the reporting period; this was an unfunded activity.

Forecast: Subactivity 1.4.3.2.6 - Pitting modeling will continue. No activity is planned for the other subactivities for FY 1994.

2.6.6.9 Activity 1.4.3.3 - Models for Degradation of Ceramic-Metal, Bimetallic/Single Metal, and Coatings and Filler Alternative Systems

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

Forecast: Work on this activity will begin during the next two reporting periods.

2.6.6.10 Activity 1.4.4.1 - Estimates of the Rates and Mechanisms of Container Degradation in the Repository Environment for Anticipated and Unanticipated Processes and Events, and Calculation of Container Failure Rate as a Function of Time

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

Forecast: No activity is planned for FY 1994.

2.6.6.11 Activity 1.4.5.1 - Determination of Whether the Substantially Complete Containment Requirement is Satisfied

Effort during this reporting period focused on two parts of the issue of substantially complete containment. The first involved the definition itself, while the second involved the determination of compliance.

Concerning substantially complete containment, the NRC stated in NUREG-1347: "The revised DOE interpretation is in substantial agreement with NRC's intent in 10 CFR 60.113." The staff noted, however, that inconsistencies existed among the tentative performance goals. The DOE developed these tentative goals based on their desire to limit the release of

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radionuclides from the Site Characterization Plan waste package as designed, which relies on a thin-wall, single-barrier, corrosion-resistant container.

The DOE has proposed a new performance goal in place of the previous goals, applicable to the waste package design concepts now being developed, focused on containment of radionuclides within intact waste packages. The goal is to achieve mean waste package lifetimes well in excess of 1000 years. This means that the number of failures at the initial tail of the distribution (i.e., during the containment period) will be very small. This is consistent with the containment requirement and the intent of the rule. The performance goal will be reflected in lower-level barrier functions and performance measures being developed. The DOE will achieve this performance goal through the use of multiple barriers with more than one failure mode. This permits the peak of the failure distribution of the combined waste package to be reduced and the distribution itself extended in time. The DOE, therefore, believes that the multibarrier design approach will provide adequate confidence that the containment requirements will be met.

The approach to meeting the substantially complete containment requirement is focused on containment with a performance goal of extended waste package lifetimes. This approach is consistent with NRC's emphasis on containment during the initial postclosure period. This approach does not contain goals for container failure rates or release of radionuclides.

As part of the CRWMS M&O Total System Performance Assessment-1993 exercise (Andrews et al., 1994), the failure times for the waste packages were reported. Several design cases and three thermal loads (70.7, 141, and 282 kW/ha [28.5, 57, and 114 kW/acre]) were evaluated. The analysis included several calculational methods and corrosion correlations, and assumed that the repository was made of seven annular rings. The outermost ring was assumed to contain the high-level waste glass, rather than commingling them with the spent fuel waste packages. For a corrosion-resistant barrier thickness of 0.95 cm and a corrosion-allowance thickness of 10 cm, failure rates were calculated using the RIP code. The failure times were calculated for each ring.

The longest failure times were for the high and low thermal load, with the intermediate thermal load having the shortest failure times. The failure times for the low thermal load ranged from 3300 to 9000 years, with the longest times for the coolest outer ring. Similarly, the failure times for the intermediate thermal load ranged from 495 to 2325 years. However, the opposite situation was found for the high thermal load case. The shortest failure time, 710 years, was for the high-level waste glass packages in the outermost ring, since aqueous processes can occur there. The failure times for the other rings containing spent fuel ranged from 4690 years for the innermost ring to 3190 years for the outermost ring. This is as a result of the heat generated by these packages which delays aqueous corrosion.

For this Total System Performance Assessment-1993 exercise, many simplifying assumptions and abstractions were made to reduce code running time. These will be re-examined for the next Total System Performance Assessment exercise. However, it is likely that the lifetimes of the waste packages will be extended rather than shortened. Thus,

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the current waste package design should meet the substantially complete containment requirement set by NRC and the goals for lifetime provided by DOE.

Forecast: No activity is planned for FY 1994.

2.6.6.12 Activity 1.5.5.2 - Radionuclide Transport Modeling in the Near-Field Waste Package Environment

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

Forecast: No activity is planned for FY 1994.

SECTION 2.7 - PERFORMANCE ASSESSMENT

2.7.1 Waste Retrievability (SCP Section 8.3.5.2)

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

Forecast: No activity is planned for FY 1994.

2.7.2 Public Radiological Exposure - Normal Conditions (SCP Section 8.3.5.3)

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

Forecast: No activity is planned for FY 1994.

2.7.3 Worker Radiological Safety - Normal Conditions (SCP Section 8.3.5.4)

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

Forecast: No activity is planned for FY 1994.

2.7.4 Accidental Radiological Release (SCP Section 8.3.5.5)

An initial assessment was performed of Exploratory Studies Facility items that when incorporated in the Mined Geologic Disposal System could be classified as items important to safety as defined in 10 CFR 60.2. This initial study was a probabilistic risk assessment using event trees. The technique was used to quantify both the probabilities of accidental radionuclide release from initiating events and the resulting radiological exposures to the public at the boundary of the restricted area.

Initiating events considered were rock-fall and transportation accidents. Both spontaneous rock falls and normal transportation accidents were considered in detail. In addition, the analysis evaluated the possibility of earthquakes increasing the annual probability of rock falls and transportation accidents. Following the initiating event, the event tree considered damage to the waste package, radionuclide release and transport to the accessible environment, atmospheric dispersion, and the resultant dose consequences. The impact of the simultaneous failure of mitigating systems was also evaluated.

Underground accident and rock-fall frequencies were obtained from the data base maintained by the Mine Safety and Health Administration. This data base has been compiled from the mandatory reporting requirements for mining operations. The analysis of the Exploratory Studies Facility made use of the underground accident and rock-fall data accumulated over the previous decade.

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The findings of the systematic conservative study were that the probabilities for an accident giving a dose above the limit for items important to safety as defined in 10 CFR 60.2 ranged from about 10^{-6} per year to less than 10^{-10} per year depending the details of the Mined Geologic Disposal System. If a ventilation system using a two stage high-efficiency particulate air filter is deployed the dose consequence is very low (sub-millirem) for all design options. The only Mined Geologic Disposal System configuration giving a (conservative) release probability of greater than 10^{-7} per year was one with a single ventilation filtration system using a thin walled (100 mm) waste container. A report on the work entitled "Preclosure Radiological Safety Assessment for the Exploratory Studies Facility" (CRWMS M&O) is in technical review.

Forecast: The mechanical robustness of the container to an energetic event will be further investigated. Work to date has identified the predicted mechanical response and subsequent radionuclide release by the waste container as the main areas of uncertainty in the results generated.

A risk assessment study will be initiated on the proposed surface facilities. Integration of the two analyses will provide an overall assessment of the likelihood and dose repercussions of accidental radionuclide release at the proposed facility.

2.7.5 Ground-Water Travel Time (SCP Section 8.3.5.12)

2.7.5.1 Activity 1.6.2.1 - Model Development

Subactivity 1.6.2.1.1 - Development of a theoretical framework for calculational models. No progress during the reporting period; this was an out-year activity.

Subactivity 1.6.2.1.2 - Development of calculational models. Technical review comments were incorporated and final DOE approval was received for publication of a document entitled "Review and Selection of Unsaturated Flow Models" (CRWMS M&O). The report reviews the range of potentially useful models for the unsaturated zone. Specifically, the overall purposes of the study are to provide the basis for overall management and integration of modeling activities, to provide a framework for focusing modeling and model development, to identify areas that require increased or decreased emphasis, and to ensure that the tools necessary for performance assessment are available.

These purposes were addressed through a four-step process that consisted of establishing the model requirements, providing a thorough review of existing models, testing of those models that best fit the established requirements, and making recommendations for future development that should be conducted. Future model enhancement will then focus on the models selected in the evaluation.

The study led to two primary conclusions summarized here in terms of specific models recommended for general Project application: (1) The TOUGH2 model offers a very capable multiphase, nonisothermal flow model using a finite element implementation. NUFT

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appears to have similar capabilities and further examination of this recently developed code is warranted; (2) FEHM offers the most capable multiphase, nonisothermal flow model using a finite element formulation. Additional recommendations and more detailed specific results are provided in the conclusions section of the document.

A package of preconditioned conjugate gradient solvers, T2CG1, has been added to TOUGH2 to complement its direct solver and significantly increase the size of tractable problems solved. The package includes three different solvers: a Bi-Conjugate Gradient (BCG) solver, a Bi-Conjugate Squared (BCGS) solver, and a Generalized Minimum Residual (GMRES) solver. Results from six test problems with up to 30,000 equations show that T2CG1 is significantly faster and requires far less memory than the MA28 direct solver, and enables solving very large three-dimensional problems, and the BCGS solver is the fastest of the three in the tested problems. The document, "T2CG1, A Package of Preconditioned Conjugate Gradient Solvers for TOUGH2" (Moridis et al.), describing this upgrade has been peer reviewed and received by DOE for final approval.

Forecast: No activity is planned for the remainder of FY 1994.

2.7.5.2 Activity 1.6.2.2 - Verification and Validation

Subactivity 1.6.2.2.1 - Verification of codes. The intent of this activity is to identify, develop, and test computational tools for use in numerical simulations of processes related to the natural and engineered system. These tools allow calculation of the effects of the processes on performance at various scales.

Barometric Pumping Simulations

A method-of-lines code developed for two-phase flow in porous media and for modeling barometric pumping of water vapor in a discrete fracture/matrix system was applied to estimate respired moisture from Yucca Mountain via barometric pumping. It was determined that the respired moisture is maximized for particular values of effective binary diffusion coefficient, matrix permeability, and fracture spacing.

Two chapters that deal with barometric pumping in a dual permeability fracture/matrix system were prepared for inclusion in the Total System Performance Assessment-1993 report, "Total-System Performance Assessment for Yucca Mountain - SNL Second Iteration (TSPA-1993)" (Wilson et al.). The chapters detail work on estimating the respired amounts of contaminant-laden gases and of moisture in the form of water vapor at Yucca Mountain by fluctuations in atmospheric barometric pressure.

Appropriateness of One-Dimensional Calculations and Fracture Permeability Effects on Dryout

Total System Performance Assessment analyses entail modeling an extremely large and complex system. Therefore, performance assessment modelers have long advocated the need

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for abstracted models in order to decrease what would otherwise be prohibitively long computer run times. However, a recurring issue in performance assessment is the validity of using one-dimensional simulations to represent three-dimensional processes such as unsaturated ground-water flow.

This study was directed at testing the ability of several computation tools and methods to allow one-dimensional simulations to numerically reproduce potentially important effects such as lateral diversion of fluid flow. The study showed that use of certain numerical methods made it possible to use one-dimensional modeling to approximate two-dimensional flow-path lines in layered systems. To some extent, these methods accounted for low-hydraulic conductivity obstructions, unsaturated fractures, random mixes of material conductivities, and nonisotropic conductivities without explicitly including them in the geometry of the model. In addition, it was shown that the effect of lateral flow, resulting from geologic dip, can be incorporated by using unit-gradient boundary conditions. The results of this study were reported in Chapter 23 of "Total-System Performance Assessment for Yucca Mountain - SNL Second Iteration (TSPA-1993)" and in "Appropriateness of One-Dimensional Calculations for Repository Analysis" (Eaton), which was submitted for presentation at the 1994 High-Level Waste Conference.

Hydrothermal Code Comparisons

The TOUGH2 and the FEHM codes were used to solve a series of test problems in an attempt to understand some of the difficulties of computing multiphase, nonisothermal flows in porous media. Thus far, it appears that the TOUGH2 code is considerably faster when running relatively small problems. However, when the mesh size increases to the 1000-node range, the FEHM code may require less central processing unit time than TOUGH2. The FEHM code continues to have difficulty solving problems that involve dynamically evolving regions of air depletion.

The TOUGH2 code was used to investigate possible dryout in the vicinity of a potential nuclear waste repository and the perching of water above the repository as a function of time after waste emplacement. An earlier parametric study predicted considerable dryout in the region of buried waste and a perched water region above the repository. Further, the perched water condition was calculated to exist for thousands of years. The earlier study was based on incrementally reducing the fracture permeabilities by several orders of magnitude and at the same time varying the fracture spacing. This method of variation was sometimes confusing. Consequently, the study was redone using a systematic variation of the fracture apertures, which resulted in a range of fracture permeability via the cubic flow relationship. These results were expected to be more readily interpreted than those in the original study. The results of the repository simulations in this study showed significant dryout and perching in the vicinity of the potential repository. These calculations also showed that the extent of dryout and perching was a strong function of the material characteristics that are used to represent the fracture zones. The results show that for a 100 μm fracture case, significant dryout and perched regions exist. However, when 1 μm fractures are used, no dryout or perching is calculated. The results of this investigation were presented in Chapter 24 of "Total-System Performance Assessment for Yucca Mountain -

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SNL Second Iteration (TSPA-1993)" and in "Effect Fractures on Repository Dryout" (Eaton), submitted for presentation at the 1994 High-Level Waste Conference.

Work has been initiated on a benchmarking exercise of near-field hydrothermal calculations. The objective of this work is twofold: (1) to compare the performance of TOUGH2 with FEHM for modeling coupled heat and fluid flow at the near-field scale, and (2) to provide useful results regarding conditions in the vicinity of the waste package as they relate to parameters such as waste package spacing, infiltration rates, vapor diffusivity and fracture permeability. Rather than use a homogeneous distribution of waste, this problem considers a typical waste package located within an array of similar waste packages. The model domain extends from the land surface to the water table. The two-dimensional x-z mesh consists of rectangular elements at the top and bottom with some refinement in the center using triangular elements to approximate a circular drift. Preliminary simulations of conduction-only cases have been completed.

Forecast: Ancillary calculations that deal with fracture permeability, dryout, and barometric pumping will continue in support of Total System Performance Assessment. Of particular value will be continued evaluations of the relative capabilities of various computer codes for performing Total System Performance Assessment-related transport modeling.

A report that discusses the formulation and numerical treatment (one-dimensional flow) of multiphase systems that was developed under the barometric pumping study included in the Total System Performance Assessment-1993 report will be prepared.

Coupled heat and fluid flow calculations will continue. A particularly important aspect will be comparisons of conduction-only model results with thermohydrologic simulations to determine the relative importance of conduction and convection in the near-field. This work will be completed during FY 1994 and documented in a report.

Subactivity 1.6.2.2.2 - Validation of models.

Flow and Transport Through Single Fractures

This activity challenges existing conceptual models of fracture flow and explores possible rapid transport mechanisms that may be relevant to performance assessment at Yucca Mountain.

An experimental sequence exploring the effects of wetted structure on the relative permeability of a horizontal analog fracture was performed. Experimental observations were analyzed relative to simple process oriented models. Results were documented in the report, "Wetting Phase Permeability in a Partially Saturated Horizontal Fracture" (Nicholl and Glass), prepared for the 1994 High-Level Waste Conference.

Methodologies for replicating natural fractures for use in flow experiments were further refined, and a revised casting process expected to minimize distortions induced during

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replication implemented. As a proof of concept exercise, silicone molds were cast from an intact fracture collected from the Bandelier Tuff and replication in transparent epoxy began.

Development of a methodology for the direct manufacture of analog fractures continued. The numerically controlled milling machine to be used in the manufacturing process arrived and was tested. Work continued on exploring physical limitations of the milling process and potential models for fracture aperture structure.

To facilitate application of confining pressures greater than the 138 kPa now in use in flow experiments, a revised pressure container was constructed that allows application of confining pressures normal to the fracture plane of up to 1030 kPa. A Lexan safety shield was also designed and constructed.

Collaborative work in support of the nonisothermal Large Block Test at the Fran Ridge test site continued. This will include looking at fracture connectivity under natural gradient conditions within the Topopah Spring welded tuff. Preliminary site visits were used to set design criteria for an appropriate test; flow controllers and measurement apparatus were constructed and tested.

Fracture Matrix Interaction

This activity challenges existing conceptual models describing the transfer of fluids and solutes between fractures and the host matrix (fracture-matrix interaction), and explores the impact of fracture-matrix interaction on rapid transport mechanisms.

Fracture-matrix interaction was investigated through combined physical and numerical experimentation. Two slabs of Topopah Spring tuff were mated to form a vertical saw cut fracture to which water was supplied. X-ray imaging techniques were applied to obtain the matrix porosity field and transient saturation fields as the water moved from the fracture into the matrix. Porosity, hydraulic conductivity, and pressure/saturation relations of the tuff matrix were measured on small cores taken from adjacent rock. Correlations between hydraulic properties and porosity were found and modeled. Numerical simulations using TOUGH2 were accomplished with a series of property fields of increasing detail. Property fields were modeled using the measured porosity field divided into 1, 3, 5, 11, and 21 porosity groups with the hydraulic properties assigned from the developed correlations and the average porosity within each group. Results are in a paper entitled "Fracture-Matrix Interaction in Topopah Spring Tuff: Experiment and Numerical Simulation" (Glass et al.) prepared for the 1994 High-Level Waste Conference.

Effective Media Property Scaling in Heterogeneous Systems

This activity challenges existing conceptual models for the scaling of effective media properties, which are critical to performance assessment at Yucca Mountain.

Numerous refinements and system improvements were made to the automated gas permeameter test system. A series of experiments were also performed to evaluate the

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capabilities and precision of the test system. Results were reported at the 1993 Fall Meeting of the American Geophysical Union in a presentation entitled "Laboratory Method for Investigating Scaling Behavior" (Tidwell, 1993).

Eight boulders of tuff collected from Yucca Mountain and vicinity were sawn into blocks measuring 0.6 to 1.3 m on a side. These tuff blocks were selected because they exhibited varying types and degrees of heterogeneity and depositional history (i.e., welding, varying pumice/lithic/lithophysae content, and size). By studying the different blocks, the effect of heterogeneity on scaling behavior is investigated. Scaling investigations were initiated which involve making over 500 measurements per block face at five different measurement scales (spanning four orders of magnitude on a per volume basis). Initial results of these investigations are reported in a paper entitled "Scaling Behavior of Gas Permeability Measurements in Volcanic Tuffs" (Tidwell) prepared for the 1994 High-Level Waste Conference.

An integrative effort was initiated with the ultimate goal of incorporating the information acquired in this task into the performance assessment exercises. A series of meetings was held to discuss approaches and potential products. Discussions focused on developing a means of evaluating the impact of property scaling on performance assessment calculations and developing an approach for testing current scaling models.

Nonisothermal Studies

Physical and numerical experiments were initiated in the summer of 1993 to investigate nonisothermal flow behavior in saturated and partially-saturated porous media. The objectives were to determine important nonisothermal processes relevant to performance and to determine the capabilities of existing numerical codes to model nonisothermal processes.

A 26 x 26-cm, two-dimensional chamber was fabricated to visualize thermally induced convection in a heated slab of sand. Temperature profiles were recorded using an array of thermocouples, and flow patterns were visualized by observing the transport of injected dye. Several initial experiments were performed with varying liquid saturations in the sand. The bottom of the test cell was heated and the top was cooled. Results showed that two counter-rotating convective cells developed in the saturated regions of all the experiments.

Numerical simulations using TOUGH2 were able to replicate the behavior observed in the physical experiments. Sensitivity analyses showed the importance of boundary conditions on the nonisothermal flow behavior observed in the experiment. In addition, a decrease in the bulk permeability of the sand showed a significant depression in the temperature profiles in the sand as a result of reduced convective velocities. Results of these studies were documented in the paper, "Studies of Non-Isothermal Flow in Saturated and Partially-Saturated Porous Media" (Ho et al.), prepared for the 1994 High-Level Waste Conference.

A new light-imaging method was later implemented in the physical experimental system. By recording the light intensities shining through the test cell, variations in liquid saturation can now be determined. This light imaging method also enhances the resolution of

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the injected dye so that velocities can be more accurately calculated. The dispersion of the dye in nonisothermal environments can also be approximated by determining the transient variation in dye concentration in the test cell.

Develop/Validate Reactive Transport Model

A report describing characterization of materials for the caisson experiment was completed and submitted for management review.

Conduct Integrated Transport Experiment

Integrated transport experiment activities include development of sorption models and batch sorption experiments in support of the intermediate-scale (caisson) experiment. The purpose of this test is to demonstrate a framework for the validation of reactive transport models in saturated and unsaturated porous and fractured media at Yucca Mountain.

Development of a model for Ni sorption by Wedron 510 sand continued. Potentiometric surface titration data were obtained on acid-washed Wedron sand using an improved technique. Double-extrapolation plots yielded intrinsic acidity and Na-association constants that differ from those obtained on the quartz standard (MIN-U-Sil-5). This may indicate that the surface area of the sand is larger than previously measured.

Batch Ni sorption experiments were completed under CO₂-free conditions in a glove box. The results indicate that formation of Ni carbonate complexes may have occurred during previous experiments. Studies of the effect of various leaching procedures on the raw sand were initiated. Modeling of Ni sorption using available sorption constants from the literature indicated that the iron oxyhydroxide partially covering the surface may be amorphous ferrihydrite. X-ray photoelectron spectroscopy measurements confirm previous scanning electron microscopy observations indicating that the sand surface is partially covered by an Al-bearing phase (kaolinite).

An Ni sorption study to compare several batch sorption methods was completed. The study showed that one method predicted a somewhat higher K_d for Ni than another for a given pH.

Procedures for water sampling and pH measurement for the caisson experiment were developed. Water samples were taken from several levels within the caisson. Analyses of concentrations of the tracers and common ground-water constituents indicate that the tap water, currently being used to establish a steady-state flow field, can be used as the background electrolyte for the tracer experiments. Preparations for the first tracer pulse (LiBr) continued at the caisson site.

A report entitled "Detailed Characterization and Preliminary Adsorption Model for Materials for Intermediate-Scale Transport Experiments" (Ward et al.) was prepared for the 1994 High-Level Waste Conference. The report describes the results of laboratory studies of

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the sand and tracers used in the caisson experiment. The data will be used in predictive modeling of tracer transport.

Development/Validation of Retardation Model for Performance Assessment

This activity seeks to improve the retardation models used in Total System Performance Assessment. Progress was made on a collaborative study to formulate a model for U sorption by mineral mixtures. Improved instrumentation was developed to measure laser-induced phosphorescence of U in moist sand samples; current detection limits are 1 ppm and 1 ppb in moist sand and solutions. An isotopic differentiation technique for measuring U sorption was successfully tested using sorption of approximately 8 ppm U onto Wedron 510 sand at 95 percent moisture saturation measured in solutions at pH 8.2.

The design of a fiber-optic probe for use in measurements of pH and U in unsaturated sand in flow and batch systems was initiated. Computer codes to average and integrate laser-induced fluorescence signals were written and used to produce a much improved signal to noise ratio at the 1 ppm concentration level than previous analyses. A polarographic technique to measure concentrations of U in batch samples was demonstrated at the 10 ppb level.

The paper entitled "Unraveling Multi-Solute Sorption by Mineral Mixtures Through Surface-Complexation Studies of Simple Systems: Sorption of Ni and Li by a Natural Sand" (Ward et al., 1993) was presented at the annual meeting of the Geological Society of America in Boston, Massachusetts, October 25-28, 1993. The paper describes progress in formulating a model to describe sorption properties of rocks based on properties of mineral components. The model will be used in future validation studies.

In this reporting period, a final draft of the User's Manual for the code was prepared, and improvements to the code were being made. These improvements included:

- Modifying the code to simulate colloidal transport in fractured media, and initiating testing of this feature
- Adapting the code to a massively parallel computing architecture, successfully running a sample problem on multiple nodes of the nCUBE computer, and initiating testing of the modified portions of the code
- Translating large binary output files to a data base format for processing by a graphics package to improve post-processing.

Benchmarking calculations involving advection and diffusion, performed previously with the HYDROGEOCHEM and LEHGC0.0 codes, were repeated with LEHGC1.0, the most current version of LEHGC, and results compared to an analytical solution for the advection-dominated case. The computed solution to the diffusion problem was compared both to experimental results and to numerical solutions using COYOTE, a well-established heat conduction code. In all cases, the agreement among results was good.

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Benchmarking of KEMOD, a mixed kinetics/equilibrium chemical speciation code, was conducted in a effort to imbed KEMOD within the LEHGC code. This effort supports sensitivity analyses of systems in which rate-limited processes, such as mineral dissolution/precipitation, are important. Efforts conducted to date were successful and indicate that the planned coupling of LEHGC and KEMOD will be successful. Additional testing is under way.

Forecast: Efforts will continue in the refinement of capabilities to cast natural fractures and manufacture controlled analog fractures for use in laboratory flow experiments. Field experiments to investigate fracture conductivity will be performed at Yucca Mountain in conjunction with the Large Block Test. Results of integrated laboratory experimentation/performance assessment calculations will be reported.

A suite of studies to continue the investigation of fracture-matrix interaction are scheduled to be conducted this summer. In these experiments, the effects of fracture roughness, fracture networks, and fracture coatings on fracture-matrix interaction will be explored.

Evaluation of the effect of rock sawing on air permeability measurements on tuff blocks will be performed. Tip seals will be evaluated and refined to minimize head loss. Scaling studies will be performed on an analog homogeneous porous system as a control for tests performed on heterogeneous tuffs. Scaling studies on volcanic tuffs will continue.

Nonisothermal flow experiments will continue, varying the hydrologic properties such as particle size and distribution to investigate the effects of permeability and heterogeneity. By determining the effects of various permeabilities on flow, consolidating models of highly heterogeneous permeability fields into coarser, more computationally efficient models while maintaining the integrity of the physical solution is intended.

Experiments to evaluate the predictive ability of alternative models that could be used in performance assessment to describe retardation due to sorption will continue. Sorption minerals under unsaturated and saturated conditions in porous and fractured media will be examined, and the degree to which absorption is controlled by trace amounts of reactive minerals that are preferentially concentrated along flow paths or other structural features will be evaluated. This information will be used to develop probability density functions for K_d s for future Total System Performance Assessments, and will provide input to geostatistical models for K_d s at Yucca Mountain. In addition, transport of contaminants by colloids using a coupled reactive transport code (LEHGC, discussed in Section 2.2.2.14) will be calculated to determine if this phenomena should be included in future Total System Performance Assessment calculations.

An intermediate-scale experiment will be conducted at the Los Alamos Experimental Engineered Test Facility. Design of additional intermediate-scale integrated reactive tracer tests will continue. Evaluation of field sites for future model validation calculations will be initiated. The locations where contaminant transport studies are being carried out include a fractured rock study site near Mirror Lake, New Hampshire, a sand and gravel aquifer site on

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Cape Cod, Massachusetts, and sites in Czechoslovakia (Straz Pod Ralskem) and Russia (Chelyabinsk), where large contamination plumes exist.

Results of the benchmarking calculations involving advection and diffusion will be included in a report on the testing and verification of LEHGC. Efforts will continue in the development of a kinetic, non-isothermal and coupled unsaturated flow and transport module for future versions of LEHGC. Efforts will also continue on the implementation and testing of LEHGC on a massively parallel computer architecture.

2.7.5.3 Activity 1.6.3.1 - Analysis of Unsaturated Flow System

Subactivity 1.6.3.1.1 - Unsaturated zone flow analysis.

Geohydrologic Data Development

Probability Distributions. An expanded reference for information contained in the Total System Performance Assessment-1993 report is presented in "Hydrogeologic Stratigraphy and Stochastic Properties Development for the Total-System Performance Assessment 1993" (Schenker et al.). The report includes normalized histograms of fracture parameters, such as frequency, spacing, orientation, porosity, conductivity, aperture, and van Genuchten alpha parameter. Normalized histograms also were included for matrix properties, such as porosity, saturated hydraulic conductivity, bulk density, and the van Genuchten air-entry, saturation/desaturation, and residual degree of saturation parameters. Normalized histograms were developed for the bulk hydraulic properties gas permeability and saturated hydraulic conductivity. Normalized probability distribution functions were derived from the histograms as beta distributions. Plots of the probability distribution functions and the histograms are presented for comparison in the appendix of the report.

Ground-Water Travel Time. Debugging of INTRAVAL test cases was completed. In this study, computer models were initially calibrated using data collected for the INTRAVAL project. Subsequently, as a blind test, the codes were run on a different transect to assess the ability of the models to reproduce in situ data. The tools developed consider the effects of heterogeneity on composite-porosity models. The heterogeneity produces some localized zones of saturation that allow fracture flow to occur. In general, the calculated volumetric content of various units matched that of obtained through in situ measurements. Plots of the results were completed, and included in the draft report "Development of Models for Fast Fluid Pathways through Heterogeneous Porous Media" (Robey). "Modeling Heterogeneous Unsaturated Porous Media Flow at Yucca Mountain" (Robey) and "Development of Stochastic Indicator Models of Lithology, Yucca Mountain, Nevada" (Rautman and Robey) further discuss the set-up and results of these simulations. Both papers were prepared for the 1994 High-Level Waste Conference.

Forecast: Documentation will continue on the INTRAVAL case study, which will contain descriptions of the modeling techniques and codes used for that study. Because of the

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ability of these tools to produce fast path flow, they will form a basis for part of the method used to calculate ground-water travel time.

Analyses of Coupled Heat and Fluid Flow in the Unsaturated Zone

Hydrothermal calculations for the unsaturated zone using the TOUGH2 code continued. The purpose of these calculations was to examine the sensitivity of the repository response (i.e., liquid saturation, temperature, darcy velocity) to fracture permeability and vapor diffusivity. Simulations were conducted using a one-dimensional dual-permeability model (with strong fracture-matrix coupling) to contrast the effects of an enhanced fracture permeability with those of an enhanced vapor diffusion. The latter appears to have the beneficial effect of reducing waste package corrosion (by keeping the repository dry) and the nonbeneficial effect of enhancing long-term liquid flows with respect to ambient levels.

A paper entitled "Subrepository Scale Hydrothermal Analysis in Support of Total System Performance Assessment at Yucca Mountain" (Mishra) was prepared for the 1994 High-Level Waste Conference. This paper summarizes panel-scale thermohydrologic simulations carried out with V-TOUGH to develop far-field temperature and saturation histories for a range of thermal loads. Tabulations of these results were provided as input to the waste package performance and geosphere performance modules of the RIP code for the Total System Performance Assessment-1993 calculations.

A paper entitled "Near Field Thermal calculations for Individual Waste Package Placement" (Linginini) was prepared for the 1994 High-Level Waste Conference. This paper summarizes the calculations using a conduction-radiation model to translate far-field temperatures from a panel-scale model into temperatures in and around an emplacement drift.

A review of recent thermohydrologic analyses was presented at a semiannual progress meeting on March 17, 1994. This presentation provided a preliminary evaluation of some of the assumptions and interpretations in recent hydrothermal studies including: (1) assumed ranges of bulk permeability vis-a-vis results from recent air-permeability tests in UE-25 UZ-16, (2) likelihood of the occurrence of conduction or convection-dominated conditions in light of (1) above, (3) definition of "dryout," and (4) persistent open questions in hydrothermal modeling from a performance assessment perspective.

Forecast: Work will continue during FY 1994 on all areas described above. The sensitivity analyses will be documented, and the significance of the results on the overall understanding of coupled heat and fluid flow processes at the repository scale will be highlighted. The panel-scale model will be extended to investigate the interplay between surficial infiltration and thermally-induced water movement. Further work on evaluating different ongoing hydrothermal modeling studies will focus on establishing bounds on key parameters based on field and lab tests and identifying uncertainties in assumptions, concepts, results and interpretations of these studies.

A sensitivity analysis of alternative conceptual geosphere models, parameters, initial conditions, and boundary conditions under ambient and nonisothermal conditions to establish

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ranges of validity of various model applications will be performed and a draft report completed.

Subactivity 1.6.3.1.2 - Saturated zone flow analysis. Saturated zone flow analyses continued in order to provide an enhancement for Total System Performance Assessment-1993 analyses and to help test specific conceptual models for the flow system that are currently under consideration by Project participants.

A flow analysis performed for the saturated zone modeled the system as a confined system in three dimensions with four layers each 50-m thick, built from five geologic units. The area modeled was about 8 x 8 km. The code STAFF3D was used for flow field calibration and for transport calculations. Calibration of calculated heads versus measured values allowed development of a fairly detailed description of flow in the saturated zone. Contaminant breakthrough curves were calculated for three different locations of a unit-concentration contaminant source for selected nodes along a 5-km boundary "fence." Details of the calculation and results are reported in Chapter 11 of Total System Performance Assessment-1993. Results of this modeling effort were also reported in "Constraining Local 3-D Models of the Saturated-Zone, Yucca Mountain, Nevada" (Barr and Shannon), which was prepared for the 1994 High-Level Waste Conference.

Forecast: Three-dimensional modeling will be completed. The results of the analyses will be the basis for saturated zone transport calculations in Total System Performance Assessment-1993. In addition, results will be discussed with participants in order to help guide the site characterization efforts necessary to adequately define the saturated zone flow system for performance assessment.

2.7.5.4 Activity 1.6.4.1 - Calculation of Pre-Waste-Emplacement Ground-Water Travel Time

Subactivity 1.6.4.1.1 - Performance allocation for Issue 1.6. No progress during the reporting period; this was an out-year activity.

Subactivity 1.6.4.1.2 - Sensitivity and uncertainty analyses of ground-water travel time. See work reported under Subactivity 1.6.4.1.3.

Subactivity 1.6.4.1.3 - Determination of the pre-waste-emplacement ground-water travel time. Results discussed in Activity 1.6.3.1.1 are being used to help define the methods used to calculate fast path formation for ground-water travel time simulations. A strategy for the calculation of ground-water travel time was prepared. This approach outlines the calculations that are necessary for the unsaturated zone, the definition of the disturbed zone, the saturated zone, and determining whether travel times that are less than 1000 years are significant to long-term performance. In addition, a preliminary schedule was developed that includes two iterations of calculations prior to the determination of technical site suitability. The three-dimensional region within the repository block to be modeled has been defined as required for

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the geostatistical simulation that will be used to generate parameters for the calculations. Locations of three two-dimensional cross-sections within the block were specified.

Data for Drillholes UE-25 UZ-16, USW UZ-6, and USW UZ-14 were interpreted and transformed into a format usable by the code STRAT, which generates conditioning data for the geostatistical indicator simulations. The STRAT code was rewritten for the ground-water travel time calculations. By using STRAT to produce the data file, the drillhole information can be easily changed to accommodate new data while avoiding errors in the data file. An additional quality control built into the code is a display of the drillhole information on screen to allow obvious errors to be detected. Each drillhole was divided up into different categories (welded, nonwelded, vitric, zeolitic) depending on the depth. STRAT uses the input from the drillholes and creates a data file for use in the geostatistical simulation. Gamma functions were used to fit pressure versus saturation data for the unsaturated zone from a number of literature sources. For the modeling problem at hand, using these functions, rather than the van Genuchten fitting formulas, improves efficiency of the unsaturated zone flow modeling calculations.

The geostatistical hydrostratigraphy that was used for Total System Performance Assessment-1993 was updated for use in the ground-water travel time calculations. Updates included differentiating the Calico Hills and the Topopah Spring zeolitic and vitric units and adding more drillholes (USW WT-4, and 18; USW UZ-14; UE-25 NRG-2, and 3) to the geostatistical simulations. A preliminary indicator geostatistical simulation was run using drillhole data files developed for Total System Performance Assessment-1993. The code CAT2POR converts the indicators of the geostatistical simulation to hydrogeologic units and then generates porosities at each grid point. The identification of the hydrologic units is somewhat problem dependent, and CAT2POR must be adapted to the current problem. Although final drillhole data were not available, CAT2POR was adapted to the simulated region of interest. CAT2POR was also updated to allow beta distributions to be sampled (instead of the previous normal distributions) and to allow the beta distribution parameters to be specified by the user in an input file. In response to the need for smaller flow elements, spatially correlated porosities were added to CAT2POR. The code SGSIM is used to generate unconditioned normally distributed simulations for each hydrogeologic unit.

Detailed lithologic logs defining the hydrogeologic units were reworked. Four additional quality-affecting logs (UE-25 NRG-2B, and 4; USW NRG-6; and USW UZ-14) were added to the data set, bringing the total to 27 logs for the ground-water travel time simulation studies. From these logs, the matrix porosity indicators can be used as major discriminators to refine the "picks" among hydrogeologic units. The logs were supplemented by the original USGS lithologic descriptions and geophysical logs for each borehole. Two additional geostatistical simulation categories were added to the set of logs used for the Total System Performance Assessment-1993 report. The new categories refine the hydrogeologic units by differentiating the Calico Hills zeolitic unit and the welded/nonwelded subunits in the Bullfrog unit.

Forecast: Work on developing methods to calculate ground-water travel time and a strategy for use of the calculational results will continue. During FY 1994, the additional

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data obtained from the 27 detailed lithologic logs will assist in resolving contacts in the members of the Paintbrush Tuff for the flow simulations. The numerical tools described above will be used to generate saturation and ground-water velocities for matrix and fracture flow along the two-dimensional transects, and eventually lead to the capability to produce defensible ground-water travel time calculations.

2.7.5.5 Activity 1.6.5.1 - Ground-Water Travel Time After Repository Construction and Waste Emplacement

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

Forecast: No activity is planned for FY 1994.

2.7.5.6 Activity 1.6.5.2 - Definition of the Disturbed Zone

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

Forecast: No activity is planned for FY 1994.

2.7.6 Total System Performance (SCP Section 8.3.5.13)

Total System Performance Assessment takes into account features, events, and processes expected to be important in estimating the behavior of a repository system for a 10,000-year regulatory period. A number of calculational exercises, including HYDROCOIN, COVE, PACE-90, Total System Performance Assessment-1991, and Total System Performance Assessment-1993, have been conducted to date for the Project. Each iteration of Total System Performance Assessment is intended to make use of improved data, data-abstraction methods, and models.

Results of Total System Performance Assessment-1993 from both the TSA and RIP modeling exercises were presented to YMSCO by both Sandia National Laboratories and CRWMS M&O, at a meeting in Las Vegas, Nevada, October 21-22, 1993. The presentations provided a preview of material to appear in the two major Total System Performance Assessment-1993 reports, "Total System Performance Assessment for Yucca Mountain - SNL Second Iteration (TSPA-1993)," and "Total System Performance Assessment - 1993: An Evaluation of the Potential Yucca Mountain Repository" (Andrews et al., 1994). In addition to the Total System Performance Assessment results, the presentations contained recommendations for additional data needs (and hence input for future site characterization activities), identified implications for repository and waste package design, evaluated the impact of alternate regulatory standards, and also provided related suggestions for work in other areas. These results and recommendations were also contained in "Total System Performance Assessments of the Potential Repository at Yucca Mountain, Nevada" (Andrews et al.); "Some Results from the Second Iteration of Total-System Performance Assessment for

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Yucca Mountain" (Wilson); and "An Updated Fracture-Flow Model for Total-System Performance Assessment of Yucca Mountain" (Gauthier), which were also prepared for of the 1994 High-Level Waste Conference.

Extensions of Total System Performance Assessment analyses to evaluate the performance of the subsystems imbedded in the total system representation of Yucca Mountain have been planned. The aim is to take the baseline Total System Performance Assessment-1993 data set and conduct sensitivity analyses of certain components of the system to evaluate various measures of subsystem performance (e.g., Engineered Barrier System release rate, "ground-water travel time") and the sensitivity in the response due to uncertain parameters. Currently, the RIP code is being used to review the important waste package/Engineered Barrier System properties controlling the total system and Engineered Barrier System performance. Simulations have been carried out to evaluate the sensitivity of parameters such as diffusion coefficient, liquid saturation and waste package surface area available for diffusion on the release rate of radionuclides vis-a-vis the NRC release criteria.

A methodology is being outlined for multilevel performance assessments of unsaturated flow, unsaturated transport, and saturated flow/transport process level foundation studies. Such analyses are an important first step for developing and testing abstractions of process model results into the 'rolled-up' total system simulators. The first two iterations of Total System Performance Assessment for Yucca Mountain have been based on several assumed abstractions, which need to be verified prior to the next iteration of Total System Performance Assessment.

To date, interactions between the YMSCO performance assessment and site characterization functions have resulted in: a reorganization of site characterization scheduling to broadly match input requirements for iterative performance assessments, and feedback to the site characterization program on information priorities. In particular, the schedule for site investigations reflects "collection points" for site information at approximately two-year intervals, mirroring the iterative structure of the performance assessment process. Guidance for site characterization provided through Total System Performance Assessment-1993 has included recommended emphasis on differentiation among possible flow models, characterization of percolation flux, refinement of understanding of gas flow and retardation, and estimation of expected dilution in the saturated zone.

Forecast: Comments from the DOE policy review of the two Total System Performance Assessment-1993 reports will be addressed and incorporated in the final reports. Presentations on results of the Total System Performance Assessment-1993 work will be made to other participants to help publicize data needs and guide site characterization studies, and to other groups for information on progress in performance assessment. A synthesis document comparing and contrasting the analyses and results of the two Total System Performance Assessment analyses will be completed during FY 1994.

Efforts will continue to ensure that results from Total System Performance Assessment-1993 are being integrated into current plans for site characterization/data collection, as well as into ongoing activities in systems studies and repository and waste package design. "Mini"

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Total System Performance Assessments to answer "what-if" questions from these organizations, as required, will be undertaken. Some of the key uncertain concepts and assumptions from the current iteration of Total System Performance Assessment will be evaluated and updated, as appropriate. Work to develop and test abstractions of geosphere performance based on detailed process models of unsaturated flow will also be initiated.

Efforts will continue to define frameworks for effective and efficient integration of experimental and process-level modeling into performance assessments. Integration of data from the process-level into realistic performance assessments will require significant investigation of coupling among the processes, as well as accounting for changes in scale between relatively homogeneous laboratory systems and the heterogeneous systems expected to exist in actual geological structures. Ongoing laboratory and field experiments are providing useful and important information on aqueous flow through fractures, scaling effects, nonisothermal effects, and site geochemistry. Work will continue to extract the essence of the process information obtained through laboratory work into abstracted models to be integrated as enhancements into future iterations of Total System Performance Assessment, which will allow Total System Performance Assessment to be used as more robust approximations of site processes. The integration work will also provide closer ties between Total System Performance Assessment and site characterization work, which will provide guidance on the type of data required and when more data are needed.

Evaluations and comparisons of the performance of various subsystems and that of the total system with respect to various measures of performance will continue. In part, these analyses are to illustrate the degree of correlation between different measures of the system and subsystem performance.

2.7.6.1 Performance Assessment Activity 1.1.2.1 - Preliminary Identification of Potentially Significant Release Scenario Classes

Subactivity 1.1.2.1.1 - Preliminary identification of potentially significant sequences of events and processes at the Yucca Mountain repository site. Project representatives attended the first meeting (in Paris, France, November 22-23, 1993) of a working group formed by Nuclear Energy Agency Performance Assessment Advisory Group. The goal of the working group is to construct an international data base of features, events, and processes of potential importance for long-term safety of nuclear waste repositories. The working group began constructing this features, events, and processes data base for participating countries in to help with the formidable problem of scenario development. The first product was planned to be a detailed examination of commercial software. Project staff agreed to investigate the use of Microsoft Access data base software for data entry and recovery. Other members of the working group investigated the use of other data base software products. At a working group meeting held in early-March 1994, the Toolbook software was chosen for primary use, but several users continue to use the Access software.

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Subactivity 1.1.2.1.2 - Preliminary identification of potentially significant release scenario classes. Review comments of the report "Scenarios Constructed for Nominal Flow in the Presence of a Repository at Yucca Mountain and Vicinity" (Barr) were resolved.

Forecast: Effort will continue in the Nuclear Energy Agency working group to oversee development of an international data base of features, events, and processes and lead the effort in its development and maintenance. It is anticipated that development of the data base will be of great use to the Project by gaining international consensus on the completeness of scenarios. For the near field in particular, the Project may be able to make use of scenarios developed for nuclear waste repositories in other nations. Evaluation of software for recording and recovering features, events, and processes will continue.

Scenarios developed under this element form the basis for numerical and analytical modeling of features, events, and processes that might contribute to release and transport of radionuclides. The activities are linked with efforts being conducted in other activity elements involving numerous participants.

2.7.6.2 Performance Assessment Activity 1.1.2.2 - Final Selection of Significant Release Scenario Classes to be Used in Licensing Assessments

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

Forecast: No activity is planned for FY 1994.

2.7.6.3 Performance Assessment Activity 1.1.3.1 - Development of Mathematical Models of the Scenario Classes

The development and use of mathematical models for performing total system assessments is discussed under this heading.

Subactivity 1.1.3.1.1 - Development of models for releases along the water pathways. Calculation of the aqueous and gaseous-release for the Total System Performance Assessment-1993 report was completed using both composite-porosity and weeps models of ground-water flow. The two different models of flow in the unsaturated zone used in performance assessment calculations emphasize two different types of possible flow behavior, for which reality is probably somewhere in between. The composite-porosity (or equivalent-continuum) model assumes Darcian flow through an equivalent porous medium of matrix and fractures. In that model, flow is dominated by capillary forces; as a result, flow is shared between the rock matrix and fractures and flow through fractures only occurs when the matrix is saturated. The weeps model assumes that there are no interactions between the fractures and the rock matrix and that water flows occur only in locally saturated fractures. As was the case in Total System Performance Assessment-1991 (Barnard et al., 1992), the weeps model predicted fewer releases of radionuclides than the composite-porosity model. Additional

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detail on the content of the Total System Performance Assessment-1993 report and related publications and presentations is contained in Section 2.7.6.

Using the weeps model, releases were calculated to be within the 40 CFR Part 191 EPA release limits. However, in the extreme cases, potential doses were calculated to be high, indicating a need for further site data and waste-package analysis in several areas. Additional weeps-model calculations were performed to investigate the sensitivity of the Total System Performance Assessment-1993 calculations to different representations of hydro-thermal processes. The two hydrothermal models produced essentially the same results. The extended-dry concept was not modeled because calculations without the extended-dry concept were considered to be more conservative.

Calculations were performed to investigate differences in flow predicted by the weeps model used in Total System Performance Assessment-1991 and the weeps model used in Total System Performance Assessment-1993. Objectives of the investigation were: to determine what is important to the weeps model at a level beyond the input parameters (e.g., to determine the significance of thermal effects and climate change), to explain better the workings and the theory behind the weeps model, and to gain insight into optimum ways to combine the weeps model with the composite-porosity model with the aim of developing a unified performance assessment flow model for Yucca Mountain. Details of the calculation results are contained in Total System Performance Assessment-1993. These results are also contained in a report entitled "An Updated Fracture-Flow Model for Total-System Performance Assessment of Yucca Mountain" (Gauthier), which was prepared for the 1994 High-Level Waste Conference.

The composite-porosity calculations were also improved in several ways relative to the calculations performed for Total System Performance Assessment-1991. Four different repository designs (two emplacement modes by two thermal loading values) were considered. Some important differences included the following.

- There were many changes in the radionuclide source release as modeled using the YMIM model.
- Peak radiation-dose rates from drinking water were calculated in addition to the EPA performance measure from 40 CFR 191.13.
- A longer time period was modeled (1,000,000 years rather than 10,000 years) so that calculations included the time of the peak drinking-water dose rate.
- Saturated zone transport velocities were based on new models of the saturated zone (also described in the Total System Performance Assessment-1993 report).
- A model for climate changes was included in an attempt to estimate the effects of potential changes in infiltration and percolation rates.

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- Many changes were made in stratigraphy and parameter distributions.
- A different set of radionuclides was considered for the aqueous-release calculations.

Additional calculations were carried out with the probabilistic RIP code. The representativeness of these analyses were significantly enhanced over those in Total System Performance Assessment-1991 by (1) directly incorporating the thermohydrologic behavior in the near-field environment, (2) directly incorporating the possible corrosion processes and their thermohydrologic dependence in the determination of the degradation time of the waste package containers, and (3) the incorporation of a more complete radionuclide inventory, which includes 39 radionuclides. The near-field environment used in Total System Performance Assessment-1993 is based on thermohydrologic analyses at the waste-emplacement panel scale in order to evaluate the potential edge effects associated with unheated portions of the repository due to the presence of the main axis drift and associated side adits, the setback of waste packages from these drifts, and the existence of lower thermal output from the defense high-level waste.

The new information included in Total System Performance Assessment-1993 includes (1) revised estimates of radionuclide solubilities and their thermal and geochemical dependency, (2) thermal and geochemical dependency of spent-fuel waste alteration and glass dissolution rates, (3) new distribution coefficient estimates, (4) revised estimates of gas-phase velocities and travel times, and (5) revised hydrologic modeling of the saturated zone, which provides updated estimates of the advective flux through the saturated zone. New design options considered include (1) alternate thermal loads, (2) alternate waste package emplacement designs, and (3) the concept of multibarrier waste package containers consisting of an outer corrosion-allowance material and an inner corrosion-resistant material of various thicknesses. The alternative conceptual models that were evaluated in Total System Performance Assessment-1993 include the assumed criteria affecting the onset of aqueous corrosion under the possible thermohydrologic conditions in the vicinity of the repository as well as the conceptual model for corrosion. Finally, the alternate postclosure total system performance measures that have been evaluated in Total System Performance Assessment-1993 include (1) normalized cumulative release of radionuclides to the accessible environment for 10,000 and 100,000 years, and (2) peak individual dose associated with possible releases for a 1,000,000-year period.

The main conclusions from the RIP analyses are as follows:

- The 10,000-year release is mostly ^{14}C and is controlled by the waste package failure distribution. The aqueous release, although negligible, shows some sensitivity to thermal load and waste package design.
- The 100,000-year release is insensitive to thermal load and barrier thickness less than 20 cm, while the 45 cm barrier provides substantial protection.
- The 1,000,000-year peak dose is fairly insensitive to thermal load and waste package design.

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Subactivity 1.1.3.1.2 - Development of a model for gas-phase releases. As noted in the previous subactivity, Total System Performance Assessment-1993 modeling was improved over Total System Performance Assessment-1991. Improvements included gas-flow calculations that were transient (rather than steady-state) and were coupled with heat flow.

Subactivity 1.1.3.1.3 - Development of a model of releases through basaltic volcanism. Extensive code modifications to the ROCKTEMP program and numerous runs of the VOLCAN and ROCKTEMP programs were made to support work reported in the chapter on volcanic activity in the Sandia National Laboratories Total System Performance Assessment-1993. The analyses for Total System Performance Assessment-1993 were restricted to investigating the effects of a magma-induced thermal excursion and attack by aggressive volatiles, causing the nearby containers to degrade at a rate 10,000 times greater than nominal oxidation rates. It was found that releases attributable to the alteration of the aqueous source term by the magmatic intrusion were not significant. This work represented a different approach than was taken for Total System Performance Assessment-1991 (Barnard et al., 1992) where effects of direct magma-container contact were investigated.

Subactivity 1.1.3.1.4 - Development of a model of releases through human intrusion. Numerous runs of DRILL and the EFIT programs were made to support work reported in the chapter on human intrusion for the Total System Performance Assessment-1993 report. The purpose of the work was to investigate the possible consequences of inadvertent human intrusion to a potential repository at Yucca Mountain. The DRILL program was used to model exploratory drilling at 12 different starting times for each of the four repository cases (48 different calculations), with each time period lasting 10,000 years. In anticipation of a time-independent dose standard, the 10,000-year results were combined, using the EFIT3 program and a spline-interpolation program, to provide estimates of repository performance over a 1,000,000-year period. Limited sensitivity studies were carried out to investigate the effect of changing drill bit size and changing assumptions about the amount of waste that can be brought up from an in-drift waste package. It was found for a 21-cm-diameter drill bit that, for near misses, there is about an order-of-magnitude reduction in release as compared to the baseline case of a 61-cm-diameter bit. For direct hits, the complementary cumulative distribution functions for release were essentially the same for 21-cm and 61-cm bits. Results of this study are also discussed in "Analyses of Releases Due to Drilling at the Potential Yucca Mountain Repository" (Barnard), which was prepared for the 1994 High-Level Waste Conference.

Forecast: A DOE-NRC Technical Exchange will be organized for September 12-13, 1994, to discuss recent iterations of Total System Performance Assessment for Yucca Mountain. Summaries of the Total System Performance Assessment-1993 analyses will be presented at that meeting.

As more information is included into the Total System Performance Assessment models, developmental work will proceed on both the composite-porosity and weeps models to allow more efficient use of the code. Work continues on coupling the weeps and composite-porosity calculations.

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Analyses in support of DOE positions on new environmental standards for Yucca Mountain were documented in a report entitled "Calculations Supporting Evaluation of Potential Environmental Standards for Yucca Mountain" (Duguid et al.), which was in programmatic review and scheduled for publication in April 1994. This report describes a series of simple performance assessments of a repository carried out using the codes: (1) UCBNE-41, which was the basis for the National Academy of Sciences Waste Isolation System Panel Report in 1983 (NAS, 1983), (2) RIP, which was the basis for one set of Total System Performance Assessment-1993 analyses, and (3) NEFTRAN-S, which was used by the EPA in support of the re-promulgation of 40 CFR Part 191 in 1993. A paper entitled "Radiation Doses From Uranium Ore Bodies" (Duguid) was prepared for the 1994 High-Level Waste Conference. Regulatory and technical staff will continue to support the Task Force for developing DOE positions on new environmental standards for Yucca Mountain.

In terms of enhancing scenario modeling, a number of topics need to be investigated. Topics of interest include: processes by which waste might be entrained by flowing magma; kinetics of dissolution of UO_2 , Zircaloy, and other materials in magma; encapsulation of waste packages by magma, followed by production and dissemination of volatiles from the waste.

2.7.6.4 Performance Assessment Activity 1.1.4.1 - The Screening of Potentially Significant Scenario Classes Against the Criterion of Relative Consequences

Work related to this activity is reported under Section 2.7.6.1, Activity 1.1.2.1.

Forecast: See Section 2.7.6.1, Performance Assessment Activity 1.1.2.1.

2.7.6.5 Performance Assessment Activity 1.1.4.2 - The Provision of Simplified, Computationally Efficient Models of the Final Scenario Classes Representing Significant Processes and Events

Work related to this activity is reported under Section 2.7.6.6, Activity 1.1.5.1.

Forecast: See Section 2.7.6.6, Performance Assessment Activity 1.1.5.1

2.7.6.6 Performance Assessment Activity 1.1.5.1 - Calculation of an Empirical Complementary Cumulative Distribution Function

There were numerous calculations of complementary cumulative distribution functions for the Total System Performance Assessment-1993 effort described in Section 2.6.3.8.

Forecast: No additional activity is planned for FY 1994. A new Total System Performance Assessment effort may be started in FY 1995.

2.7.7 Individual Protection (SCP Section 8.3.5.14)

2.7.7.1 Activity 1.2.1.1 - Calculation of Doses Through the Ground-Water Pathway

There were numerous calculations of complementary cumulative distribution functions for the Total System Performance Assessment-1993 effort described in Section 2.6.3.8.

Forecast: No additional activity is planned for FY 1994. A new Total System Performance Assessment effort may be started in FY 1995.

2.7.7.2 Activity 1.2.2.1 - Calculation of Transport of Gaseous Carbon-14 Dioxide Through the Overburden

No progress during the reporting period other than that already discussed in Section 2.7.6; this was an out-year activity.

Forecast: No activity is planned for FY 1994.

2.7.7.3 Activity 1.2.2.2 - Calculation of Land-Surface Dose and Dose to the Public in the Accessible Environment Through the Gaseous Pathway of Carbon-14

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

Forecast: No activity is planned for FY 1994.

2.7.8 Ground-Water Protection (SCP Section 8.3.5.15)

2.7.8.1 Analysis 1.3.1.1 - Determine Whether Any Aquifers Near the Site Meet the Class I or Special Source Criteria

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

Forecast: No activity is planned for FY 1994.

2.7.8.2 Analysis 1.3.2.1 - Determine the Concentrations of Waste Products in any Special Source of Ground Water During the First 1,000 Years After Disposal

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

Forecast: No activity is planned for FY 1994.

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2.7.9 Performance Confirmation (SCP Section 8.3.5.16)

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

Forecast: No activity is planned for FY 1994.

2.7.10 U.S. Nuclear Regulatory Commission Siting Criteria (SCP Section 8.3.5.17)

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

Forecast: No activity is planned for FY 1994.

2.7.11 Higher-Level Findings-Postclosure System and Technical Guidelines (SCP Section 8.3.5.18)

2.7.11.1 Planning for Site Suitability Evaluation

The DOE initiated activities related to the process of determining site suitability. These included (1) an evaluation of DOE siting guidelines, 10 CFR Part 960, to address changes in the program that have occurred over the past several years; and (2) development of a process to be used for the determination of site suitability, which will be consistent with the results of the evaluation of 10 CFR Part 960. As DOE proceeds with site characterization activities, DOE recognizes the need to seek public involvement in the evaluation of the suitability of the Yucca Mountain site. The process for evaluating site suitability will be developed taking into account the views of interested parties regarding an evaluation process that can earn public trust and confidence in the suitability evaluations for the Yucca Mountain site.

Forecast: The DOE plans to issue a Notice requesting written comments from interested parties on the process for evaluating the suitability of the Yucca Mountain site. The notice specifically requests comments on (1) how and when interested parties wish to provide input to the evaluation of site suitability, (2) use of peer review for technical information supporting suitability evaluations, and (3) development of the site suitability process. In addition, DOE is planning to schedule public meetings for discussion of concerns and issues related to the process of determining site suitability.

2.7.11.2 Preclosure System Technology (SCP Section 8.3.5.7)

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

Forecast: No activity is planned for FY 1994.

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2.7.11.3 Preclosure Radiological Safety (Issue 4.1)

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

Forecast: No activity is planned for FY 1994.

SECTION 2.8 EXPLORATORY STUDIES FACILITY DESIGN AND CONSTRUCTION

The Site Characterization Plan, in Section 8.4.2, presented the rationale for the planned testing and described the surface testing and the underground test facility. In the Site Characterization Plan the underground testing was to be conducted by means of an "Exploratory Shaft Facility." The change to a ramp and drift "Exploratory Studies Facility" means the following description of progress does not closely parallel the Site Characterization Plan structure and there are, therefore, not as many references to Site Characterization Plan sections as there are elsewhere in this report.

The Exploratory Studies Facility design and construction activities have progressed significantly during this reporting period. The design change for the enhancement to the current Exploratory Studies Facility configuration as reported in Progress Report #9 (DOE, 1994f) is being implemented.

2.8.1 Exploratory Studies Facility Design

Ongoing modifications in the form of Field Change Requests and Change Requests continue to be made against Design Package 1A. Also the design was finalized on the tunnel boring machine launch chamber in the Starter Tunnel. This portion of Package 1A will be baselined by the Project Change Control Board and released for construction early in the third quarter of FY 1994. Package 1A consists of the following elements:

- North Portal pad
- Topsoil storage area
- Exploratory Studies Facility access road
- Sewage collection and treatment system
- North Portal pad water supply system
- Tunnel boring machine Starter Tunnel
- Rock storage area
- Switchgear building

A change in the split of the balance of Package 1 was effected during this reporting period to add Package 1E to support construction initiatives. This resulted in a change in the elements contained in Packages 1B, 1C, and 1D. Definition of elements formerly in packages 1B, 1C, and 1D are contained in Progress Report #9. Design Package 1C has undergone a 90 percent design review during this period. Design Package 1B was baselined by the Project Change Control Board and issued for construction early in the second quarter of FY 1994. Package 1B now consists of the following elements:

- Change house building (contains other services to include portal control)
- Shop building
- Sanitary sewer system
- Power distribution

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- Water distribution system
- Subsurface wastewater system
- H-road, site grading, and paving
- Explosive storage area
- Site grounding
- Redesign North Portal pad drainage
- Reconfigure North Portal pad for surface soil

Package 1C, which completed design and underwent a 90 percent design review during this period, now consists of the following elements:

- Compressed air system
- Stand-by power
- Site lighting (partial)

Package 1D, for which design was initiated during this reporting period, now consists of the following elements:

- Finish grading and paving plan
- Muck storage area
- Conveyor maintenance access road
- Covered storage
- Integrated Data & Control System block diagram and procurement specification
- Fuel storage system
- Site lighting (remaining)
- Off site communications system
- Standby power shed (if necessary)
- Equipment foundations and oily water containment
- Fence and fence grounding (partial)
- Electrical ductbanks (remaining)

Package 1E will be completed in FY 1995 and consists of the following elements:

- Warehouse
- Operations building
- North Portal entry structure
- Sanitary sewer system (off-pad)
- Steam cleaning system

The design of Subsurface Package 2, North Ramp continued. Package 2 is split into Packages 2A, 2B, and 2C. Design Package 2A was baselined by the Project Change Control Board and issued for construction in the second quarter of FY 1994. Package 2A consists of the following elements:

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- Surface and subsurface conveyor specification including arrangement drawings
- Electrical switchgear, transformers, and power center procurement specifications
- Transportation alternatives study

Package 2B which underwent a 90 percent design review during this period, consists of the following elements:

- Concrete foundations for the muck conveyor transfer tower
- Utility analysis
- Tunnel ventilation specification and drawings
- Rail haulage system
- Mapping platform procurement specification
- Excavation, ventilation and muck storage trade studies
- Control system specification and drawings
- Monitoring and warning system specifications

This package contains procurement information for these elements.

Package 2C, completing design during this period, consists of the following elements:

- Concrete and structural steel for surface and subsurface conveyors
- North Ramp to Topopah Spring Level excavation and ground support specifications and drawings
- Remaining utility systems for North Ramp
- Electrical power, lighting, and grounding
- Monitoring and warning systems

This package primarily contains construction and installation information for these elements.

During this reporting period, the Exploratory Studies Facility Title II Design team developed a cost savings initiative associated with the change from four to two tunnel boring machines described in Progress Report #8 (DOE 1993o). The initiative was a proposed relocation of the muck storage area to the east of the North Portal access road and an expansion of the existing North Portal pad to the southeast for additional storage of equipment and material on the pad. These proposals are currently being incorporated into the appropriate design packages.

Forecast: The Project Change Control Board is preparing directions to the CRWMS M&O to transition the control of Exploratory Studies Facility drawings and specifications from the Level 2 Project Change Control Board to the Level 3 M&O Change Control Board. It is planned for Package 1C to be baselined and issued for construction in the third quarter of FY 1994. Package 1D, in design during this reporting period, will be completed in FY 1994. Package 1E design will be initiated in the fourth quarter of FY 1994. It is planned for Package 2B to be baselined and issued for construction in the third quarter of FY 1994. Package 2C will undergo a 90 percent design review in the third quarter of FY 1994 and be baselined and issued for construction early in the fourth quarter of FY 1994.

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2.8.2 Technical Assessment of the Exploratory Studies Facility Seismic Design

A technical assessment of the Exploratory Studies Facility seismic design inputs continued during the reporting period. The purpose of this technical assessment was to review the "Exploratory Shaft Seismic Design Basis Working Group Report" (Subramanian et al., 1990) to determine if the proposed seismic design basis is still appropriate given the current configuration of the Exploratory Studies Facility and the current understanding of seismic hazards at Yucca Mountain. If the seismic design basis proposed by Subramanian et al. (1990) is no longer appropriate, the technical assessment team will then develop seismic design inputs for Exploratory Studies Facility design based on currently available data and analyses.

The review of Subramanian et al. (1990) has been completed. Review comments can be broadly classified into three categories:

1. Assumptions related to the configuration of the Exploratory Shaft Facility are now inappropriate given the new configuration involving ramps and drifts.
2. Conclusions based on geologic data available at the time of the report need to be revised based on new information gathered since that time.
3. The multiple levels of conservatism recommended in the report are inappropriate.

Based on this evaluation, the seismic design basis presented in Subramanian et al. (1990) can no longer be supported. Hence the technical assessment team implemented the second phase of its charter: develop seismic design inputs appropriate for design of the Exploratory Studies Facility at Yucca Mountain.

As part of the process to develop these inputs, a probabilistic assessment of vibratory ground motion hazard at Yucca Mountain was carried out. The results of the probabilistic assessment yield values of peak horizontal acceleration and velocity as a function of their annual probability of being exceeded. The results also provide the information needed to determine a design basis earthquake and associated response spectrum. This approach incorporates the time dependence of earthquake occurrence, allows uncertainties in assessment inputs to be explicitly incorporated in the analysis, and provides an evaluation of hazard from potential sources of future seismicity.

The results of the probabilistic hazard assessment indicate that for annual exceedance probabilities greater than about 10^{-4} (return periods of less than 10,000 years) the primary source of ground motion hazard at the site is a background earthquake. Values of peak horizontal acceleration with annual probabilities of being exceeded of 2×10^{-3} , 1×10^{-3} , 5×10^{-4} , and 1×10^{-4} , are 0.19 g, 0.27 g, 0.37 g, and 0.66 g, respectively.

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Forecast: The technical assessment will be completed during the third quarter of FY 1994. A recommended design response spectrum and recommended values of peak horizontal acceleration and velocity will be provided along with reduction factors as a function of depth. Upon completion of these tasks, the program baseline will be updated.

2.8.3 Exploratory Studies Facility Construction

One of the most notable activities during this reporting period was the excavation and completion of Test Alcove 1 which will be used for radial borehole and hydrochemistry tests. The face of Test Alcove 1 is at 34.5 m as measured from the centerline of the Starter Tunnel.

Other significant construction accomplishments include: the completion of the excavation and installation (excluding backfill) of the water line from UE-25 J-13 to the Booster Pump Station. The 69 kV power became available at the North Portal substation on March 15, 1994. Erection of the concrete batch plant near UE-25 J-13 to support construction activities at the North Portal pad was completed and testing of the batch plant was begun. The assembly pad for the tunnel boring machine was formed and poured. The underground utilities that cross under the tunnel boring machine assembly area are being completed.

Delivery began of the tunnel boring machine from Construction and Tunneling Services, Inc. of Kent, Washington. The first components arrived at the Yucca Mountain site on March 29, 1994.

During this period, planning for upcoming work and monitoring of ongoing work was performed. The planning included a schedule that will allow installation of adequate site infrastructure to support assembly and start up of the tunnel boring machine on August 8, 1994. Close monitoring of the tunnel boring machine design, fabrication, and checkout as well as the infrastructure installation on the North Portal pad was maintained.

Forecast: Complete the tunnel boring machine assembly area and assemble and checkout the tunnel boring machine on the North Portal pad. Initiate testing and checkout of the tunnel boring machine in the last quarter of FY 1994 with full operations to commence in the second quarter of FY 1995. Continue construction of the on-pad utilities. Complete those portions of the sanitary sewer system, subsurface waste water system, and the switchgear building on the North Portal pad. Complete testing of the concrete batch plant and fabricate the initial precast concrete segments for the Starter Tunnel to support the tunnel boring machine excavation.

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2.8.4 Proposed Enhancements to the Current Exploratory Studies Facility Configuration

The background, rationale and description of this enhancement was provided in Progress Report #9. The Project Change Control Board approved this change during this reporting period and it is currently being implemented into the design of the Exploratory Studies Facility.

CHAPTER 3 - SCHEDULE

In late November 1989, a new proposed Program schedule was announced in the Secretary's report to Congress (DOE, 1989). The new schedule was based on consideration of the duration required to obtain Yucca Mountain site access from the NRC, the State of Nevada, and others; and the work scope described in the Site Characterization Plan and the more-detailed study plans. In January 1990, the schedule presented in the Secretary's report to Congress was finalized by OCRWM in the Program Cost and Schedule Baseline (DOE, 1990b). This Program Cost and Schedule Baseline was revised in March 1991, in November 1991, and again in September 1992. Factors external to the Program, including uncertainties associated with Program funding levels, and study plan review, continue to affect the Program schedule.

This section presents the schedule baseline for the Project as of the end of this reporting period (March 31, 1994). More detailed schedules are maintained at YMSCO, in combination with work scopes and the funding needed to accomplish this work. Based on progress, funding, and re-baselining activities, as well as the Secretary's review of the Program, a new schedule will be published in the near future.

Table 3-1 presents the summary milestones for the Project. Figure 3-1 shows the relationship of the summary milestones to the major activities.

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Table 3-1. Summary Milestones ^a

Milestone	Baseline Date	Actual Date
<u>Surface-Based Testing</u>		
Obtain Permits	12/91	7/91
Start New Surface-Based Testing	1/92	7/91
Complete Deep Unsaturated Zone Hydrologic Hole Drilling	6/95	
<u>Exploratory Studies Facility</u>		
Start Final Exploratory Studies Facility Title II Design	10/91	10/91
Start Exploratory Studies Facility Site Preparation	11/92	11/92
Start Exploratory Studies Facility In Situ Test Phase	6/96	
Complete Exploratory Studies Facility Development Drifting	11/97	
Provide Engineering Barrier System Data to Waste Package License Application Design	7/98	
<u>Waste Package/Repository Design</u>		
Complete Repository Program Plan	3/91	9/91
Start Waste Package/Repository Advanced Conceptual Design	10/92	10/92
Start Waste Package/Repository License Application Design	6/96	
<u>Environmental Impact Statement</u>		
Issue Environmental Impact Statement Notice of Intent	5/97	
Issue Environmental Impact Statement Implementation Plan	2/98	
Notify State of Proposed Site Selection	10/99	
Issue Draft Environmental Impact Statement	10/99	
Issue Final Environmental Impact Statement	3/01	
Notify State of Site Selection	10/99	
Issue Record of Decision	4/01	
Issue Site Recommendation Report to the President	4/01	
<u>License Application</u>		
Provide Recommendation to the Director, OCRWM, on Alternative License Application Strategies for Review	8/91	8/91
Submit License Application to NRC	10/01	

^aTable shows approved Program Schedule Baseline and actual completion dates as of March 31, 1994. The baseline schedule is currently under review and will be revised and published in the near future.

(This schedule is currently under review and will be revised and published in the near future)

▼	PROGRAM COST AND SCHEDULE
BASELINE MILESTONE	(
▼	ACTUAL START/COMPLETION DATE	

CHAPTER 4 - PROGRAM OUTREACH

4.1 INTERNATIONAL PROGRAM

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

The cooperative work with Canada included eight technical tasks concerning radionuclide retardation model development, field tracer test development, natural analogue studies at Cigar Lake, fundamental materials investigations, in situ stress determination, spent fuel dissolution model development, hydrochemical tool testing, and performance assessment technology. High-temperature tests on cementitious sealing materials continued in Canada at facilities not available in the United States, under conditions simulating those expected at Yucca Mountain. Additional existing Canadian instruments have been modified for measuring in situ stress in fractured tuff at Yucca Mountain. Spent-fuel dissolution tests have been conducted for Project waste package and performance assessment analyses. Prototype testing continued on complex downhole packer strings for use at C-Well tracer testing at Yucca Mountain. Planning continued for large-block radioactive tracer testing in Canada for a tuff sample that has not yet been obtained at Yucca Mountain. Radionuclide release and transport rates that were measured in ground water at a high-grade uranium ore site in Canada continued to be analyzed and are being evaluated for use in Yucca Mountain performance assessment analyses. Planning continued for calibration testing in Canada at laboratory and field sites not available in the United States for a Swedish hydrochemical tool for use in Yucca Mountain C-Well tests.

The cooperative work with the Swiss included five technical tasks concerning transport characterization in fractured rocks, multiphase flow in fractured porous rocks, seismic tomographic imaging, mechanistic approach to sorption of radionuclides, and borehole fluid logging. Accomplishments included the use of the experimental facility, previously built and demonstrated as noted in Progress Report #9 (DOE, 1994f), to characterize two-phase flow conditions that could apply to unsaturated Yucca Mountain regimes. Development continued of a conceptual model for fracture flow systems that may be encountered at Yucca Mountain. Development continued of a mechanistic model to predict sorption of radionuclides at Yucca Mountain. Seismic imaging hardware was further improved. Data acquisition and processing systems continued to be improved to provide real-time interpretation in site characterization efforts at Yucca Mountain. Finally, development continued for advanced borehole logging techniques usable in fluid property conditions that may exist at Yucca Mountain. This technology has been developed using the underground rock laboratory at the Grimsel Test Site laboratories and surface facilities, operated by the Swiss National Cooperative for the Disposal of Radioactive Waste, and the United States.

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The cooperative work with Sweden, Hard Rock Laboratory Project Agreement, included five technical tasks concerning flow and transport characterization in fractured rocks, disturbed zone effects, geochemical modeling, ground-water flow and water-rock interactions using radiogenic isotopes, and the development of the capability for integration of construction and testing related to the Exploratory Studies Facility. Other nations participating in studies at Sweden's Hard Rock Laboratory include the United Kingdom, Finland, France, Japan, and Canada. During the reporting period, United States scientists observed Hard Rock Laboratory operation and brought back technical and management techniques for the United States to use for integration and coordination of scientific efforts during Exploratory Studies Facility construction. Continuing activities include: (1) developing a two-phase flow model to analyze ground-water flow in fractured, unsaturated rocks at Yucca Mountain; (2) participation in an international fracture flow modeling task force for comparison and transfer of technology to the Project; (3) developing a method to assess ground-water travel time requirements and to determine a ground-water travel time distribution range appropriate for Yucca Mountain; (4) participation in design and evaluation of underground hydrological and geochemical testing at the Hard Rock Laboratory; and (5) development of isotopic analyses of samples obtained from the Hard Rock Laboratory. The results of these activities will be used to establish sampling and analysis techniques for preconstruction site characterization. This underground technical program has provided direct input to the development of site characterization techniques used at Yucca Mountain, and to the development of an integrated testing program for both natural and engineered barrier components at the Yucca Mountain Exploratory Studies Facility.

During the past several years the Project has been cooperating with the Nuclear Energy Agency of the Paris-based Organization for Economic Cooperation and Development on compiling a comprehensively reviewed thermochemical data base for use in geochemical modeling. A volume for uranium data was published in 1992. During this reporting period, the volume for americium data has been compiled and is ready for external peer review. Progress has also been made on completing the work for neptunium, plutonium, and technetium, the only other elements presently included in the scope of work.

The Project has begun to participate in the international geochemical modeling effort, CHEMVAL II, an activity of the Commission of the European Community. Preliminary planning was completed at meetings during the reporting period.

The international program began work in the New Zealand Geothermal Field Geochemical Code Validation program. The proposed studies in New Zealand have been implemented in cooperation with the New Zealand Crown Research Institute for Geochemistry and Nuclear Science to validate geochemical and hydrologic models used to simulate transport and hydrological processes, especially in the near field. Planning and some preliminary and scoping investigations have been completed.

A collaboration agreement between DOE and Spain's radioactive waste program, Empresa Nacional de Residuos Radioactive, S.A., has been completed. Areas of collaboration discussed include container material performance, spent fuel and cladding performance, engineering backfill, and the effects of man-made materials.

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Forecast: The International Program will sponsor and support the development of the Commission of the European Community's 6th biennial Natural Analogue Working Group Workshop in the United States. This Workshop will be hosted by OCRWM program scientists from Los Alamos National Laboratory and is scheduled to be held in Santa Fe, New Mexico, in September 1994.

Activities described above under the Canadian, Swedish, and Swiss programs will continue, in keeping with the applicable international agreements. Of particular significance will be the continuation and expansion of significant cooperative work in New Zealand, the scope and purpose of which has been noted earlier.

By October 1994, it is expected that the review of the americium volume of the Nuclear Energy Agency thermochemical data base will be complete. This agency identified three United States scientists, independent of OCRWM, to review this volume, which was compiled by other scientists last year as they reviewed the available literature. Work will also proceed for the compilation of the neptunium-plutonium volume and should bring it close to readiness for the independent peer review. The volume for technetium is scheduled to be nearly ready for peer review.

During the next six months actual investigations by United States scientists are expected to start in cooperation with CHEMVAL II.

4.2 PUBLIC OUTREACH

Ninety-four tours of Yucca Mountain, including six Public Open House tours, were conducted for approximately 3000 members of the public and other interested parties. The remaining tours were for special groups, including Chubu Electric Power; Licensing Support System Advisory Review Panel; Nevada Association of Counties; NRC; NAS Tunnel Technology Committee; ACNW; Steering Committee on High-Level Radioactive Waste Project - Japan; Congressman Michael Bilirakis (R)-Florida, 9th District, who is the ranking minority member of the U.S. House of Representatives Energy and Power Subcommittee; American Nuclear Energy Council; and NWTRB.

Numerous programmatic and technical workshops, presentations, and meetings were held in various Nevada communities to provide current information to the public regarding site characterization progress. The Project also coordinated and attended two Affected Units of Government Meetings and the Public Participation Plan meeting for the Affected Units of Government. A total audience of approximately 12,700 people attended 184 speaking presentations during this period, which included 10 technical presentations, 61 general project overview presentations, and 113 educational presentations.

The Yucca Mountain Science Centers located in Las Vegas, Beatty, and Pahrump, Nevada, received approximately 7800 visitors during this period. At the Science Centers, the project presented five Yucca Mountain Speaker Series presentations, five Girl Scout Geology Badge Workshops, a Critical Thinking Teacher Workshop, a Teacher Steering Committee, a

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two-part Teachers Workshop, and two LESSONS Teacher Workshops. Project public information exhibits were staffed for 18 events, with approximately 7600 visitors.

The Project produced and distributed a variety of public information products, including the public newsletter, "Of Mountains and Science," announcements for monthly public tours and speakers series, four fact sheets, and five information videos. A new Exploratory Studies Facility exhibit for the Las Vegas Yucca Mountain Science Center was also coordinated.

Various Project staff participated in the 1994 DOE Nevada Regional High School Science Bowl. The Project co-sponsored the annual Southern Nevada Science Fair. The fair was open to students in Nye, Esmeralda, Lincoln, and Clark counties. Project staff also coordinated and assisted with the JASON V Project, with over 22,000 students nationwide experiencing scientific discovery as it happened through live broadcasts from Belize, Central America.

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CHAPTER 5 - EPILOGUE

This section provides a brief summary of key events that occurred after the close of the reporting period on March 31, 1994 and prior to printing this report. Where appropriate, a reference to the applicable text section is provided for each item.

On June 21, 1994, 27 states and state utility regulatory commissions joined together and filed suit against DOE in the U.S. Court of Appeals for the District of Columbia, seeking an order from the Court declaring that the Nuclear Waste Policy Act of 1982, as amended, imposes on DOE a binding, non-discretionary obligation to begin accepting spent nuclear fuel and high-level waste by January 31, 1998. In addition, 14 nuclear utilities filed a similar action with that Court requesting similar relief.

The FY 1995 appropriation for OCRWM was determined by the conference committee to be \$522.2M. The conference report was adopted by both the House and the Senate, and signed into law by the President.

Several presentations on the Proposed Program Approach have been given to various groups, including the NRC Division of Waste Management on May 19, 1994, a Stakeholders' Meeting on May 21, 1994, and the NRC Commissioners on June 6, 1994. At the May 21, 1994, OCRWM-sponsored Stakeholders' Meeting in Las Vegas, Nevada, DOE explained the Proposed Program Approach and solicited public input in the decision-making process. The morning session also included an update of activities in response to the August 10, 1993, Stakeholders' Workshop. The afternoon session focused on the site suitability evaluation process. The DOE considered written comments from the April 25, 1994, Notice of Inquiry and discussion at the May 21, 1994, meeting; developed a draft report describing the site suitability process; published the description in the Federal Register on August 4, 1994, requesting written comments from interested parties; and held public meetings on August 27, 1994, in Las Vegas and August 30, 1994, in Washington, D.C. to elicit comments. After review of comments, DOE will finalize the description and make it available to the public. [Sections 1.3.1 and 2.1.11]

The DOE initiated the focused Advanced Conceptual Design concept late in the reporting period to focus and integrate design activities and avoid unnecessary duplication of efforts. This approach to Advanced Conceptual Design relies on identifying assumptions to be verified as site characterization progresses. The fundamental objectives of Advanced Conceptual Design are to: (1) develop a Project scope that satisfies program needs, (2) assure and validate Project feasibility and attainable technical performance levels, (3) identify and quantify Project risks, and (4) develop a reliable cost estimate and a realistic performance schedule. The focused Advanced Conceptual Design process will expedite the development of an Advanced Conceptual Design for the repository and waste package that is consistent with DOE Order 4700.1 and NRC regulation 10 CFR 60.21(c)(1)(ii)(D), which requires a comparative evaluation of alternatives to the major design features that are important to waste isolation.

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The focused Advanced Conceptual Design process is based on the selection of a single primary design concept that meets the repository and waste package requirements. The selection of the primary concept is based on management decisions and assumptions that are in turn based on the best available technical data. A substantiation activity will be identified for each assumption that is not supported by sufficient technical data. As the design and substantiation activities progress, the assumptions will be modified as necessary. The selection of a single concept will occur at the completion of the Advanced Conceptual Design activities.

Assumptions developed to date were documented in the Controlled Design Assumption Document on August 29, 1994 (CRWMS M&O). Four types of assumptions are included in the document: (1) key or management assumptions, (2) assumptions dealing with statements in the applicable requirements documents, (3) design related assumptions based on engineering judgment, and (4) assumptions related to the technical data needed to support repository and waste package advanced conceptual designs. [Sections 2.4 and 2.6]

The operational readiness review of the tunnel boring machine was conducted the week of July 18-22, 1994. Assembly of the machine was essentially completed by August 5, 1994. Testing and checkout were completed, and the machine moved to the tunnel face in early August. First excavation is anticipated by the end of September. [Section 2.8.3]

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APPENDIX A

Status of Site Characterization Analysis Open Items

Appendix A. Status of Site Characterization Analysis Open Items

<u>Item ID</u>	<u>Item Description</u>	<u>Status</u>	<u>Action Description</u>
Comment 1	A systematic, iterative approach to identify and collect data during site characterization to support a license application not demonstrated to be in place.		Submit Mined Geological Disposal System License Application Annotated Outline, Rev. 3 to NRC. Rev. 3 identifies/indexes info needed for potential License Application for Chapter 3
			Submit a supplemental response to the NRC. This response will be used to close Comments 10, 18, 49, and 60.
Comment 2	Performance Assessment: Confidence in performance.		Submit a supplemental response to the NRC.
Comment 3	Reliance on expert judgment to supply licensing information.		Supplemental response submitted to the NRC. Awaiting NRC concurrence.
Comment 4	Rationale for the testing needs; integration of testing with design and performance assessment needs.		Develop parametric calculations to refine parameter goals.
			Develop plans for collecting all necessary data.
			Supply NRC with the information in semiannual progress reports.
			Submit a supplemental response to the NRC.
Comment 5	Waste Package: Interpretation of substantially complete containment.		Submit a supplemental response to the NRC.
Comment 6	Performance Assessment: Hypothesis Testing Table and alternative conceptual models.		Submit a supplemental response to the NRC.
Comment 7	Use of expert judgment versus peer review.		Supplemental response submitted to the NRC. Awaiting NRC concurrence.
Comment 8	Alternative Tectonic Models		Study Plan 8.3.1.17.4.12 "Tectonic Models and Synthesis" needs to be completed and approved.
			Submit a supplemental response to the NRC.

Appendix A. Status of Site Characterization Analysis Open Items

<u>Item ID</u>	<u>Item Description</u>	<u>Status</u>	<u>Action Description</u>
Comment 9	Use of expert judgment during the development of Hypothesis Testing Table.		Submit a supplemental response to the NRC.
Comment 10	Assessment of significance of site hydrologic characteristics		Resolve concerns in Comment 1. Resolution of Comment 1 will address the cross-issues for this comment.
Comment 11	No hypothesis on the thermal effects of waste emplacement in the hydrologic environments presented.		Submit a supplemental response to the NRC.
Comment 12	Porous flow in the Calico Hills unit.	Closed	NRC letter lifting Objection 1. NRC considers this comment closed.
Comment 13	Surface Hydrology: Surface water gaging station locations and the natural infiltration measurements.	Closed	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 14	Hydrologic properties of the tuffaceous beds of the Calico Hills nonwelded unit.	Closed	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 15	Solitario Canyon horizontal borehole activity is inadequate to discriminate between the hypotheses that faults are barriers to fluid flow in non-welded tuff units or faults are conduits for liquid-water flow.		Revise Study Plan 8.3.1.2.2.4 "Characterization of the Yucca Mountain Unsaturated Zone in the Exploratory Studies Facility" and submit to the NRC.
			Submit a supplemental response to the NRC.
Comment 16	Characterization of the hydrologic properties of the Calico Hills unit.	Closed	NRC letter lifting Objection 1. NRC considers this comment closed.
Comment 17	Multi-purpose borehole testing near the shafts.	Closed	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 18	Initial hydrologic modeling studies are not supported by planned studies.		Resolve concerns in Comment 1. Resolution of Comment 1 will address cross-issues for this comment.

Appendix A. Status of Site Characterization Analysis Open Items

<u>Item ID</u>	<u>Item Description</u>	<u>Status</u>	<u>Action Description</u>
Comment 19	Saturated Zone: Work is not adequate for saturated zone characterization		Develop and submit plan to define sufficient testing of the saturated zone. Submit a supplemental response to the NRC.
Comment 20	Saturated Zone: Potentiometric surface will not adequately be defined.		Identify what additional work/drilling will be performed to characterize the southern area. Submit a supplemental response to the NRC.
Comment 21	Saturated Zone: Tc-199 and I-129 are not included to be characterized in the ground water flow and radionuclide analysis background concentrations.		DOE letter to NRC closing Comment 21 and 22. Awaiting NRC concurrence.
Comment 22	Saturated Zone: Hydrochemical samples.		DOE letter to NRC closing Comments 21 and 22. Awaiting NRC concurrence.
Comment 23	Unsaturated Zone: Evaluation of radionuclide concentrations on fracture surfaces.	Closed	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 24	Approaches are not sufficient for determining reliable thermodynamic properties.		Complete Study Plan 8.3.1.3.3.2 "Kinetics & Thermodynamics of Mineral Evolution" and submit to NRC. Receive Study Plan from Los Alamos National Laboratory. Original Administrative Procedure had to be rewritten and resubmitted because of length of time. Los Alamos National Laboratory budgeted for work in 1994.
Comment 25	Waste Package: Rationale on additional testing on waste and interactions between and among radionuclides on sorption.		Submit Study Plan 8.3.4.2.4.1 "Characterization of Chemical and Mineralogical Changes in Post-Emplacement Environment" to NRC. Submit a supplemental response to the NRC.
Comment 26	Sorption Batch Studies	Closed	NRC evaluation of DOE responses. NRC considers this comment closed.

Appendix A. Status of Site Characterization Analysis Open Items

<u>Item ID</u>	<u>Item Description</u>	<u>Status</u>	<u>Action Description</u>
Comment 27	Batch Sorption Measurements	Closed	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 28	Sorption on Particulates and Colloids.	Closed	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 29	Biological Sorption and Transport.	Closed	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 30	Solubility Modeling.	Closed	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 31	Some parameters and conditions under fracture flow are not planned and need to be determined.		Submit Study Plan 8.3.1.3.6.1 "Dynamic Transport Column Experiments" to the NRC. Submit a supplemental response to the NRC.
Comment 32	Rock characteristics program: Geophysical integration is insufficient.		Geophysical Integration Group needs to develop a plan to implement integration. Submit a supplemental response to the NRC.
Comment 33	Engineering rock parameters are not adequately integrated to develop 3-D rock characteristics models		Prepare Study Plan 8.3.1.4.2.3 "Three-Dimensional Geologic Modeling" and submit to the NRC. Complete Study Plan 8.3.1.4.3.1 "Systematic Acquisition of Site Specific Data" and submit to the NRC. Submit a supplemental response to the NRC.
Comment 34	Drilling Program: It is unclear how data from various drill holes will be used in support of various studies, how uncertainties in core retrieval and data analyses will be handled, and how the large volume of existing information will be used to plan the drilling program.		Complete Study Plans 8.3.1.4.2.1 "Characterization of the Vertical and Lateral Distribution of Stratigraphic Units in the Site Area" and 8.3.1.2.2.4 "Characterization of the Yucca Mountain Unsaturated Zone Exploratory Studies Facility Study" and submit to NRC

Appendix A. Status of Site Characterization Analysis Open Items

<u>Item ID</u>	<u>Item Description</u>	<u>Status</u>	<u>Action Description</u>
			Submit a supplemental response to the NRC.
Comment 35	Adequacy of lithological, structural, and drifting activities to characterize the site.	Closed	NRC letter lifting Objection 1. NRC considers this comment closed.
Comment 36	Rationale for investigation 8.3.1.4.2 may not be accurate for the perimeter drift defining lower concentrations of faults.		Submit a supplemental response to the NRC.
Comment 37	Identification of blast fractures.	Closed	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 38	Characterization of faults in the subsurface.	Closed	Supplemental response submitted to NRC.
Comment 39	Systematic Drilling Program: No assessment is provided to support the estimated maximum range of statistical correlation for porosity and air permeability.	Closed	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 40	Systematic Drilling Program: Spacing of the 30 sample borehole pairs in a range of up to 10,000 feet may represent a lower bound for geostatistical analysis.	Closed	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 41	Systematic Drilling Program: Tight clustering of sample locations SD-8 and SD-12 has not been justified	Closed	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 42	Adequacy of evaluation of escarpment retreat.		DOE letter on comments 42 & 43. Awaiting NRC concurrence.
Comment 43	Adequacy of numerical goals in erosion, post-closure tectonics, and pre-closure tectonics performance assessment tables.		DOE letter on comments 42 & 43. Awaiting NRC concurrence.
Comment 44	Waste Package: Overall goal is not consistent with substantially complete containment	Closed	NRC evaluation of DOE responses. NRC considers this comment closed.

Appendix A. Status of Site Characterization Analysis Open Items

<u>Item ID</u>	<u>Item Description</u>	<u>Status</u>	<u>Action Description</u>
Comment 45	Volcanic rate calculations independent of underlying volcanic-tectonic processes.		Supplemental response submitted to NRC. Awaiting NRC concurrence.
Comment 46	Postclosure Tectonics.	Closed	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 47	Waste Package: Relationship of postclosure tectonics to the waste package and the EBS requirements.		Supplemental response submitted to the NRC. Awaiting NRC concurrence.
Comment 48	Use of fault slip rates on the repository facilities are not conservative.		Prepare and issue topical report "Seismic Design Criteria" in accordance with the Seismic Hazards Issue Resolution Group's Issue Resolution Action Plan. Submit a supplemental response to the NRC.
Comment 49	Volcanism: Results from investigations on basaltic volcanism may fail to meet overall system performance.		Resolve concerns in Comment 1. Resolution of Comment 1 will address the cross-issues for this comment.
Comment 50	Effects of faulting may be underestimated.	Closed	NRC evaluation of DOE responses. NRC considers the comment closed.
Comment 51	Adequacy of Geophysics program to determine deep and shallow crustal features.		Geophysical Integration group needs to develop a plan to implement integration. Submit a supplemental response to the NRC.
Comment 52	Use of Geophysics to identify volcanic/igneous features.		Complete assessment by independent consultant of planned and potential geophysical studies that could be contributed to resolution of volcanism issue. Supply consultant's preliminary findings to the NRC for use during the technical exchange. Submit a supplemental response to the NRC.
Comment 53	Adequacy of natural resource assessment; consideration of ore deposition models.		DOE supplemental response. Awaiting NRC concurrence.
Comment 54	Inconsistencies in Site Characterization Plan	Closed	NRC evaluation of DOE responses. NRC considers this comment closed.

Appendix A. Status of Site Characterization Analysis Open Items

<u>Item ID</u>	<u>Item Description</u>	<u>Status</u>	<u>Action Description</u>
Chapter 8.			
Comment 55	Adequacy of geostatistical approach to geomechanical and thermal properties.		<p>The review of Performance Allocations for Activity 8.3.1.15 "Rock Characteristics Program" needs to be completed.</p> <p>Submit a supplemental response to the NRC.</p>
Comment 56	Validation of models for mechanical and thermal properties.		<p>Complete and supply NRC with study plans relating to in situ tests. 8.3.1.15.1.5, rev.1 "Excavation Investigations," 8.3.1.15.1.6 "In Situ Thermomechanical Properties," and 8.3.1.15.1.7 "In Situ Mechanical Properties"</p> <p>The Review of Performance Allocations for Activity 8.3.1.15 "Rock Characteristics Program" needs to be completed.</p> <p>Submit a supplemental response to the NRC.</p>
Comment 57	Design verification does not consider alternative methods of excavation.	Closed	NRC letter lifting Objection 1. NRC considers comment closed.
Comment 58	Descriptions in the in situ design verification section do not include tests to verify design reports.	Closed	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 59	Description of tectonic and igneous events do not allow for determination of actual investigations to be conducted, and sequencing of activities.		<p>Submit a supplemental response to the NRC.</p> <p>Prepare Study Plan 8.3.1.17.4.7 "Subsurface Geometry and Concealed Extensions of Quaternary Faults at Yucca Mountain" and submit to the NRC.</p>
Comment 60	Performance Assessment: Adequacy of preclosure design and performance goals and characterization parameters.		Resolve concerns in Comment 1. Resolution of Comment 1 will address cross-issues of this comment.

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<u>Item ID</u>	<u>Item Description</u>	<u>Status</u>	<u>Action Description</u>
Comment 61	Assumption that future faulting will follow previous faulting.		<p>Prepare Study Plan 8.3.1.17.2.1 "Faulting Potential at Repository" and submit to the NRC.</p> <p>Submit a supplemental response to the NRC.</p>
Comment 62	The studies of faulting at the surface facilities do not indicate how DOE is proposing to use standoff distances.		<p>Prepare Study Plan 8.3.1.17.2.1 "Faulting Potential at the Repository" and submit to the NRC.</p> <p>Submit a supplemental response to the NRC.</p>
Comment 63	Use of pre-existing and unavailable information for the preclosure tectonics program and the surface facilities.		Submit a supplemental response to the NRC which will describe where in the study plan and the "Test and Evaluation Plan" the concerns of the NRC are addressed.
Comment 64	Adequacy of faults study for design and performance.		<p>Conduct a NRC/DOE interaction to further discuss the identification and investigation of fault displacement and seismic hazards.</p> <p>Submit a supplemental response to the NRC.</p>
Comment 65	Use of domains to define areas of faulting potential	Closed	NRC evaluation of DOE response. NRC considers this comment closed.
Comment 66	Release via a single event 10,000 year cumulative slip earthquake.		<p>Complete detailed study to show the facility can conservatively withstand an event exceeding the design basis ground motion.</p> <p>Submit a supplemental response to the NRC.</p>
Comment 67	Data on earthquakes having a cutoff of a magnitude 5.5 may not be sufficient to support an evaluation of the effects of site geology on surface and subsurface motion.	Closed	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 68	Adequacy of treatment on detachment faulting affects.		Prepare Study Plan 8.3.1.17.4.12 "Tectonic Models and Synthesis" and submit to the NRC.

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<u>Item ID</u>	<u>Item Description</u>	<u>Status</u>	<u>Action Description</u>
			Submit a supplemental response to the NRC.
Comment 69	Synthesis of data on the northwest trending faulting.		Prepare Study Plan 8.3.1.17.4.12 "Tectonic Models and Synthesis" and submit to the NRC.
			Submit supplemental response to the NRC.
Comment 70	Blast control procedures are less important to post-closure performance not justified.	Closed	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 71	Adequacy of technologies in assessing faulting for construction, operation, and closure.		Submit a supplemental response to the NRC.
Comment 72	Adequacy of the seal program.	Closed	NRC letter lifting Objection 1. NRC considers this comment closed.
Comment 73	Performance Assessment: Adequacy of required backfill hydraulic conductivity.		Resume work on the seals program investigation.
			Prepare the study plan for the measurement of the hydraulic conductivity (there is no numeric designator for this SP yet).
			Submit a supplemental response to the NRC.
Comment 74	Testing of Seal Components: No indication is given as to whether and when the testing to evaluate the behavior of selected sealing components under in situ test conditions will be initiated.		Prepare Study Plan 8.3.3.2.2.3 "In Situ Testing of Seal Components."
			Submit a supplemental response to the NRC.
Comment 75	Definition of and inconsistent use of geologic setting.	Closed	NRC Evaluation of DOE Responses. NRC considers this comment closed.
Comment 76	NRC reviews cannot be relied on as peer	Closed	NRC evaluation of DOE responses. NRC considers this comment closed.

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<u>Item ID</u>	<u>Item Description</u>	<u>Status</u>	<u>Action Description</u>
	reviews.		
Comment 77	Adequacy of considerations of retrieval operations in evaluating the effects of credible accidents on radiological exposure.		Evaluate the effects of credible accidents on radiological exposures during retrieval operation of the Advanced Conceptual Design. Submit a supplemental response to the NRC.
Comment 78	10 CFR Part 20 requirements need to be considered for postclosure.	Closed	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 79	Waste Package: Adequacy of waste package corrosion tests for the repository.		Complete the reviews and revisions of Study Plan 8.3.4.2.4.1 "Characterization of Chemical and Mineralogical Changes in the Post Emplacement Environment" and submit to the NRC. Supply the NRC with the Lawrence Livermore National Laboratory report, "Metal Barrier Selection and Testing," LLNL SIP CM-01. Submit a supplemental response to the NRC.
Comment 80	Performance goals consistent with interpretation and intent of substantially complete containment.		Submitted a supplemental response to the NRC. Awaiting NRC concurrence.
Comment 81	Waste Package: Adequacy of program in stress corrosion cracking behavior of waste packages.		The metals barriers scientific investigation plan to be completed. Evaluation of the extended dry concept with drift emplacement needs to be completed which may make this concern moot. The metals barrier scientific investigation must be initiated and preliminary results released. Submit a supplemental response to the NRC.

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<u>Item ID</u>	<u>Item Description</u>	<u>Status</u>	<u>Action Description</u>
Comment 82	Waste Package: There is an inadequate discussion on how the waste package performance may be verified at the time of license application.		<p>Prepare Study Plan 8.3.4.2.4.4 "Engineered Barrier System Field Test" and submit to the NRC.</p> <p>Submit a supplemental response to the NRC.</p>
Comment 83	The term 'uniform corrosion' is misleading.	Closed	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 84	Issue resolution strategy and testing package for the waste package and Engineering Barrier System do not take into account the full range of likely natural conditions that might affect performance of the barrier.		<p>Consider the effect of unanticipated processes and events on the overall system in the ongoing issue resolution process.</p> <p>Submit a supplemental response to the NRC.</p>
Comment 85	Performance Assessment: Temporal changes in the state of stress due to corrosion of the container is not accounted for.		<p>The metals barriers scientific investigation plan to be completed.</p> <p>Evaluation of the extended dry concept with drift emplacement needs to be completed which may make this concern moot.</p> <p>The metals barrier scientific investigation must be initiated and preliminary results released.</p> <p>Submit a supplemental response to the NRC.</p>
Comment 86	Waste Package: Degradation modes of copper-based alloys do not appear to agree with scientific literature.		<p>Complete the degradation modes surveys for candidate materials and test plans for promising materials.</p> <p>Submit a supplemental response to the NRC.</p>
Comment 87	Waste Package: Adequacy of effects of		Advance the waste package design which will narrow the waste package

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<u>Item ID</u>	<u>Item Description</u>	<u>Status</u>	<u>Action Description</u>
	dissimilar metal contacts causing corrosion.		option down to three designs. Describe the use of data from galvanic testing in the waste package design plan. Submit a supplemental response to the NRC.
Comment 88	Waste Package: Assumption of reduced uncertainties because of the unsaturated zone.		Lawrence Livermore National Laboratory scientific investigation SIP-CM-01 (Rev. 1), "Metal Barrier Selection and Testing" needs to be completed and supplied to the NRC. Submit a supplemental response to the NRC.
Comment 89	Waste Package: Construction materials may change the local pH and affect the corrosion of the metal containers and the leach rates of radionuclides from the glass.		Prepare Study Plan 8.3.4.2.4.5 "Manmade Materials" and submit to the NRC. Submit a supplemental response to the NRC.
Comment 90	Waste Package: Consideration of varying oxygen concentrations on the corrosion of metal containers.		Provide details on how the effects of oxygen on the waste package will be considered. These details will be described in the metal barriers investigation plan. Complete evaluation of the drift emplacement alternative. This alternative would make this concern moot. Submit a supplemental response to the NRC.
Comment 91	Waste Package/Performance Assessment: Consideration of alternative canisters for C-14 releases.		Evaluate and describe performance of alternative waste package designs to be considered in Advanced Conceptual Design. Review the new Environmental Protection Agency standards when they become available.

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<u>Item ID</u>	<u>Item Description</u>	<u>Status</u>	<u>Action Description</u>
			Alternative waste package scenarios need to be developed. A robust design may make this concern moot.
			Submit a supplemental response to the NRC.
Comment 92	Disturbed Zone: Boundary definition does not include properties affected by heat generated by waste emplacement	Closed	NRC evaluation of DOE responses. NRC considers the comment closed.
Comment 93	Performance Assessment: Will the site meet the performance objective for prewaste emplacement.	Closed	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 94	Performance Assessment: Assumption about features, events, processes related to the hydraulic systems in the modeling strategy.	Closed	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 95	Performance Assessment: Logic used to develop and screen scenarios and its implementation appear to be deficient.		Supplemental Response submitted to the NRC. Awaiting NRC concurrence.
Comment 96	Adequacy of the use of Kd for modeling heterogeneous medium.		Study Plan 8.3.1.3.4.2 "Biological Sorption and Transport" submitted to the NRC.
			Complete and submit to the NRC Study Plans 8.3.1.3.4.1 "Sorption Study," 8.3.1.3.4.3 "Development of Sorption Models," and 8.3.1.3.5.1 "Dissolved Species Concentration Limit."
			Submit a supplemental response to the NRC.
Comment 97	Adequacy of evidence to eliminate iodine as an important radionuclide.	Closed	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 98	Performance Assessment: Appropriateness of weighting Complementary Cumulative Distribution Functions by expert judgment.		Continue the development of the alternative conceptual models.

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<u>Item ID</u>	<u>Item Description</u>	<u>Status</u>	<u>Action Description</u>
			Address the Complementary Cumulative Distribution Functions through the iterative TSPA process.
			Prepare and provide the NRC with documentation on the TSPA and sensitivity studies (related to schedule in Comment 9).
			Submit a supplemental response to the NRC.
Comment 99	Performance Assessment: Quantification of all release		Submit a supplemental response to the NRC.
Comment 100	Performance Assessment: Adequacy of considerations of faulting release scenarios.	Closed	NRC letter closing 7 Site Characterization Analysis comments.
Comment 101	Performance Assessment: Appropriateness of equation used to estimate the partial performance for the 4th scenario class involving release along the water pathway.		Submit a supplemental response to the NRC.
Comment 102	Performance Assessment: Adequacy of Ross sequences in comparison to the hydrologic flow model.		Submit a supplemental response to the NRC.
Comment 103	Performance Assessment: Ross sequences address anticipated conditions and not scenarios.		Submit a supplemental response to the NRC.
Comment 104	Performance Assessment: Ross sequences address spent fuel but not vitrified waste form.	Closed	NRC letter closing 7 Site Characterization Analysis comments.
Comment 105	Performance Assessment: Rationale for elimination of scenarios.		Supplemental response submitted to the NRC. Awaiting NRC concurrence.
Comment 106	Performance Assessment: Missing coupling	Closed	NRC/DOE technical exchange on scenario development.

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<u>Item ID</u>	<u>Item Description</u>	<u>Status</u>	<u>Action Description</u>
	term for calculation of liquid phase radionuclide transport.		
Comment 107	Performance Assessment: Awaiting time in calculation is OK but care needs to be taken in the empirical Complementary Cumulative Distribution Functions in approximating.	Closed	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 108	Performance Assessment: Use of the Estimated Partial Performance Measures to screen scenarios and establish goals.	Closed	NRC/DOE technical exchange on scenario development.
Comment 109	Performance Assessment: Adequacy of treatment of coupling time between matrix and fracture flow in hypothesis testing tables.		Continue Total System Performance Analysis activity which will continue to analyze the coupling times for the transfer of radionuclides between matrix and fracture flow. Submit a supplemental response to the NRC.
Comment 110	Performance Assessment: Adequacy of dealing with human intrusion in the Complementary Cumulative Distribution Function.	Closed	NRC letter closing 7 Site Characterization Analysis comments.
Comment 111	Inconsistencies exist in the Site Characterization Plan on Total System Performance.	Closed	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 112	Adequate discussion of state variables as constants or as random variables.	Closed	NRC letter closing 7 Site Characterization Analysis comments.
Comment 113	Consistency of definition of Complementary Cumulative Distribution Function and the unit step function.	Closed	NRC letter closing 7 Site Characterization Analysis comments.
Comment 114	The term 'independent' is used instead of 'mutually exclusive.'	Closed	NRC evaluation of DOE responses. NRC considers this comment closed.

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<u>Item ID</u>	<u>Item Description</u>	<u>Status</u>	<u>Action Description</u>
Comment 115	Adequacy of expanding of Complementary Cumulative Distribution Function in terms of scenario classes.		Submitted a supplemental response to the NRC. Awaiting NRC concurrence.
Comment 116	Individual exposures via potable water may need to be expanded.		<p>Issuance by the Environmental Protection Agency of a new standard (40 CFR 191) for individual exposure standards per the Energy Policy Act of 1992.</p> <p>Revise issue resolution strategy for Site Characterization Plan Issue 1.2.</p> <p>Prepare additional response to NRC.</p> <p>Submit revised issue resolution strategy and response to NRC.</p>
Comment 117	Individual exposure rate of C-14 may need to consider advective and diffusive flow rates.		<p>Address the behavior of C-14 through the iterative Total System Performance Analysis and will continually update through the Total System Performance Analysis as more data become available.</p> <p>Submit a supplemental response to the NRC.</p>
Comment 118	The monitoring and testing activities should include long-term in situ and long-term waste package activities		<p>Determine testing requirements after site characteristics have advanced far enough to define the performance program.</p> <p>Submit a supplemental response to the NRC.</p>
Comment 119	Performance Confirmation: The information presented is insufficient to determine if the confirmation program meets the requirements of 10 CFR 60.		<p>Conduct NRC/DOE interaction on the performance confirmation program.</p> <p>Prepare Study Plan 8.3.3.2.2.3 "In Situ Testing of Seal Components" and then submit to the NRC for acceptance.</p> <p>Prepare Study Plan 8.3.1.15.1.6 "In Situ Thermo-mechanical Properties" and submit to the NRC.</p>

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<u>Item ID</u>	<u>Item Description</u>	<u>Status</u>	<u>Action Description</u>
			Prepare Study Plan 8.3.4.2.4.4 "Engineered Barrier Field Tests" and submit to the NRC.
			Submit a supplemental response to the NRC.
Comment 120	Model and computer code validation studies.		Prepare and provide to the NRC the model and computer code validation strategy.
			Submit a supplemental response to the NRC.
Comment 121	Exploratory Shaft Facility: Adequacy of seismic design of Exploratory Shaft Facility.		Submit a supplemental response to the NRC.
Comment 122	Demonstration and acceptability of the dry coring method.		Submit a supplemental response to NRC.
Comment 123	Assessment of effects of ventilation on the Exploratory Shaft Facility.	Closed	Submit a supplemental response to the NRC.
Comment 124	Potential causes for a reduction in the drainage capacity.	Closed	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 125	Existing data used in the licensing process needs to be qualified.	Closed	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 126	Items covered by 10 CFR Part 60 (G) are incomplete.	Closed	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 127	Design Acceptability Analysis.	Closed	NRC letter lifting Objection 1. NRC considers this comment closed.
Comment 128	Requirements applicable to the Exploratory Shaft Facility.	Closed	NRC letter lifting Objection 1. NRC considers this comment closed.
Comment 129	Design Acceptability Analysis and the Exploratory Studies Facility Design	Closed	NRC evaluation of DOE responses. NRC considers this comment closed.

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	Requirements do not consider 10 CFR 60 requirements		
Comment 130	Only 22 of fifty-two (52) requirements applicable to the Exploratory Shaft Facility were focused on in the Title I design. The rigor and completeness of the Design Acceptability Analysis are questioned.		Prepare a supplemental response after the ESFDR document is issued. The response will identify where in the ESFDR document the 29 requirements are addressed and discuss how the 30th requirement is addressed by the SCP.
Comment 131	Design Acceptability Analysis.	Closed	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 132	Design Acceptability Analysis.	Closed	NRC letter lifting Objection 1. NRC considers this comment closed.
Comment 133	Design Acceptability Analysis.	Closed	NRC evaluation of DOE responses. NRC considers this comment closed.
Objection 1	Adequacy of Title I design control process.	Closed	NRC letter lifting Objection 1. NRC considers this objection closed.
Objection 2	Acceptability of DOE Quality Assurance Program	Closed	NRC letter lifting Objection 2. NRC considers this objection closed.
Question 1	Integration of mapping efforts.	Closed	Submitted a supplemental response to NRC.
Question 2	Performance Assessment: Relation between mechanical and hydraulic apertures.	Closed	NRC evaluation of DOE responses. NRC considers this question closed.
Question 3	Repository Design: Rationale used for selecting the total repository area is not presented.		Submit a supplemental response to the NRC.
Question 4	Adequacy of temperature logging to evaluate anomalously low heat flow.	Closed	NRC evaluation of DOE responses. NRC considers this question closed.
Question 5	Adequacy of vertical boreholes for evaluation of faults and fractures.		Submitted a supplemental response which discusses the reconfiguration of the Exploratory Shaft Facility and its use for evaluating faults to the NRC. Awaiting NRC concurrence.

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Question 6	Meaning of statement in last paragraph page 8.3.1-75.	Closed	NRC evaluation of DOE responses. NRC considers this question closed.
Question 7	Face mapping of exploratory drifts restricted to areas of anomolous conditions.	Closed	NRC evaluation of DOE responses. NRC considers this question closed.
Question 8	Rock Properties: Level of detail and uncertainty in 3D model.		Complete DOE review of Study Plans 8.3.1.4.3.1 "Systematic Acquisition of Site-Specific Subsurface Information" and 8.3.1.4.3.2 "Three-Dimensional Rock Characteristics Models" and submit to the NRC for review. Submit a supplemental response to the NRC.
Question 9	Systematic Drilling Program: Adequacy of sampling same sequences for rock properties.		Complete review of Study Plan 8.3.1.4.3.1 "Systematic Acquisition of Site-Specific Subsurface Information" and submit to the NRC. Submit a supplemental response to the NRC.
Question 10	How will 3D block model account for variability in the block?	Closed	NRC evaluation of DOE responses. NRC considers this question closed.
Question 11	Rationale to start drilling prior to approval of study plans.	Closed	NRC evaluation of DOE responses. NRC considers this question closed.
Question 12	Rationale for exclusion of lunar crater basaltic field as natural analog.		NRC Phase II review of Study Plan 8.3.1.8.1.1 "Probability of a Volcanic Eruption Penetrating the Repository" completed.
Question 13	Basis for statements made about the migration, structural boundaries, and stage of volcanism.	Closed	NRC evaluation of DOE responses. NRC considers this question closed.
Question 14	Natural Resources: Adequacy of evaluation of previous mining and drilling leases.	Closed	NRC evaluation of DOE responses. NRC considers this question closed.
Question 15	Resource exploration and mineral resource potential.	Closed	NRC evaluation of DOE response. NRC considers this question closed.

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Question 16	Methods for determining the impact of ground motion from underground nuclear explosions.	Closed	NRC evaluation of DOE responses. NRC considers this question closed.
Question 17	Rock Properties: Activities to investigate effects on	Closed	NRC considers comment closed. (Letter- Shelor to Holonich)
Question 18	Allowable movements on joints related to rock mass strength.	Closed	NRC evaluation of DOE responses. NRC considers this question closed.
Question 19	Side Looking Airborne Radar (SLAR).	Closed	NRC evaluation of DOE responses. NRC considers this question closed.
Question 20	Repository Design: Discussion of vertical or horizontal emplacement.		Prepare a supplemental response describing how the Advanced Conceptual Design will address this issue.
Question 21	Process to assure the parameters for performance goal C2 (radiation shielding of rock) is comprehensive enough and expected values realistic.		Further develop the advanced conceptual design.
			Submit a supplemental response to the NRC.
Question 22	Parameters related to repository construction and operation.		Develop performance goals for the repository as part of the Advanced Conceptual Design..
Question 23	Computer code verification and validation.		MGDSRD approved.
			Submit a supplemental response to the NRC.
Question 24	Justification that the shaft liner does not provide structural support for the formation.	Closed	NRC evaluation of DOE responses. NRC considers this question closed.
Question 25	Heterogeneous air flow characteristics for seal program.		Supplemental response issued to NRC. (Letter- Shelor to Holonich) Awaiting NRC concurrence.
Question 26	Inconsistency between tentative Design Goals	Closed	NRC evaluation of DOE responses. NRC considers this question closed.

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	and Design Performance Goals.		
Question 27	Storage capacity at base of shaft for attaining the tentative design goals.	Closed	NRC evaluation of DOE responses. NRC considers this question closed.
Question 28	ES-1 penetration of the Calico Hills Unit: Impacts of the current sealing program and issue resolution strategy 4.4.		<p>Prepare seal design concepts (Sandia National Laboratories).</p> <p>Conduct performance assessment of seal program.</p> <p>Submit a supplemental response to the NRC.</p>
Question 29	Justification that references cited present results representative of conditions at Yucca Mountain.	Closed	NRC evaluation of DOE responses. NRC considers this question closed.
Question 30	Waste Package: Water quality as related to waste package design.		<p>Complete the activities in the metal barriers scientific investigation plan and waste form scientific investigation plan.</p> <p>Complete evaluation of the drift emplacement alternative needs. This alternative would make this concern moot.</p> <p>Submit a supplemental response to the NRC.</p>
Question 31	Waste Package: Integrity of spent fuel cladding.		DOE letter on question 31. Awaiting NRC concurrence.
Question 32	Waste package: Container 'similarity' for borosilicate glass waste vs. spent fuel.		<p>Advance the waste package design and narrow the waste package options down to three designs.</p> <p>Submit a supplemental response to the NRC.</p>
Question 33	Waste Package: Emplacement hole drainage concerns.		Evaluate water-vapor interface, crevice corrosion, and galvanic corrosion testing in the metal barriers scientific investigation plan during Advanced Conceptual Design.

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			Complete evaluation of the drift emplacement alternative. This alternative would make this concern moot.
			Submit a supplemental response to the NRC.
Question 34	Waste Package/ Performance Assessment: Meaning of undetected defective closures.		Submit a supplemental response to the NRC.
Question 35	Waste Package: Acceptance criteria for helium leak results.		Submit a supplemental response which will present the leak rate calculations and results to the NRC.
Question 36	Waste Package: Contact of canisters with corrosive elements during shipping and handling.		Advance the waste package design and narrow options down to three designs.
			Submit a supplemental response which will further address the issue of eliminating corrosion elements during manufacture of the container to the NRC.
Question 37	Waste package: Basis for 10-cm of free fall for canister and contents.		Submit a supplemental response to the NRC which will show when and how during the waste package container design and testing, the drop height of the container will be addressed.
Question 39	Waste Package: Defining 'unusual process history' of canister.		Advance the design of the waste package.
			Submit a supplemental response to the NRC.
Question 40	Waste Package: Basis for factor of 2 on borehole liner in comparison to container material.		Study effects of water containing liner corrosion products on degradation of the container in accordance with the metal barriers scientific investigation plan.
			Submit a supplemental response to the NRC.
Question 41	Repository: Consideration of 10 CFR 60.132		Conduct engineering studies to evaluate the waste throughput requirements.

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	(a) in resolution of Issue 2.4.		Submit a supplemental response to the NRC.
Question 42	Repository: Assumption of stability of vertical emplacement hole.		Advance the Advanced Conceptual Design. Drift emplacement may make this comment moot. Submit a supplemental response to the NRC.
Question 43	Waste Package: Anticipated operational occurrences considered part of normal conditions on the preclosure design and analysis.	Closed	NRC evaluation of DOE responses. NRC considers this question closed.
Question 44	Waste Package/Performance Assessment: Basis for assumed numbers of breached assemblies or canisters.		Provide information on failures of waste forms in multiple locations. Prepare and provide the NRC with documentation on the Total System Performance Assessment. Advance the Advanced Conceptual Design and narrow options to two candidate designs. Submit a supplemental response to the NRC.
Question 45	Waste Package: Investigation of particulate source terms, retention factors, and plate-out of waste package during accident conditions.		The development of source terms from rationalized release from breached waste package is being accomplished as part of iterative PA. The sophistication of the source term model will increase with each successive iteration as more data becomes available. Submit a supplemental response to the NRC.
Question 46	Waste Package: Basis for stricter containment of long half-life isotopes.		Submit a supplemental response to the NRC.

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Question 47	Waste Package: Assumption on breached waste containers.		Submit a supplemental response to the NRC.
Question 48	Waste Package: Selection of peer review panel on waste package.	Closed	NRC evaluation of DOE responses. NRC considers this question closed.
Question 49	Waste Package: Effects of low temperature oxidation on containers.		Complete the metal barriers scientific investigation plan. Advance the design of the waste package to three options. Submit a supplemental response to the NRC.
Question 50	Waste Package: Assumption that stress propagation results in corrosion.	Closed	NRC evaluation of DOE responses. NRC considers this question closed.
Question 51	Design second research criteria for accepting waste from Idaho National Engineering Laboratory and Hanford.		Submit a supplemental response to the NRC.
Question 52	Waste Package: Leaching properties specification will require the producer to control leaching characteristics of the glass waste.	Closed	NRC evaluation of DOE responses. NRC considers this question closed.
Question 53	Waste Package: Specification of cooling rate of the glass waste.		Submit a supplemental response to the NRC.
Question 54	Waste Package: Release rates of radionuclides from spent fuels.	Closed	NRC evaluation of DOE responses. NRC considers this question closed.
Question 55	Exploratory Shaft Facility: Interference at the Exploratory Shaft Facility by waste storage tanks, septic field, and waste water lagoon.		Submit a supplemental response to the NRC.

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<u>Item ID</u>	<u>Item Description</u>	<u>Status</u>	<u>Action Description</u>
Question 56	Basis for 5 cm of fault displacement in waste package environment.		Submit a supplemental response to the NRC.
Question 57	Effects of drilling multipurpose boreholes.		Supplemental response submitted to the NRC. Awaiting NRC concurrence.
Question 58	Flexibility of the Exploratory Shaft Facility design to accommodate in situ testing of the waste package, if required.		Submitted a supplemental response to the NRC. Awaiting NRC concurrence.
Question 59	Basis for length of in situ thermal tests.		Prepare Study Plan 8.3.1.15.1.6 "In Situ Thermomechanical Properties" and submit to NRC. Submit a supplemental response to the NRC.
Question 60	Exploratory Shaft Facility: Timing of Exploratory Shaft Facility radial borehole test.	Closed	NRC evaluation of DOE responses. NRC considers this question closed.
Question 61	Exploratory Shaft Facility: Accommodation of design changes during Exploratory Shaft Facility construction.	Closed	NRC letter lifting Objection 1. NRC considers this question closed.
Question 62	Repository: Basis for 500 feet of separation from Exploratory Shaft Facility and waste emplacement panel.		Mined Geologic Disposal Systems Requirements Document approved. Complete Mined Geologic Disposal System Requirements Document and submit to NRC. Submit a supplemental response to the NRC.
Question 63	Certifying Training Attendance Record reviewers were not principal investigators.	Closed	NRC evaluation of DOE responses. NRC considers this question closed.

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APPENDIX B

Change Control Board Actions from October 1, 1993 - March 31, 1994

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Change Control Board Actions from October 1, 1993 - March 31, 1994

Title	Change Description	Status
Revise Specification Package SP01	Incorporate 5 FCRs and other spec changes to North Portal utilities and access road.	Closed
Removal of TBV5 from Drawings and Specifications	Based on DIE results, remove TBV5 call outs and required controls on water, such as water meters.	Closed
Additional Activities at Boreholes UE-25 NRG-2a and 2b; Change to Job Packages 93-05 and 93-09	Pull casing to allow geophysical logging activities at 3 boreholes.	Closed
Issue Drawings for Construction Trenching at Duct Banks (initial issue) and Delete Five Drawings	Allow trenching for duct banks regarding electrical power distribution at North Portal Pad.	Closed
Additional Activities at Borehole UE-25-NRG-4	Pull casing to allow geophysical logging activities at borehole.	Closed
Revision to Switchgear Building 5010	Provide new utility exit, change duct work arrangement and change grading around building.	Open
Baseline ESF Design Package 1B	Baseline Title II drawings and specs H-road, shop building, sub-surface waste water system, explosive storage area at North Portal utility.	Open
Revise Specification Package SP07	Incorporate 6 FCRs into specification	Closed
Submit ESF Design Drawings and Specifications for Technical Baseline Approval, Package 2A	Baseline design of mechanical and electrical systems to support TBM operations. Includes muck handling conveyor, chemical tracer inspection system, sub-surface medium voltage power center and switchgear.	Open
Revision to JP 92-20	Incorporates FCRs; add TFM reporting requirements.	Closed
Incorporated Enhanced ESF Configuration into the Project Baseline	Provide flatter gradients in North Ramp and TSL drift.	Open
Issue Specification Section 01500 for Construction	Adding requirements for temporary construction facilities and controls to avoid interference with waste isolation.	Open

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APPENDIX C

Study Plan Status as of March 31, 1994

Study Plan Status as of March 31, 1994

Study Plan Number	Study Plan Title	Submitted to YMSCO	Approved by YMSCO	Reviewed by NRC	Reviewed by NV
8.3.1.2.1.1	Characterization of the Meteorology for Regional Hydrology	6/26/90	3/13/91	10/21/91	12/10/91
8.3.1.2.1.2	Characterization of Runoff and Streamflow	3/27/89	8/21/90	5/14/91	4/12/91
8.3.1.2.1.3	Characterization of the Regional Ground-Water Flow System	3/1/90	1/18/91	10/4/91	3/19/93
8.3.1.2.1.4	Regional Hydrologic System Synthesis and Modeling	6/6/90	12/18/91	5/6/92	1/29/93
8.3.1.2.2.1	Characterization of Unsaturated-Zone Infiltration	3/9/90	1/18/91	5/31/91	
8.3.1.2.2.2	Water Movement Test	9/23/87	11/9/89	4/8/93	
8.3.1.2.2.3	Characterization of Percolation in the Unsaturated Zone--Surface-Based Study	8/12/88	4/08/91	3/26/92	
8.3.1.2.2.4	Characterization of the Yucca Mountain Unsaturated Zone in the Exploratory Studies Facility	9/8/87	1/09/89	3/5/93	
8.3.1.2.2.5	Diffusion Tests in the Exploratory Studies Facility	11/1/88	4/22/92	1/19/93	11/1/93
8.3.1.2.2.6	Characterization of Gaseous-Phase Movement in the Unsaturated Zone	6/12/89	6/11/91	10/07/91	5/1/92
8.3.1.2.2.7	Hydrochemical Characterization of the Unsaturated Zone	10/24/88	9/18/90	5/1/92	12/28/92
8.3.1.2.2.8	Fluid Flow in Unsaturated, Fractured Rock	9/7/90	8/12/92	1/28/93	
8.3.1.2.2.9	Site Unsaturated-Zone Modeling and Synthesis	1/25/91	7/1/93	11/8/93	

Study Plan Number	Study Plan Title	Submitted to YMSCO	Approved by YMSCO	Reviewed by NRC	Reviewed by NV
8.3.1.2.3.1	Characterization of the Site Saturated-Zone Ground-Water Flow System	2/8/88	2/22/90	12/6/91	
8.3.1.2.3.2	Characterization of the Saturated-Zone Hydrochemistry	3/28/90	4/22/92	1/4/93	
8.3.1.2.3.3	Saturated-Zone Hydrologic System Synthesis and Modeling	9/4/90	1/14/93	6/16/93	
8.3.1.3.1.1	Ground-Water Chemistry Model	3/15/91			
8.3.1.3.2.1	Mineralogy, Petrology, and Chemistry of Transport Pathway	1/22/88	6/13/89	8/20/90	12/28/92
8.3.1.3.2.2	History of Mineralogical and Geochemical Alteration of Yucca Mountain	3/28/88	12/18/91	4/27/92	1/24/94
8.3.1.3.3.1	Natural Analog of Hydrothermal Systems in Tuff				
8.3.1.3.3.2	Kinetics and Thermodynamics of Mineral Evolution	3/25/94			
8.3.1.3.3.3	Conceptual Model of Mineral Evolution				
8.3.1.3.4.1	Batch Sorption Studies	10/28/92			
8.3.1.3.4.2	Biological Sorption and Transport	12/12/88	11/25/92	3/25/93	
8.3.1.3.4.3	Development of Sorption Models	10/28/92			
8.3.1.3.5.1	Dissolved Species Concentration Limits	9/7/90	9/9/93		
8.3.1.3.5.2	Colloid Behavior	9/7/90	9/9/93		
8.3.1.3.6.1	Dynamic Transport Column Experiments	3/10/93			
8.3.1.3.6.2	Diffusion	7/24/89	8/6/93	1/19/94	

Study Plan Number	Study Plan Title	Submitted to YMSCO	Approved by YMSCO	Reviewed by NRC	Reviewed by NV
8.3.1.3.7.1	Retardation Sensitivity Analysis	12/14/88	8/11/92	1/19/93	
8.3.1.3.7.2	Demonstration of Applicability of Laboratory Data to Repository Transport Calculations				
8.3.1.3.8.1	Gaseous Radionuclide Transport Calculations and Measurements				
8.3.1.4.2.1	Characterization of the Vertical and Lateral Distribution of Stratigraphic Units Within the Site Area	4/12/90	6/9/92	12/14/92	
8.3.1.4.2.2	Characterization of the Structural Features Within the Site Area	9/4/87	2/3/89	2/8/93	
8.3.1.4.2.3	Three-Dimensional Geologic Model				
8.3.1.4.3.1	Systematic Acquisition of Site-Specific Subsurface Information	3/27/90	12/8/92	7/19/93	
8.3.1.4.3.2	Three-Dimensional Rock Characteristics Models				
8.3.1.5.1.1	Characterization of Modern Regional Climate	6/24/93			
8.3.1.5.1.2	Paleoclimate Study: Lake, Playa, and Marsh Deposits	10/25/90	10/31/91	4/27/92	1/24/94
8.3.1.5.1.3	Climatic Implications of Terrestrial Paleoecology	2/11/91	1/17/92	8/27/92	1/24/94
8.3.1.5.1.4	Analysis of the Paleoenvironmental History of the Yucca Mountain Region	3/30/90	5/29/91	12/06/91	1/11/93
8.3.1.5.1.5	Paleoclimate-Paleoenvironmental Synthesis				

Study Plan Number	Study Plan Title	Submitted to YMSCO	Approved by YMSCO	Reviewed by NRC	Reviewed by NV
8.3.1.5.1.6	Characterization of the Future Regional Climate and Environments	12/29/93			
8.3.1.5.2.1	Characterization of the Quaternary Regional Hydrology	1/26/88	6/8/89	11/24/89	4/9/91
8.3.1.5.2.2	Characterization of Future Regional Hydrology Due to Climate Changes	1/16/91	11/10/92	4/5/93	11/1/93
8.3.1.6.1.1	Distribution and Characteristics of Present and Past Erosion				
8.3.1.6.2.1	Influence of Future Climatic Conditions on Locations and Rates of Erosion				
8.3.1.6.3.1	Evaluation of the Effects of Future Tectonic Activity on Erosion at Yucca Mountain				
8.3.1.6.4.1	Development of a Topical Report on the Effects of Erosion				
8.3.1.8.1.1	Probability of Magmatic Disruption of the Repository	3/29/89	9/19/90	10/5/91	8/8/91
8.3.1.8.1.2	Physical Processes of Magmatism and Effects on the Repository	10/21/92	9/21/93		
8.3.1.8.2.1	Analysis of Waste Package Rupture Due to Tectonic Processes and Events	12/15/89	11/16/92	11/19/93	

Study Plan Number	Study Plan Title	Submitted to YMSCO	Approved by YMSCO	Reviewed by NRC	Reviewed by NV
8.3.1.8.3.1	Analysis of the Effects of Tectonic Processes and Events on Average Percolation Flux Rates Over the Repository				
8.3.1.8.3.2	Analysis of the Effects of Tectonic Processes and Events on Changes in Water-Table Elevation				
8.3.1.8.3.3	Analysis of the Effects of Tectonic Processes and Events on Local Fracture Permeability and Effective Porosity				
8.3.1.8.4.1	Analysis of the Effects of Tectonic Processes and Events on Rock Geochemical Properties				
8.3.1.8.5.1	Characterization of Volcanic Features	12/14/88	4/18/90	8/20/90	2/21/91
8.3.1.8.5.2	Characterization of Igneous Intrusive Features	10/13/92	3/7/94		
8.3.1.8.5.3	Investigation of Folds in Miocene and Younger Rocks of the Region				
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				
8.3.1.9.2.1	Natural Resource Assessment of Yucca Mountain, Nye County, Nevada	7/13/90	11/6/92	3/16/93	2/11/94

Study Plan Number	Study Plan Title	Submitted to YMSCO	Approved by YMSCO	Reviewed by NRC	Reviewed by NV
8.3.1.9.2.2	Water Resource Assessment of Yucca Mountain, Nevada	10/6/89	8/26/91	5/4/92	12/28/92
8.3.1.9.3.1	Evaluation of Data Needed to Support an Assessment of the Likelihood of Future Inadvertent Human Intrusion at Yucca Mountain as a Result of Exploration and/or Extraction of Natural Resources				
8.3.1.9.3.2	An Evaluation of the Potential Effects of Exploration for, or Extraction of, Natural Resources on the Hydrologic Characteristics at Yucca Mountain				
8.3.1.12.2.1	Meteorological Data Collection at the Yucca Mountain Site	9/28/90	3/20/91	11/12/91	12/2/91
8.3.1.14.2	Studies to Provide Soil/Rock Properties of Potential Locations of Surface/Subsurface Facilities	7/15/91	10/01/91	1/24/92	4/6/92
8.3.1.15.1.1	Laboratory Thermal Properties	3/17/88	10/21/90	Deferred	
8.3.1.15.1.2	Laboratory Thermal Expansion Testing	12/1/88	8/21/90	Deferred	
8.3.1.15.1.3	Laboratory Determination of Mechanical Properties of Intact Rock	2/8/88	5/21/91	Deferred	
8.3.1.15.1.4	Laboratory Determination of the Mechanical Properties of Fractures	10/23/91			

Study Plan Number	Study Plan Title	Submitted to YMSCO	Approved by YMSCO	Reviewed by NRC	Reviewed by NV
8.3.1.15.1.5	Excavation Investigations	3/26/87	1/09/89	Deferred	
8.3.1.15.1.6	In Situ Thermomechanical Properties				
8.3.1.15.1.7	In Situ Mechanical Properties				
8.3.1.15.1.8	In Situ Design Verification	3/20/90	2/3/93	4/15/93	11/1/93
8.3.1.15.2.1	Characterization of the Site Ambient Stress Conditions	9/22/87	1/11/89	Deferred	
8.3.1.15.2.2	Characterization of the Site Ambient Thermal Conditions	10/13/92			
8.3.1.16.1.1	Characterization of Flood Potential of the Yucca Mountain Site	3/30/89	9/17/90	5/8/91	1/22/91
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				
8.3.1.16.3.1	Determination of the Preclosure Hydrologic Conditions of the Unsaturated Zone at Yucca Mountain, Nevada				
8.3.1.17.1.1	Potential for Ash Fall at the Site				
8.3.1.17.2.1	Faulting Potential at the Repository				
8.3.1.17.3.1	Relevant Earthquake Sources	8/1/90	12/18/91	5/18/92	1/13/93
8.3.1.17.3.2	Underground Nuclear Explosion Sources				
8.3.1.17.3.3	Ground Motion from Regional Earthquakes and Underground Nuclear Explosions	2/2/94			

Study Plan Number	Study Plan Title	Submitted to YMSCO	Approved by YMSCO	Reviewed by NRC	Reviewed by NV
8.3.1.17.3.4	Effects of Local Site Geology on Surface and Subsurface Motions	7/6/90	11/14/91	6/8/92	1/11/93
8.3.1.17.3.5	Ground Motion at the Site from Controlling Seismic Events	10/4/90	7/9/93	11/2/93	
8.3.1.17.3.6	Probabilistic Seismic Hazards Analyses				
8.3.1.17.4.1	Historical and Current Seismicity	10/17/89	9/17/90	5/14/91	11/1/93
8.3.1.17.4.2	Location and Recency of Faulting Near the Prospective Surface Facilities	12/6/88	5/22/89	11/24/89	
8.3.1.17.4.3	Quaternary Faulting Within 100 km of Yucca Mountain, Including the Walker Lane	3/25/92	1/21/93	9/2/93	3/3/94
8.3.1.17.4.4	Quaternary Faulting Proximal to the Site Within Northeast-Trending Fault Zones	8/3/92	3/18/93	9/2/93	
8.3.1.17.4.5	Detachment Faults at or Proximal to Yucca Mountain	5/1/90	7/20/92	2/1/93	1/24/94
8.3.1.17.4.6	Quaternary Faulting Within the Site Area	10/14/88	1/23/91	10/3/91	1/13/93
8.3.1.17.4.7	Subsurface Geometry and Concealed Extensions of Quaternary Faults at Yucca Mountain				
8.3.1.17.4.8	Stress Field Within and Proximal to the Site Area				
8.3.1.17.4.9	Tectonic Geomorphology of the Yucca Mountain Region				
8.3.1.17.4.10	Geodetic Leveling	3/30/90	1/18/91	10/4/91	2/1/93
8.3.1.17.4.11	Characterization of Regional Lateral Crustal Movement				
8.3.1.17.4.12	Tectonic Models and Synthesis	4/30/93			

Study Plan Number	Study Plan Title	Submitted to YMSCO	Approved by YMSCO	Reviewed by NRC	Reviewed by NV
8.3.3.2.2.1	Seal Material Properties Development				
8.3.4.2.4.1	Characterization of the Chemical and Mineral Changes in the Postemplacement Environment				
8.3.4.2.4.2	Hydrological Properties of Waste Package Environment	12/20/93			
8.3.4.2.4.3	Characterization of the Geomechanical Attributes for the Waste Package Environment	6/28/89	12/11/92	4/21/93	
8.3.4.2.4.4	Engineered Barrier System Field Tests	7/9/93			
8.3.4.2.4.5	Effects of Man-Made Materials on Water Chemistry				

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APPENDIX D

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All technical reports and research products published by participating organizations on the Project are generally available through the Office of Scientific and Technical Information (OSTI) at Oak Ridge, Tennessee. OSTI is the national center for dissemination of non-classified scientific and technical information prepared from research sponsored by DOE. The references cited in this section are available through OSTI, the open literature, or through proceedings volumes for symposia and technical conferences.

Copies of Project reports and other documents published by DOE and the participating organizations, which are available through OSTI, can be ordered from:

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

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APPENDIX E

Acronyms, Abbreviations, and Symbols

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ACRONYMS, ABBREVIATIONS, AND SYMBOLS

ACNW	Advisory Committee on Nuclear Waste
BLM	Bureau of Land Management
CRWMS M&O	Civilian Radioactive Waste Management System Management and Operating Contractor
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
FY	fiscal year
M&O	Civilian Radioactive Waste Management System Management and Operating Contractor
NAS	National Academy of Sciences
NRC	U.S. Nuclear Regulatory Commission
NWTRB	Nuclear Waste Technical Review Board
OCRWM	Office of Civilian Radioactive Waste Management
Project	Yucca Mountain Site Characterization Project
QA	quality assurance
SCP	Site Characterization Plan
USGS	U.S. Geological Survey
YMSCO	Yucca Mountain Site Characterization Office

Designations

Tuff

CHn	Calico Hills nonwelded
PTn	Paintbrush nonwelded
TCw	Tiva Canyon welded
TSw1	Topopah Spring densely welded devitrified lithophysal-rich tuff
TSw2	Topopah Spring densely welded devitrified lithophysal-poor tuff
TSw3	Topopah Spring basal vitrophyre

Boreholes

NRG	North Ramp Geologic
SD	Systematic Drilling
SRG	South Ramp Geologic
UE	Underground Exploratory
USW	Underground Southern Nevada Waste
UZ	Unsaturated Zone

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ACRONYMS, ABBREVIATIONS, AND SYMBOLS (Continued)

Trenches

BMT	Bare Mountain Trench
CF	Crater Flat
MWV	Midway Valley
NRT	North Ramp Trench
SCR	Stagecoach Road
SCF	Solitario Canyon fault

Metric Units

°C	degree Celsius
cc	cubic centimeters (cm ³)
cm	centimeter (= 10 ⁻² m or 2.54 inches)
d	day
g	gram (= 0.3527 ounce)
h	hour
ha	hectare (= 2.48 acres)
Hz	hertz (cycles per second)
J	joule (kilogram-meter)
°K	degree kelvin
kg	kilogram (= 10 ³ grams or 2.2046 pounds)
km	kilometer (= 10 ³ m or 0.6213 mile)
L	liter (= 0.2641 gallon)
MTU	metric tons of uranium
MTIHM	metric tons of initial heavy metal
m	meter (= 3.2808 feet)
mg	milligram (= 10 ⁻³ g)
mL	milliliter (= 10 ⁻³ L)
mm	millimeter (= 10 ⁻³ m)
µm	micrometer (= 10 ⁻⁶ m)
nm	nanometer (= 10 ⁻⁹ m)
Pa	pascal (also, MPa = megapascal, kPa = kilopascal)
S	siemens
s	second
V	volt
W	watt
kWh	kilowatt-hour
MWh	megawatt-hour
MWd	megawatt-day
GWd	gigawatt-day

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ACRONYMS, ABBREVIATIONS, AND SYMBOLS (Continued)

Scientific/Engineering Terms and Units

darcy	$= 10^{-12} \text{m}^2$ (permeability)
ka	kiloannum (thousand years ago)
Ma	megannum (million years ago)
pH	negative log of hydrogen ion concentration (acidity/alkalinity)
ppb	parts per billion
ppm	parts per million