1 of 4

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April 1, 1993 - September 30, 1993

Number 9

February 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

February 10, 1994

NOTE TO READERS:

In accordance with section 113(b)(3) of the Nuclear Waste Policy Act of 1982, as amended, the Department has prepared the ninth 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 April 1, 1993 through September 30, 1993.

The Civilian Radioactive Waste Management Program made significant progress at the Yucca Mountain Site Characterization Project during this reporting period. Construction of the Exploratory Studies Facility North Ramp Starter Tunnel began on April 2, 1993, and was completed on September 9, 1993, to a distance of about 200 feet. In addition, a contract was awarded for purchase of the Tunnel Boring Machine that will be used to excavate the remainder of the main ramps and tunnels. Deep borehole drilling and testing continued, with the second deep borehole reaching a depth of 1300 feet. All boreholes, 99 in total, were completed for the Neutron Access Program. Surface trenching and excavation continued to determine geologic faulting and volcanism history as well as to define seismic hazard basis.

Advanced conceptual design of the waste package continued, and feasibility and implementation studies were conducted for the use of a Multipurpose Canister system. Field testing progressed on the large block heater test and engineered barrier system tests.

Review and revision of the entire set of System Requirements Documents were completed during this period and implemented.

Formal interactions continued between the Project Office and the Nuclear Waste Technical Review Board in April, July, and September. In April, the Yucca Mountain Site Characterization Project hosted a tour of Yucca Mountain and presented its process for resolving difficult issues. In July, the Department presented its approach for Electing and Validating a thermal loading strategy to the Review Board. On September 21-23, the Project Office held a workshop to discuss alternative concepts for the repository waste package in response to recommendations by the Review Board.

In interactions with the Nuclear Regulatory Commission, the Department forwarded Revision 2 of the "Mined Geologic Disposal System Annotated Outline Skeleton Text for the Preparation of a License Application." In addition, the Department and the Commission participated in a technical exchange on "Substantially Complete Containment and the Waste Package/Engineered Barrier System Design Concepts" in August.

The Department continues to interact with the National Academy of Sciences as the Academy develops recommendations on health-based standards for protection of the public from releases from a repository at the Yucca Mountain site, as described in Section 801 of the Energy Policy Act of 1992.

To comply with requirements of Section 803 of the Energy Policy Act of 1992, the Department prepared and issued for public review and comment a draft report entitled "Adequacy of Management Plans for Future Generations of Spent Nuclear Fuel and High-Level Radioactive Waste."

Public outreach activities were continued with 68 tours of Yucca Mountain conducted for about 2600 members of the public and other interested parties. In addition, various programmatic and technical workshops and presentations were conducted by Yucca Mountain Site Characterization Project staff.

The Department will continue to issue progress reports on a semi-annual basis, as specified in the Nuclear Waste Policy Act.

Sincerely,

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

Please Add ☐

Please Delete ☐

**my name for receiving the Site Characterization Progress Report
on Yucca Mountain, Nevada from the 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 2.7 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 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 2.7.

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 the Appendix. Also, while serious effort has been made to minimize the use of acronyms throughout the document, a list of acronyms, abbreviations, and symbols used throughout this document is included to further assist the reader.

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EXECUTIVE SUMMARY

In accordance with 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 April 1, 1993, through September 30, 1993. This report is the ninth 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 high-level radioactive waste. Also included in this report are 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.

On April 2, 1993, a major Program milestone was reached as excavation of the Exploratory Studies Facility North Ramp Starter Tunnel began. The Exploratory Studies Facility is designed to be an underground laboratory to enable scientists and engineers to examine, at depth, the geologic, hydrologic, geoengineering, and geochemical characteristics of the potential repository host rock. The facility will consist of two main access ramps from the surface ("North Ramp" and "South Ramp") to either end of a 3.2-kilometer long main tunnel oriented at N 34° E at the potential repository level in the Topopah Spring geologic unit. Two additional smaller-diameter ramps will extend from the main ramps to either end of a second main drift lying directly below the Topopah Spring level main drift at a lower level in the Calico Hills geologic unit. Various side tunnels will be driven to provide access to fault zones and other areas of potential interest. In total, 23,400 meters of tunnel will be excavated, resulting in approximately 1,550,000 metric tons of excavated rock.

The Starter Tunnel was completed on September 9, 1993, using conventional drill and blast techniques. In future construction of the Exploratory Studies Facility, mechanical excavation methods will be used when possible with conventional excavation only in situations where mechanical methods will not work. A modified version of the New Austrian Tunnelling Method was used to excavate this portion of the North Ramp. This method sequentially removes material, and the entry is supported to ensure maximum possible safety to the workers. The resultant tunnel measured approximately 9.8 meters by 9.8 meters and is 61 meters long. A large-diameter Tunnel Boring Machine will be employed to excavate the remainder of the main ramps and tunnels. The contract to fabricate the 7.6-meter-diameter Tunnel Boring Machine was awarded on May 27, 1993, to Construction Tunnel Services, and the machine is due to arrive in early April 1994.

An enhanced Exploratory Studies Facility layout is being considered, which would change the orientation of the main tunnel to almost north-south, and would substantially reduce the inclination of the North Ramp. The enhanced configuration also could have advantages for future repository designs, should a repository be developed at Yucca Mountain. If formally approved, the new configuration will become part of the technical baseline and serve as the basis for future design work.

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In other activities associated with the excavation of the Exploratory Studies Facility Starter Tunnel, geologic mapping was completed to the end of the Starter Tunnel and a Consolidated Sampling Program was conducted to obtain samples for geomechanical and mineralogical analyses.

Boreholes, drilled into Yucca Mountain to obtain information on geological structure, faults, rock characteristics, depth to water table, water quality, infiltration, and water movement in soil and rock, continue to be a very important part of the site characterization program. During this reporting period, all boreholes, 99 in total, for the Neutron Access Program were completed. Early results from this program suggest that infiltration models will need to distinguish among ridge tops, sideslopes, alluvial terraces and active channels. In addition, five boreholes along the North Portal Ramp alignment were completed.

Also as part of site characterization, trenches and test pits are excavated to expose subsurface layers of soil and rock in order to allow evaluation of possible geologic faults and to interpret volcanic history. Such trenching and evaluation proceeded during this reporting period, with particular interest focused on trenches across the Stagecoach Road, Solitario Canyon, and Bare Mountain faults. In addition, a surface excavation across an exposure of the Ghost Dance fault, which transects the repository block, was constructed for mapping. Information of recency of movement and slip rates will be used to define the seismic hazard design basis for potential repository facilities.

In the area of repository and waste package design, advanced conceptual design of the waste package, which commenced in October 1992, has proceeded with detailed thermal, criticality, and shielding evaluations on the seven concepts previously selected for advanced conceptual design. Advances have been made in the hydrologic modeling of Yucca Mountain, and planning and testing moved forward on the large block test and the engineered barrier system field tests. These tests will provide essential information for near-field and container performance models.

Also with regard to the waste package system, the Director of the Office of Civilian Radioactive Waste Management instructed that a study be conducted to evaluate the feasibility of using a multipurpose canister in the Civilian Radioactive Waste Management System. The feasibility study was completed in March 1993. Based on the results of this study, the Department directed the Civilian Radioactive Waste Management System Management and Operating Contractor to complete the Multipurpose Canister Implementation Program Conceptual Design Phase Report. This report was completed in September 1993, and will assist the U.S. Department of Energy in making a final decision on whether to proceed with further development of the multipurpose canister for the Civilian Radioactive Waste Management System.

Repository design activities have included evaluations of alternative emplacement modes. Consideration of a multipurpose canister leads to the need to evaluate the concept of in-drift emplacement to accommodate larger canisters. Thermal loading alternatives are being evaluated as part of advanced conceptual repository design, as well as alternative types of

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equipment and shielding that could be used for transporting waste packages to underground emplacement areas.

The second Total System Performance Assessment was conducted during this period. Improvements over previous assessments include a more realistic source term, enhanced site stratigraphy, and a more realistic representation of hydrologic flow processes. In addition, a broader suite of sensitivity calculations were completed. A summary of this work will be presented to the Nuclear Waste Technical Review Board in January 1994, and a Department of Energy document describing the effort is scheduled to be completed in Spring 1994.

Before the Yucca Mountain Site Characterization Project Office can conduct some of its site characterization activities, it must obtain permits and approvals from other Federal and State of Nevada regulatory agencies. Within this reporting period, the State of Nevada issued several new permits to the Yucca Mountain Site Characterization Project Office. These included water appropriation permits and a permit for a potable water supply system for the Exploratory Studies Facility.

To ensure compliance with the large number of requirements imposed upon it by many laws, regulations, orders, and standards, the Office of Civilian Radioactive Waste Management has systematically reviewed and revised the System Requirements Documents. These System Requirements Documents were developed based on a systematic review of regulatory documentation and the functions the system must perform. The set of documents includes an overall Civilian Radioactive Waste Management System Requirements Document and subordinate documents addressing the Mined Geologic Disposal System, the Monitored Retrievable Storage System, the Transportation System and the Waste Acceptance System. Five subordinate Project-level documents were also approved addressing the Repository, Engineered Barrier, Site Design and Test Requirements, Exploratory Studies Facility, and Surface-Based Test Facilities. The entire set of requirements documents was completed during this period and implemented, replacing the previously existing documents.

In the conduct of its site characterization activities, the Department continues to interact with the State of Nevada, affected counties, and a number of external agencies and groups, including the Nuclear Waste Technical Review Board, the Nuclear Regulatory Commission, the National Academy of Sciences, and others, including the international community. Continuing its interactions with the Nuclear Waste Technical Review Board, in May 1993, the Department formally responded to the recommendations made by the Review Board in its Sixth and Special Reports.

The Department conducted formal interactions with the Review Board in April and July 1993. In April, the Yucca Mountain Site Characterization Project hosted a tour of the environmental activities at the candidate Yucca Mountain site prior to the Board's spring meeting. During the spring Full Board meeting, the Project presented its process for resolving difficult scientific issues using infiltration as an example. In July 1993, the Department presented its approach for selecting and validating a thermal loading strategy to the Board. These discussions focused on integration of engineering and science to carefully evaluate a range of thermal loading options prior to the selection of a preferred strategy.

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On September 21-23, 1993, the Yucca Mountain Site Characterization Project Office held a three-day workshop in Las Vegas, Nevada, to discuss alternative concepts for the repository waste package as recommended by the Nuclear Waste Technical Review Board in its Fourth Report. The workshop was open to the public and was attended by over 100 interested people. Participants included members of the Review Board and its staff, representatives from the State of Nevada and the regulatory agencies, international experts in the fields of engineering materials and corrosion, Project personnel, and members of the public.

In interactions with the Nuclear Regulatory Commission, the Program sent Revision 2 of the "Mined Geologic Disposal System Annotated Outline Skeleton Text for the Preparation of a License Application" to the Nuclear Regulatory Commission, the Advisory Committee on Nuclear Waste, the State of Nevada, and to Affected Counties in May 1993. The focus of this revision was the framework and layout for the Performance Assessment and Performance Confirmation programs.

On August 24, 1993, the Department of Energy and the Nuclear Regulatory Commission conducted a Technical Exchange on Substantially Complete Containment and the Waste Package/Engineered Barrier System design concepts. The purpose of the Technical Exchange was to discuss the Department's interpretation of Substantially Complete Containment and its use in design, the status and progress of the Department's waste package design effort, and the Department's plans for resolving related open Site Characterization Analysis comments and questions.

A topical report entitled "Topical Report: Methodology To Assess Seismic Hazards At Yucca Mountain" is in preparation. The topical report presents the Department's methodology to assess seismic hazards for a potential geologic repository at Yucca Mountain. A Technical Exchange with the Nuclear Regulatory Commission on this subject is planned for November 1993.

The Project continues to work toward resolving the Nuclear Regulatory Commission's Site Characterization Analysis open items. During this reporting period, the Nuclear Regulatory Commission agreed, by letter dated April 21, 1993, that the Office of Civilian Radioactive Waste Management had provided the technical basis to resolve Question 17. Therefore, as of the end of this reporting period, 78 items have been closed (including the two objections) and 120 remain open. The majority of the remaining open items await data acquired through site characterization activities for their resolution. Of the 120 open items, 19 are presently being reviewed by the Nuclear Regulatory Commission.

The Department of Energy continues to interact with the National Academy of Sciences. Section 801 of the Energy Policy Act of 1992 directed the Environmental Protection Agency to contract with the Academy to perform a study and provide recommendations regarding development of health-based standards for protection of the public from releases from a repository at the Yucca Mountain site. As a result, the Academy formed a Committee on Technical Bases for Yucca Mountain Standards in April 1993, which is currently evaluating the question. The Department supports the activities of the Committee

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and has responded to requests for input. The Department is currently evaluating issues associated with development of standards and regulations and is preparing an overall position on preferences for a new standard. This position will be completed by April 1994, in time to provide timely support for deliberations by the Committee prior to their transmitting recommendations to the Environmental Protection Agency by December 1994.

The U.S. Congress, in the Energy Policy Act of 1992, instructed the Department of Energy to evaluate whether its current programs and plans for management of nuclear waste were adequate to deal with volumes or categories that might be generated through new nuclear power plants. The Congress also asked the Secretary of Energy to report on additional transportation, interim storage, and geologic repositories needed for these new wastes. A draft report entitled "Adequacy of Management Plans for the Future Generation of Spent Nuclear Fuel and High-Level Radioactive Waste" was released in June 1993 for public review and comment. A revised version is undergoing Department review.

In the international program, cooperative efforts have continued with a number of countries including major cooperative research project agreements with Canada, Switzerland, and Sweden. In addition, the program participated in a workshop on Near-Field Performance Assessment held at Cadarache, France, May 11-13, 1993, where topics included near-field environment, releases, transport, modeling, and performance assessment integration. The program is also beginning work in New Zealand, where geothermal field observations will be used for a geochemical code validation program. The results of this work will directly complement laboratory-based model validation activities and will provide a direct demonstration of the ability of the codes to model relevant processes in natural systems.

The Yucca Mountain Site Characterization Project Office continued its public outreach activities regarding nuclear waste disposal concepts and the Yucca Mountain site characterization program. Sixty-eight tours of Yucca Mountain were conducted for about 2,600 members of the public and other interested parties during this period. Numerous programmatic and technical workshops and presentations were conducted by the Yucca Mountain Site Characterization Project staff. Meetings were held in various communities in Nevada to provide current information to the public and appropriate agency personnel regarding progress on site characterization. These meetings were structured to allow the public to have good opportunities to communicate with the Yucca Mountain staff.

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CHAPTER 1 - INTRODUCTION

1.1 PURPOSE AND SCOPE

In accordance with Section 113(b)(3) of the Nuclear Waste Policy Act of 1982 (NWPA, 1983), as amended (NWPA, 1987) (hereinafter referred to as "the Act") and 10 CFR 60.18(g), the U.S. Department of Energy (hereinafter referred to as the "Department") has prepared this report for the U.S. Nuclear Regulatory Commission (hereinafter referred to as the "Commission") on the progress of site characterization activities at Yucca Mountain, Nevada, for the period April 1, 1993, through September 30, 1993. This report is the ninth 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 Act states that "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 that "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 during the reporting period, work in progress, and work completed and documented during the reporting period. In addition, this report is the vehicle for documenting and discussing changes to the Office of Civilian Radioactive Waste Management (OCRWM) Site Characterization Program (hereinafter referred to as the "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.

Documents cited in the text are available for inspection at U.S. Department of Energy (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 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 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, the Commission, the Nuclear Waste Technical Review Board (hereinafter referred to as the "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 the Program will be required to demonstrate to the Commission 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, the Program will terminate all characterization activities at the site. Should that occur, OCRWM will, in accordance with provisions of the Act, notify Congress and the Governor and legislature of the State of Nevada of its action and the reason for such action.

The Program plans for site characterization are described in the Site Characterization Plan (SCP) (DOE, 1988a). More detailed information is presented in study plans for the various site characterization studies and their component activities. The SCP was submitted to the Commission in December 1988, and their "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") issued in July 1989. Responses to over 5000 comments from the Commission, 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 (hereinafter referred to as the "Project"). Changes to the statutory SCP 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 (ESF), laboratory tests, modeling, and analyses. Performance Assessment will assist in evaluating (1) whether a repository can be constructed and operated at the site without adversely affecting the health and safety of the public and workers during repository operations, 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 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

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and underground tests will continue beyond the site characterization phase. Appropriate new tests and monitoring will also be initiated and continued while the Program is constructing the repository and during waste emplacement, until there is adequate confidence that the repository is performing as expected, and the Commission 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 ESF North Portal.

1.3 PROGRAM OUTREACH

1.3.1 International Program

The OCRWM international program continued to cooperate with a number of countries and international organizations to exchange information of mutual interest, to work towards achieving consensus on common issues, and to develop and conduct cooperative activities of mutual benefit.

Work also continued on three major cooperative research agreements with Canada (Atomic Energy of Canada, Ltd [AECL]), Switzerland (National Cooperative for the Disposal of Radioactive Waste [NAGRA]) and Sweden (Nuclear Fuel and Waste Management Co.).

The cooperative agreement with Canada includes 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 have been conducted in Canada at facilities not available in the United States, but at conditions expected at Yucca Mountain. Existing Canadian instruments have been modified for measuring in situ stress in fractured tuff at Yucca Mountain. Quality affecting spent-fuel dissolution tests have been conducted for Yucca Mountain Site Characterization Project (YMP) waste package and performance assessment analyses. Prototype tests were conducted on complex downhole packer strings to be used at C-Wells testing at Yucca Mountain; this testing resulted in major modifications to the system. Planning was done for large-block radioactive tracer testing in Canada at facilities not available in the United States for a tuff sample obtained at Yucca Mountain. Release and transport rates for ground water were measured at a high-grade

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uranium site in Canada for use in Yucca Mountain performance assessment analyses. A Swedish hydrochemical tool was purchased for use at Yucca Mountain C-Wells; planning was done for calibration testing in Canada at laboratory and field sites not available in the United States. An automated ground water flow data acquisition system was developed for use at Yucca Mountain. This type of technology is being developed using the AECL Underground Research Laboratory and laboratories and facilities in Canada.

The cooperative agreement with the Swiss includes five technical tasks concerning: transport characterization in fractured rocks, multi-phase flow in fractured porous rocks, seismic tomographic imaging, mechanistic approach to sorption of radionuclides, and borehole fluid logging. Accomplishments include: building and demonstrating an experimental facility to characterize two-phase flow conditions that apply to unsaturated Yucca Mountain regimes; development of a conceptual model for fracture flow systems that will be encountered at Yucca Mountain; development of a mechanistic model to predict sorption and radionuclides at Yucca Mountain; improvement of seismic imaging hardware, data acquisition and processing systems to provide real-time interpretation in site characterization efforts at Yucca Mountain; and development of advanced borehole logging techniques and fluid property conditions that may exist at Yucca Mountain. This technology is being developed using the underground rock laboratory at the Grimsel Test Site and laboratories and surface facilities operated by NAGRA.

The cooperative agreement with Sweden includes 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 (HRL) include the United Kingdom, Finland, France, Japan, and Canada.

United States scientists have observed HRL operation and brought back technical and management techniques for the United States to use for integration and coordination of scientific efforts during ESF construction. Other activities have involved developing a two-phase flow model to analyze ground-water flow in fractured, unsaturated rocks at Yucca Mountain; participation in an international fracture flow modeling task force for comparison and transfer of technology to the YMP; developing a method to assess ground-water travel time requirements and to determine a ground-water travel time distribution range appropriate for Yucca Mountain; participation in design and evaluation of underground hydrological and geochemical testing at the HRL—this experience will be used in the ESF effort; and development and performance of isotopic analyses of samples obtained from the HRL—the results will be used to establish sampling and analysis techniques for preconstruction site characterization, including that for Yucca Mountain. This underground technical program relates directly to the development of site characterization activities at Yucca Mountain and the development of an integrated testing program for both natural and engineered barrier components at the Yucca Mountain ESF.

The international program is also beginning work in the New Zealand Geothermal Field Geochemical Code Validation Program. The proposed studies in New Zealand are to be

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implemented by Lawrence Livermore National Laboratory in cooperation with the New Zealand Crown Research Institute for Geochemistry and Nuclear Science to validate geochemical and hydrologic codes and models used to simulate transport and hydrological processes, especially in the near-field. Planning is essentially complete, and some preliminary and scoping investigations were completed.

Forecast: The international program will sponsor and support the development of the 1994 Commission of European Communities Natural Analogue Working Group Workshop No. 6 in the United States. It is proposed that the workshop will be hosted by OCRWM Program scientists from Los Alamos National Laboratory. The workshops are held biennially; the 4th Workshop was held in Scotland in 1990, and the 5th in Spain in 1992.

The National Research Council of the National Academy of Sciences (hereinafter referred to as "NAS" or the "Academy") and the Review Board have urged OCRWM to enhance the role of natural analogues. By hosting this workshop in the United States the Program will benefit by a number of Department staff being able to attend presentations by international experts, who have developed and implemented successful programs to study natural analogues that apply to radioactive waste disposal.

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 start of cooperative work in New Zealand, the scope and purpose of which has been noted earlier.

1.3.2 Public Outreach

Efforts continue to provide a broad-based, thorough, and extensive public information program. This program has been met with a high degree of public approval and has resulted in a heightened public understanding of the Program.

Tours of Yucca Mountain continue to be among the most successful of the outreach activities. Sixty-eight tours of Yucca Mountain were conducted for approximately 2600 members of the public and other interested parties. Six of these were Public Open House tours, while the rest were special group tours, including the U.S. Council for Energy Awareness, the French Radiation Waste Regulatory Agency, International High-Level Radioactive Waste Management Conference, Institute of Shaft Drilling Technology, International Safeguards Group, Empresa Nacional de Residuos Radiactivos S.A., Congressman John T. Myers and two staff members of the Energy and Water Development Appropriations Subcommittee, Nuclear Programs from China, Edison Electric Institute High-Level Waste Working Group, and the Western Legislative Conference.

The Project conducted numerous programmatic and technical workshops, and presentations, including meetings held in various Nevada communities to provide current information to the public and appropriate agencies regarding progress on site characterization. Among these were the Project Public Update Meetings held in Beatty, Reno, and Las Vegas.

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The Project conducted a workshop on Developing a Consultative Process for Stakeholders and the Public at the University of Nevada, Las Vegas, on August 10, 1993. This workshop provided an opportunity to involve stakeholders in the Program's decision-making process. Although a wide-ranging and robust discussion took place and no consensus was reached on any one best method for involving the public, the workshop did offer a unique opportunity for stakeholders to meet face-to-face on this issue. The resulting summary report, entitled "Summary of Discussion and Suggestions at the Workshop on Developing a Consultative Process" (JK Research Assoc., Inc., 1993) summarizes and synthesizes the workshop discussion and suggestions so they can be considered in planning a process for public involvement in the Program.

In addition, the Project continued to operate the Yucca Mountain Science Centers located in Las Vegas, Beatty, and Pahrump. These centers received approximately 7700 visitors during this period. The Project also continued to produce and distribute the public newsletter "Of Mountains and Science," staffed public events, prepared new exhibits for the Field Operations Center, and completed three information videos, as well as a variety of information products, including a new fact sheet.

A total audience of approximately 9220 people attended 148 speaking presentations during this period. These included 9 technical presentations, 63 general Project overview presentations, 67 educational presentations, and 9 pretour briefings.

CHAPTER 2 - STATUS OF SITE CHARACTERIZATION

Specific details regarding site characterization activities during this reporting period are presented throughout Chapter 2. Figures 2.1-1 and 2.1-2 show the locations where such activities were being performed.

SECTION 2.1 - PREPARATORY ACTIVITIES

This section provides discussions of activities, conducted during the current reporting period, which are necessary to plan and conduct actual site characterization and design studies and activities.

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

2.1.1.1 Interactions with U.S. Nuclear Regulatory Commission

During the reporting period the Department participated in the following interactions with the Commission:

April 15, 1993	Quality Assurance (QA) Meeting in Rockville, Maryland, to discuss the status of implementation of the Quality Assurance Requirements Document (QARD), the QA oversight of field activities, the fiscal year (FY) 1993 audit schedule, recent audit results, and the Department evaluation of the Civilian Radioactive Waste Management System Management and Operating Contractor (hereinafter referred to as "the M&O") QA program implementation.
May 3, 1993	Management Meeting in Las Vegas, Nevada, to discuss the Department use of topical reports and the Commission Draft Topical Report Review Plan.
May 25-26, 1993	Site visit to Yucca Mountain, Nevada, to provide the U.S. Nuclear Regulatory Commission (NRC) staff an opportunity to observe the preliminary results of the U.S. Department of Energy (DOE) trench mapping activities at Crater Flats and the Exploratory Studies Facility (ESF), and to discuss the results with DOE and principal investigators.
June 7, 1993	Management Meeting in Las Vegas, Nevada, to discuss and agree to the interactions to be conducted by DOE and NRC during the period of July to December 1993.

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- June 8, 1993 Technical Exchange in Las Vegas, Nevada, to discuss the integration of the geophysics program and progress in resolving Site Characterization Analysis Comments 51, 52, and 59 as related to the integration of planned geophysical activities with other site characterization activities.
- June 9, 1993 Technical Exchange in Las Vegas, Nevada, to discuss the progress and results of volcanism studies at Yucca Mountain as detailed in the Los Alamos National Laboratory (Los Alamos) status report on volcanic hazard investigations.
- July 20, 1993 QA Meeting in Rockville, Maryland, to discuss the status of the implementation of the DOE QARD, QA oversight of field activities, the FY 1993 audit schedule, QA review of study plans, DOE response to NRC comments on the DOE QARD, QA role in issue resolution, and the status of the new DOE QA support contractor.
- August 10, 1993 Appendix 7 Meeting in Denver, Colorado, to discuss and demonstrate the use of the three-dimensional modeling (LYNX) program.
- August 11, 1993 Appendix 7 meeting in Las Vegas, Nevada, to discuss the Earth Vision dynamic graphics three-dimensional modeling program and its interface with the LYNX modeling program.
- August 24, 1993 Technical Exchange in Bethesda, Maryland, to discuss Substantially Complete Containment and Waste Package/Engineered Barrier System Design concepts, DOE interpretation of Substantially Complete Containment regulations and their use as a guide in design, status/progress of the waste package design effort, and plans for addressing related Site Characterization Analysis open items.
- September 17, 1993 Management Meeting in Rockville, Maryland, to discuss the NRC letter dated August 20, 1993, regarding ESF design and design control problems.

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Figure 2.1-1

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Figure 2.1-2

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

Resolving Site Characterization Analysis (NRC, 1989) open items is a bilateral process that consists of (1) the Program providing documentation or other basis to the Commission to claim resolution of specific open items, and (2) the Commission accepting (or not accepting) the basis for resolution, and informing the Office of Civilian Radioactive Waste Management (OCRWM). Both steps are needed to remove open items from further consideration.

The Project continues to work toward resolving the open items. During this reporting period, the Commission agreed, by letter dated April 21, 1993, that the Program had provided the technical basis to resolve Question 17. In addition, OCRWM provided supplementary responses to Comments 3, 7, 45, 47, 95, 105, 115 and Questions 12, 25, and 38 and stated that these items should be resolved. In a letter dated May 5, 1993, the Commission informed DOE that the proposed December 1991 resolution of Question 1 did not sufficiently address the staff's concerns and Question 1 remained open. Therefore, as of the end of this reporting period, 78 items have been closed (including the 2 objections) and 120 remain open. The majority of the remaining open items await data acquired through site characterization activities for their resolution. Of the 120 open items, 19 were being reviewed by the Commission.

Table 2.1-1 identifies all remaining Site Characterization Analysis open items. For each item the 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 information pertinent to each of the items.

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Table 2.1-1. Status of Site Characterization Analysis Open Items

Open Item #	Description of Open Item
COMMENTS	
1	<p>A systematic, iterative approach to identify and collect data for a license application.</p> <p><u>Further Action Required:</u> Submit Mined Geologic Disposal System (MGDS) License Application Annotated Outline, Rev. 3 to NRC. Complete linkage to site data through performance assessment.</p>
2	<p>Confidence in performance allocation goals.</p> <p><u>Further Action Required:</u> Prepare a supplemental response and submit it to NRC.</p>
3	<p>Reliance on expert judgment for supplying licensing information.</p> <p><u>Further Action Required:</u> None. Supplemental response submitted to NRC to close the item. Awaiting NRC confirmation.</p>
4	<p>Rationale for testing needs; integration of testing with design and performance assessment.</p> <p><u>Further Action Required:</u> Develop Parametric Calculations to refine parameter goals and complete the development of plans to collect that data.</p>
5	<p>Waste package: Interpretation of "substantially complete containment."</p> <p><u>Further Action Required:</u> Develop a position on how technological limitations and uncertainties might impact demonstration of compliance with 10 CFR 60.113. Coordinate with Comment 80.</p>

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Table 2.1-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
COMMENTS (Continued)	
6	<p>Performance assessment: Hypothesis Testing Table and alternative conceptual models.</p> <p><u>Further Action Required:</u> Prepare a supplemental response and submit it to NRC.</p>
7	<p>Use of expert judgment versus peer review.</p> <p><u>Further Action Required:</u> None. Supplemental response submitted to NRC to close the item. Awaiting NRC confirmation.</p>
8	<p>Alternative Tectonic Models.</p> <p><u>Further Action Required:</u> Prepare and issue Study Plan 8.3.1.17.4.12, "Tectonic Models and Synthesis."</p>
9	<p>Use of Expert Judgment during the development of Hypothesis Testing Tables.</p> <p><u>Further Action Required:</u> Prepare a supplemental response and submit it to NRC.</p>
10	<p>Assessment of significance of site hydrologic characteristics.</p> <p><u>Further Action Required:</u> Resolution of Comment 1.</p>
11	<p>No hypothesis on the thermal effects of waste emplacement in hydrologic environment.</p> <p><u>Further Action Required:</u> Prepare a supplemental response and submit it to NRC.</p>

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Table 2.1-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
COMMENTS (Continued)	
15	<p>Solitario Canyon horizontal borehole activity is inadequate to discriminate between the hypotheses that faults are barriers to fluid flow in nonwelded tuff units, or that faults are conduits for liquid-water flow.</p> <p><u>Further Action Required:</u> Revise Study Plan 8.3.1.2.2.4, "Characterization of the Yucca Mountain Unsaturated Zone in the Exploratory Studies Facility" to add the activity entitled "Hydrologic properties of major faults encountered in the Exploratory Studies Facility."</p>
18	<p>Initial modeling studies are not supported by planned activities.</p> <p><u>Further Action Required:</u> Resolve Comment 1.</p>
19	<p>Saturated zone work is not adequate for saturated zone characterization.</p> <p><u>Further Action Required:</u> Develop a plan to sufficiently test and define the saturated zone.</p>
20	<p>Potentiometric surface is not adequately defined.</p> <p><u>Further Action Required:</u> Identify what additional work/drilling needs to be done to characterize the southern area.</p>
21	<p>Saturated zone: ^{99}Tc and ^{129}I are not included to characterize ground-water flow and nuclide background concentrations.</p> <p><u>Further Action Required:</u> None. Supplemental response submitted to NRC to close the item. Awaiting NRC confirmation.</p>

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Table 2.1.1-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
COMMENTS (Continued)	
22	<p>Saturated zone: Hydrochemical sampling.</p> <p><u>Further Action Required:</u> None. Supplemental response submitted to NRC to close the item. Awaiting NRC confirmation.</p>
24	<p>Standard solubility approaches are not adequate for thermodynamic properties of zeolites.</p> <p><u>Further Action Required:</u> Prepare and issue Study Plan 8.3.1.3.3.2, "Kinetics and Thermodynamics of Mineral Evolution."</p>
25	<p>Waste package degradation products and interactions between radionuclides on sorption.</p> <p><u>Further Action Required:</u> Prepare and issue Study Plan 8.3.4.2.4.1, "Characterization of Chemical and Mineralogical Changes in Post-Emplacement Environment."</p>
31	<p>Some parameters for speciation, kinetics, and matrix diffusion are not planned.</p> <p><u>Further Actions Required:</u> Prepare and issue Study Plan 8.3.1.3.6.1, "Dynamic Transport Column Experiments."</p>
32	<p>Integration of geophysics and discussion is not included.</p> <p><u>Further Actions Required:</u> Issue the integration strategy developed by the Geophysics Integration Task Force.</p>

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Table 2.1-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
COMMENTS (Continued)	
33	<p>Engineering rock characteristics are not integrated into three-dimensional models.</p> <p><u>Further Action Required:</u> Prepare and issue Study Plan 8.3.1.4.2.3, "Three Dimensional Geologic Modeling."</p>
34	<p>Integration of drilling program.</p> <p><u>Further Action Required:</u> Complete and issue Study Plans 8.3.1.4.2.1, "Characterization of the Vertical and Lateral Distribution of Stratigraphic Units Within the Site Area" and 8.3.1.2.2.4, "Characterization of the Yucca Mountain Unsaturated Zone in the Exploratory Studies Facility."</p>
36	<p>Adequacy of location of perimeter drift and the concentration of faults.</p> <p><u>Further Action Required:</u> Conduct a DOE-NRC Technical Exchange to discuss how many faults represent a significant concentration."</p>
42	<p>Adequacy of evaluation of escarpment retreat</p> <p><u>Further Action Required:</u> None. Supplemental response submitted to NRC to close the item. Awaiting NRC confirmation.</p>
43	<p>Adequacy of numerical goals in erosion, postclosure tectonics, and preclosure tectonics performance assessment tables.</p> <p><u>Further Action Required:</u> None. Supplemental response submitted to NRC to close the item. Awaiting NRC confirmation.</p>

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Table 2.1-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
COMMENTS (Continued)	
45	<p>Volcanic rate calculations independent of underlying volcanic tectonic processes.</p> <p><u>Further Action Required:</u> None. Supplemental response submitted to NRC to close the item. Awaiting NRC confirmation.</p>
47	<p>Relationship of postclosure tectonics to the waste package and engineered barrier system requirements.</p> <p><u>Further Action Required:</u> None. Supplemental response submitted to NRC to close the item. Awaiting NRC confirmation.</p>
48	<p>Use of fault slip rates on the repository facilities are not conservative.</p> <p><u>Further Action Required:</u> Issue a topical report on seismic hazards methodology.</p>
49	<p>Investigations on basaltic volcanism will fail to meet overall system performance.</p> <p><u>Further Action Required:</u> Resolve Comment 1.</p>
51	<p>Adequacy of geophysics to determine deep and shallow crustal features.</p> <p><u>Further Action Required:</u> Issue the integration strategy developed by the Geophysics Integration Task Force.</p>

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Table 2.1-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
COMMENTS (Continued)	
52	Use of geophysics in evaluating basaltic volcanism. <u>Further Action Required:</u> Complete an assessment by an independent geophysical consultant. Submit results of assessment to NRC.
53	Adequacy of natural resource assessment; consideration of ore deposition models <u>Further Action Required:</u> None. Supplemental response submitted to NRC to close the item. Awaiting NRC confirmation.
55	Adequacy of geostatistical approach to geomechanical and thermal properties. <u>Further Action Required:</u> Evaluate the performance allocations for Activity 8.3.1.15.
56	Validation of models for mechanical and thermal properties. <u>Further Action Required:</u> Prepare and issue Study Plans 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." Evaluate the performance allocations for Activity 8.3.1.15.
59	Preclosure tectonics activities to be performed and timing of activities <u>Further Action Required:</u> Prepare and issue Study Plans 8.3.1.17.3.5, "Ground Motion at the Site from Controlling Seismic Events" and 8.3.1.17.4.7, "Subsurface Geometry and Concealed Extensions of Quaternary Faults at Yucca Mountain." Geophysical Integration Task Force to sequence activities.

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Table 2.1-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
COMMENTS (Continued)	
60	Adequacy of preclosure design and performance goals and characterization parameters. <u>Further Action Required:</u> Resolve comment 1.
61	Assumption that future faulting will follow previous faulting. <u>Further Action Required:</u> Prepare and issue Study Plan 8.3.1.17.2.1, "Faulting Potential at the Repository."
62	Use of standoff distances in preclosure tectonics for surface facilities. <u>Further Action Required:</u> Prepare and issue Study Plan 8.3.1.17.2.1, "Faulting Potential at the Repository."
63	Use of pre-existing and unavailable information for the preclosure tectonics program and the surface facilities. <u>Further Action Required:</u> Prepare a supplemental response and submit it to NRC.
64	Adequacy of study of faults for design and performance. <u>Further Action Required:</u> Conduct a DOE-NRC interaction on identification and investigations of fault displacement and seismic hazards.

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Table 2.1-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
COMMENTS (Continued)	
66	Release via a single event (10,000 year cumulative slip earthquake). <u>Further Action Required:</u> Prepare and issue report on how the facility will withstand an event exceeding the design basis ground motion.
68	Adequacy of treatment on detachment faulting affects. <u>Further Action Required:</u> Prepare and issue Study Plan 8.3.1.17.4.12, "Tectonic Models and Synthesis."
69	Synthesis of data on the northwest trending of faulting. <u>Further Action Required:</u> Prepare and issue Study Plan 8.3.1.17.4.12, "Tectonic Models and Synthesis."
71	Adequacy of technologies in assessing faulting for construction, operation, and closure. <u>Further Action Required:</u> Prepare and issue topical report on seismic hazards methodology.
73	Adequacy of required backfill hydraulic conductivity. <u>Further Action Required:</u> Continue work on the seals program. Prepare the study plan for the determination of the hydraulic conductivity of the backfill.
74	Testing of seal components. <u>Further Action Required:</u> Prepare and issue Study Plan 8.3.3.2.2.3, "In Situ Testing of Seal Components."

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Table 2.1-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
COMMENTS (Continued)	
75	<p>Definition of and inconsistent use of "geologic setting."</p> <p><u>Further Action Required:</u> Prepare supplemental response and submit it to NRC.</p>
77	<p>Adequacy of consideration of retrieval operations.</p> <p><u>Further Action Required:</u> During the development of the Advanced Conceptual Design, evaluate the effects of credible accidents on radiological exposures during retrieval operation.</p>
79	<p>Adequacy of waste package corrosion tests for the repository.</p> <p><u>Further Action Required:</u> Prepare and issue Study Plan 8.3.4.2.4.1, "Characterization of Chemical and Mineralogical Changes in the Post Emplacement Environment." Supply NRC with the Lawrence Livermore National Laboratory (LLNL) report entitled "Metal Barrier Selection and Testing," LLNL SIP CM-01.</p>
80	<p>Performance goals consistent with interpretation and intent of "substantially complete containment."</p> <p><u>Further Action Required:</u> Prepare a supplemental response and submit it to NRC.</p>
81	<p>Waste package: Adequacy of program in stress corrosion cracking behavior of the waste package.</p> <p><u>Further Action Required:</u> Complete the Metals Barrier Scientific Investigation Plan and initiate the study. Evaluate the extended dry concept with drift emplacement.</p>

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Table 2.1-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
COMMENTS (Continued)	
82	<p>Waste package: Adequacy of waste package performance at licensing.</p> <p><u>Further Action Required:</u> Prepare and issue Study Plan 8.3.4.2.4.4, "Engineered Barrier System Field Test." Prepare and provide the NRC with the Waste Package Advanced Conceptual Design Report.</p>
84	<p>Adequacy of issue resolution strategy for the engineered barrier system and waste package.</p> <p><u>Further Action Required:</u> Evaluate the effect of unanticipated processes and events on the engineered barrier system and waste package.</p>
85	<p>Performance assessment: Accounting of temporal changes in state of stress due to corrosion of container.</p> <p><u>Further Action Required:</u> Complete the Metals Barrier Scientific Investigation Plan and initiate the study. Evaluate the extended dry concept with drift emplacement.</p>
86	<p>Waste package: Adequacy of degradation models of copper-based alloys.</p> <p><u>Further Action Required:</u> Complete the degradation mode surveys for candidate materials and test plans for promising materials.</p>
87	<p>Waste package: Adequacy of effect of the contact of dissimilar metals causing corrosion.</p> <p><u>Further Action Required:</u> Continue development of the waste package design until the number of package options is down to three designs. Describe the use of data from galvanic testing in the waste package design plan.</p>

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Table 2.1-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
COMMENTS (Continued)	
88	<p>Waste package: Assumption of reduced uncertainties because of the unsaturated zone.</p> <p><u>Further Action Required:</u> Supply NRC with LLNL report "Metal Barrier Selection and Testing" (LLNL SIP CM-01).</p>
89	<p>Waste package: Effect of introduction of materials that affect performance of the waste package and glass.</p> <p><u>Further Action Required:</u> Prepare and issue Study Plan 8.3.4.2.4.5, "Manmade Materials."</p>
90	<p>Waste package: Consideration of varying oxygen concentrations on corrosion of the waste package.</p> <p><u>Further Action Required:</u> Provide details in the Metal Barriers Scientific Investigation Plan on how the effect of oxygen on the waste package will be considered. Complete the evaluation of the drift emplacement alternative.</p>
91	<p>Waste package/performance assessment: Consideration of alternate canisters for reduction of ^{14}C releases.</p> <p><u>Further Action Required:</u> Evaluate and describe the performance of alternative waste package designs to be considered in the Advanced Conceptual Design. Review the new Environmental Protection Agency (EPA) standard, when available. Develop alternative waste package scenarios.</p>

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Table 2.1-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
COMMENTS (Continued)	
95	<p>Performance assessment: Adequacy of logic to screen and develop release scenarios.</p> <p><u>Further Action Required:</u> None. Supplemental response submitted to NRC to close the item. Awaiting NRC confirmation.</p>
96	<p>Adequacy of the use of K_d for modeling heterogeneous medium.</p> <p><u>Further Action Required:</u> Prepare and issue 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."</p>
98	<p>Performance assessment: Appropriateness of weighting complementary cumulative distribution function by expert judgment.</p> <p><u>Further Action Required:</u> Continue development of alternative conceptual models. Address the complementary cumulative distribution functions through the Total System Performance Assessment (TSPA) process. Submit documentation to NRC on the TSPA and sensitivity studies.</p>
99	<p>Performance assessment: Quantification of all release modes.</p> <p><u>Further Action Required:</u> Prepare a supplemental response and submit it to NRC.</p>
101	<p>Adequacy of Site Characterization Plan (SCP) equation 8.3.5.13-21.</p> <p><u>Further Action Required:</u> Prepare a supplemental response and submit it to NRC.</p>

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Table 2.1-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
COMMENTS (Continued)	
102	<p>Adequacy of Ross sequences in comparison to the hydrologic flow model.</p> <p><u>Further Action Required:</u> Prepare a supplemental response and submit it to NRC.</p>
103	<p>Ross sequences addressing anticipated conditions and not scenarios.</p> <p><u>Further Action Required:</u> Prepare a supplemental response and submit it to NRC.</p>
105	<p>Performance assessment: Rationale for elimination of scenarios.</p> <p><u>Further Action Required:</u> None. Supplemental response submitted to NRC to close the item. Awaiting NRC confirmation.</p>
109	<p>Adequacy of treatment of coupling time between matrix and fracture flow in hypothesis testing tables.</p> <p><u>Further Action Required:</u> Continue the TSPA activities which will analyze the coupling times for the transfer of radionuclides between matrix and fracture flow.</p>
115	<p>Adequacy of expanding of complementary cumulative distribution function in terms of scenario classes.</p> <p><u>Further Action Required:</u> None. Supplemental response submitted to NRC to close the item. Awaiting NRC confirmation.</p>

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Table 2.1-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
COMMENTS (Continued)	
116	<p>Individual exposures via potable water may need to be expanded.</p> <p><u>Further Action Required:</u> Awaiting the issuance by EPA of a new standard for individual exposure per Energy Policy Act of 1992 (U.S. Congress, 1992). Revise issue resolution strategy for SCP Issue 1.2.</p>
117	<p>Individual exposure rates of ^{14}C may need to consider advective and diffusive flow rates.</p> <p><u>Further Action Required:</u> Address the behavior of ^{14}C through the iterative TSPA process.</p>
118	<p>Conduct long-term in situ laboratory waste package activities.</p> <p><u>Further Action Required:</u> Determine the testing requirements after site characterization has progressed far enough to define the performance confirmation program.</p>
119	<p>Adequacy of performance confirmation testing (10 CFR 60).</p> <p><u>Further Action Required:</u> Conduct a DOE-NRC interaction on the performance confirmation program. Prepare and issue Study Plans 8.3.3.2.2.3, "In Situ Testing of Seal Components," 8.3.1.15.1.6, "In Situ Thermomechanical Properties," and 8.3.4.2.4.4, "Engineered Barrier Field Tests."</p>
120	<p>Model and computer code validation studies.</p> <p><u>Further Action Required:</u> Prepare and issue the model and computer code validation strategy.</p>

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Table 2.1-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
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COMMENTS (Continued)

121 Adequacy of seismic design of ESF.

Further Action Required:

Submit the Exploratory Studies Facility Design Requirements Document (DOE, 1993b) to NRC.

122 Demonstration and acceptability of the dry coring method.

Further Action Required:

Prepare a supplemental response and submit it to NRC.

123 Assessment of effects of ventilation on the ESF.

Further Action Required:

Conduct evaluations to determine what monitoring is required to evaluate the affects of drying of the repository block by the ESF. Evaluate what impacts the drying will have on waste isolation.

130 Design Acceptability Analysis.

Further Action Required:

Submit the Exploratory Studies Facility Design Requirements Document (DOE, 1993b) to NRC.

QUESTIONS

1 Integration of mapping efforts.

Further Action Required:

Prepare a supplemental response and submit it to NRC.

PROGRESS REPORT #9

Table 2.1-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
QUESTIONS (Continued)	
3	Area of repository development. <u>Further Action Required:</u> Evaluate existing data. Establish thermal boundaries. Evaluate the performance of the repository. Prepare and issue the Thermal Studies Report.
5	Adequacy of vertical boreholes for evaluation of faults and fractures. <u>Further Action Required:</u> Prepare a supplemental response and submit it to NRC.
8	Rock properties: level of detail and uncertainty in three-dimensional model. <u>Further Action Required:</u> Prepare and issue Study Plan 8.3.1.4.3.2, "Three-Dimensional Rock Characteristics Models."
9	Systematic drilling program: adequacy of sampling same specimens for rock properties. <u>Further Action Required:</u> Prepare a supplemental response and submit it to NRC.
12	Rationale for exclusion of Lunar Crater basaltic field as analogue. <u>Further Action Required:</u> None. Supplemental response submitted to NRC to close the item. Awaiting NRC confirmation.

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Table 2.1-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
QUESTIONS (Continued)	
14	<p>Natural resources: adequacy of evaluation of previous mining and drilling leases on the site.</p> <p><u>Further Action Required:</u> None. Supplemental response submitted to NRC to close the item. Awaiting NRC confirmation.</p>
15	<p>Resource exploration and mineral resource potential.</p> <p><u>Further Action Required:</u> None. Supplemental response submitted to NRC to close the item. Awaiting NRC confirmation.</p>
20	<p>Discussion on vertical or horizontal emplacement.</p> <p><u>Further Action Required:</u> Prepare a supplemental response and submit it to NRC.</p>
21	<p>Parameters for radiation shielding properties of the host rock.</p> <p><u>Further Action Required:</u> Further develop the Advanced Conceptual Design.</p>
22	<p>Parameters related to repository construction and operation.</p> <p><u>Further Action Required:</u> Develop the performance goals during the Advanced Conceptual Design of the repository.</p>
23	<p>Computer code verification and validation.</p> <p><u>Further Action Required:</u> Prepare and issue the model and computer code validation strategy.</p>

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Table 2.1-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
QUESTIONS (Continued)	
25	<p>Heterogeneous air flow characteristics for seal program.</p> <p><u>Further Action Required:</u> None. Supplemental response submitted to NRC to close the item. Awaiting NRC confirmation.</p>
28	<p>ES-1 penetration of the Calico Hills Unit: impacts of the current sealing program and issue resolution strategy 4.4.</p> <p><u>Further Action Required:</u> Develop seal design concepts and conduct performance assessments.</p>
30	<p>Waste package: Water quality as related to waste package design.</p> <p><u>Further Action Required:</u> Complete the activities in the Metal Barriers Scientific Investigation Plan and Waste Form Scientific Investigation Plan. Complete evaluation of the drift emplacement alternative needs.</p>
31	<p>Integrity of spent fuel cladding.</p> <p><u>Further Action Required:</u> None. The OCRWM has submitted a supplemental response to NRC to close the item. Awaiting NRC confirmation.</p>
32	<p>Container "similarity" for borosilicate glass waste versus spent fuel.</p> <p><u>Further Action Required:</u> Continue development of the waste package design and narrow the design options to three designs.</p>

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Table 2.1-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
QUESTIONS (Continued)	
33	Emplacement hole drainage concerns. <u>Further Action Required:</u> Evaluate the water-vapor interface, crevice corrosion, and galvanic corrosion testing in the Metal Barriers Scientific Investigation Plan during Advanced Conceptual Design. Complete evaluation of the drift emplacement alternative.
34	Meaning of undetected defective closures. <u>Further Action Required:</u> Prepare a supplemental response and submit it to NRC.
35	Acceptance criteria for helium leak tests. <u>Further Action Required:</u> Complete the leak rate calculations using current industry standards.
36	Contact of canisters with corrosive elements during shipping and handling. <u>Further Action Required:</u> Continue development of the waste package design and narrow the options to three designs.
37	Basis for 10 cm of free fall for canister and contents. <u>Further Action Required:</u> Prepare a supplemental response and submit it to NRC.
38	Basis for 1 mm of thinning of canister due to impact or handling. <u>Further Action Required:</u> None. Supplemental response submitted to NRC to close the item. Awaiting NRC confirmation.

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Table 2.1-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
QUESTIONS (Continued)	
39	Definition of "unusual process history" of canister. <u>Further Action Required:</u> Further develop the waste package design.
40	Basis for factor of 2 on borehole liner in comparison to container material. <u>Further Action Required:</u> Study the effects of water containing liner corrosion products on degradation of the container in accordance with the Metal Barriers Scientific Investigation Plan.
41	Consideration of 10 CFR 60.132 (a) in resolution of Issue 2.4. <u>Further Action Required:</u> Incorporate regulation 10 CFR 60.132 into the Repository Design Requirements Document (DOE, 1993c). Conduct engineering studies to evaluate throughput requirements.
42	Assumption of stability of vertical emplacement hole. <u>Further Action Required:</u> Further develop the Advanced Conceptual Design.
44	Basis for assumed numbers of breached assemblies or canisters. <u>Further Action Required:</u> Develop information on failures of waste forms in multiple locations. Document the waste package corrosion model(s) utilized for TSPA. Further develop the Advanced Conceptual Design and narrow options down to three candidate designs.

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Table 2.1-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
QUESTIONS (Continued)	
45	<p>Investigation of particulate source terms for waste package, particulate retention factors by containing vessels, or plateout factors for the geologic repository operations area during accident conditions.</p> <p><u>Further Action Required:</u> Develop source terms for radionuclide release from breached waste packages during iterative performance assessments.</p>
46	<p>Basis for stricter containment of long half-life isotopes.</p> <p><u>Further Action Required:</u> Submit the Engineered Barrier Design Requirements Document (DOE, 1993d) to NRC.</p>
47	<p>Assumption on breaches of waste containers.</p> <p><u>Further Action Required:</u> Submit the Engineered Barrier Design Requirements Document (DOE, 1993d) to NRC.</p>
49	<p>Effects of low-temperature oxidation on containers.</p> <p><u>Further Action Required:</u> Prepare and issue the Metals Barriers Scientific Investigation Plan. Refine the waste package design down to three options.</p>
51	<p>Design and research criteria for accepting waste from Idaho National Engineering Laboratory and Hanford.</p> <p><u>Further Action Required:</u> Prepare a supplemental response and submit it to NRC.</p>

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Table 2.1-1 Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
QUESTIONS (Continued)	
53	<p>Specification of cooling rate of the glass waste.</p> <p><u>Further Action Required:</u> Prepare a supplemental response and submit it to NRC.</p>
55	<p>Interference at the ESF by water storage tanks, septic field, and waste water lagoon.</p> <p><u>Further Action Required:</u> Submit the Exploratory Studies Facility Design Requirements Document (DOE, 1993b) to NRC. Conduct an evaluation of the water uses by the ESF on test interference and waste isolation.</p>
56	<p>Basis for 5 cm of fault displacement in waste package environment</p> <p><u>Further Action Required:</u> Submit the Exploratory Studies Facility Design Requirements Document (DOE, 1993b) to NRC.</p>
57	<p>Effects of drilling multipurpose boreholes.</p> <p><u>Further Action Required:</u> None. Supplemental response submitted to NRC to close the item. Awaiting NRC confirmation.</p>
58	<p>Flexibility of ESF to accommodate in situ testing of waste package.</p> <p><u>Further Action Required:</u> Submit the Exploratory Studies Facility Design Requirements Document (DOE, 1993b) to NRC.</p>

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Table 2.1-1 Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
QUESTIONS (Continued)	
59	Basis for length of in situ thermal tests. <u>Further Action Required:</u> Prepare and issue Study Plan 8.3.1.15.1.6, "In Situ Thermomechanical Properties."
62	Basis for 30 m separation between ESF and potential waste emplacement panels, and waste emplacement within 500 ft of the ESF. <u>Further Action Required:</u> Submit the Mined Geologic Disposal System Requirements Document (DOE, 1993e) to NRC.

2.1.1.3 Interactions with Advisory Committee on Nuclear Waste

There were five meetings of the Advisory Committee on Nuclear Waste (ACNW) during this reporting period.

On May 19-20, 1993, the 53rd ACNW meeting was held in Bethesda, Maryland. The meeting included a briefing by the Project on site characterization study plans and progress reports. Other topics related to high-level waste included the NRC Systematic Regulatory Analysis, and the Commission's high-level waste research program.

On July 20-22, 1993, the 55th ACNW meeting was held in Bethesda, Maryland. The meeting included an NRC staff discussion on QA in the high-level waste program.

On September 29-30, 1993, the 57th ACNW meeting was held in Bethesda, Maryland. The meeting included committee discussion of a letter from the Department offering suggestions on improving coordination between ACNW and DOE.

2.1.1.4 Interactions with Nuclear Waste Technical Review Board

During the reporting period DOE participated in the following interactions with the Review Board:

April 19, 1993	Environment and Public Health and Safety Panel Site Tour. The Department and Project Participants toured the Yucca Mountain environmental reclamation sites.
April 21-22, 1993	Full Board meeting in Reno, Nevada. The Department and Project Participants made presentations to the Review Board on the process used to resolve difficult issues. Infiltration and the effects of climate change on infiltration was used as an example.
July 13-14, 1993	Full Board meeting in Denver, Colorado. The Department and Project Participants made presentations to the Review Board to discuss the following thermal-loading issues: natural analogue studies; DOE initiatives to reassess the SCP thermal goals; how the science is applied to engineering and Advanced Conceptual Design; and plans for TSPA 1993.

The Project has also continued its efforts to address many of the Review Board's concerns as a part of the ongoing site characterization activities. Examples of specific efforts include: (1) continued ESF design and construction activities to gain early underground access to Yucca Mountain as recommended in the Review Board's Fourth and Fifth Reports; (2) an ongoing evaluation of thermal strategies as recommended in the Board's Fifth Report; (3) the initiation of limited Advanced Conceptual Design work for the waste package as recommended in the Review Board's Third, Fourth, and Fifth Reports; and (4) planning for a follow-up workshop on engineered barrier system concepts to be held in the Fall of 1993 as recommended in the Review Board's Fourth Report. The Project also welcomed the participation of the Review Board and its staff at various Project meetings, internal workshops, and scientific symposiums.

2.1.1.5 Interactions with National Academy of Sciences

The Energy Policy Act of 1992 (U.S. Congress, 1992) directed the EPA to contract with NAS (hereinafter referred to as "NAS" or the "Academy") 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 the EPA, based on the recommendations of the Academy, to promulgate public health and safety standards for a repository at the Yucca Mountain site. Furthermore, the Commission was directed to modify its requirements to be consistent with EPA standards and the recommendations of the Academy.

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The Academy formed the Committee on Technical Bases for Yucca Mountain Standards to prepare its recommendations to EPA. The committee held meetings May 27-29, 1993, and August 26-27, 1993. Further meetings have been scheduled for November 9-10, 1993; December 16-17, 1993; February 7-8, 1994; and April 28-29, 1994. A committee report, containing recommendations to EPA, is expected by the end of 1994.

At the request of the Academy, the Department designated a technical liaison representative to the NAS committee. In addition, the Program formed a task force to monitor activities associated with developing a standard for Yucca Mountain, and to provide input to the NAS committee. The Department made presentations to the Academy at the May meeting, identifying key issues related to a Yucca Mountain standard. Several scientists associated with the Project made presentations to the Academy at the August meeting. The Department is currently formulating its position on a standard, as well as the implementing regulations, and the task force anticipates providing this input to the NAS committee in 1994.

2.1.2 Issue Resolution

The Program is continuing an issue resolution process to help in the identification, clarification, and resolution of technical and regulatory issues raised during site characterization. The process has been developed based on the "Issues-Based Approach to Planning Site Characterization" contained in the SCP (p. 8.1-1). Issue resolution is directed toward receiving guidance and comment from NRC staff regarding 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 cannot be considered "closed" during this precicensing period, and any issue can be revisited based on new information, it is important to seek clarification and come to early resolution with NRC staff on as many areas of uncertainty as possible. This clarification will be accomplished by frequent interaction and communication with the Commission. These interactions may include reports sent to NRC staff for review and comment (e.g., topical or technical reports), letters, submittals of the Annotated Outline (see Section 2.1.3), or meetings. In addition, the resolution of the Site Characterization Analysis (NRC, 1989) open items (see Section 2.1.1.2) is being coordinated within the issue resolution process. Issue resolution activities during the reporting period include the following:

- **Volcanism:** A Technical Exchange was held with the Commission on June 9, 1993, to discuss the preliminary draft of the Los Alamos technical report (LA-9325, Volume III) on the status of the Project volcanism studies. The Commission provided written comments on draft LA-9325 to OCRWM in an August 18, 1993, letter. Revisions to Study Plans 8.3.1.8.1.1 and 8.3.1.8.5.1 were submitted to the Commission for review in March 1993.
- **Calcite-Silica:** Technical Report YMP/93-11-R, "Report on the Origin of Calcite-Silica Deposits at Trench 14 and Busted Butte and Methodologies Used to Determine Their Origin" (DOE, 1993f) was completed. The report was transmitted

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to the Commission for information on September 17, 1993, and the information is to be included in a future revision of the Annotated Outline.

- **Seismic Hazards:** A draft topical report, "Methodology to Assess Seismic Hazard at Yucca Mountain" was prepared and internal review has begun. An annotated outline of the proposed topical report was submitted to the Commission on August 18, 1993, in preparation for a DOE-NRC Technical Exchange scheduled for November 17, 1993.
- **Engineered Barrier System Boundary:** A letter report on the definition of the boundary of the engineered barrier system was completed (CRWMS M&O, 1993a). The report documents agreement with the Commission's interpretation that the engineered barrier system boundary does not include a portion of the host rock. This information will be included in a future revision of the Annotated Outline.
- **Substantially Complete Containment:** On August 24, 1993, a DOE-NRC Technical Exchange was held to discuss the methodology for compliance with the substantially complete containment provisions in 10 CFR Part 60. The Department is proposing a qualitative interpretation for compliance demonstration. The methodology is presently being documented as part of the Department's efforts associated with closure of Site Characterization Analysis open items and will be submitted to the Commission for review.

Forecast: During the first half of FY 1994, the Project intends to accomplish the following through the issue resolution process: (1) receive a Commission safety evaluation of the topical report entitled "Evaluation of the Potentially Adverse Condition 'Evidence of Extreme Erosion during the Quaternary Period' at Yucca Mountain" (DOE, 1993g) (hereinafter referred to as the "Erosion Topical Report"); (2) transmit, for Commission review, Study Plan 8.3.1.8.5.2, "Characterization of Intrusive Igneous Features" and Study Plan 8.3.1.8.1.2, "Physical Processes of Magmatism and Effects on the Repository;" (3) issue, for Commission review, the Los Alamos final report LA-9325 on the status of volcanic hazards investigations at the proposed Yucca Mountain repository; (4) interact with the Commission in Technical Exchanges on the Commission's preliminary questions on the Erosion Topical Report, on status of work relevant to characterization of the saturated and unsaturated zone flow, and on the methodology for seismic hazard assessment; (5) issue, for Commission review, the topical report entitled, "Methodology to Assess Seismic Hazard of Yucca Mountain;" and (6) continue to resolve additional Site Characterization Analysis open items.

2.1.3 License Application Annotated Outline

The process of developing the MGDS Annotated Outline for Skeleton Text for the License Application (hereinafter referred to as the "Annotated Outline") is a product-oriented management tool that has a key role in the Project's program management and licensing strategies. Specifically, the Annotated Outline process: (1) integrates site characterization, performance assessment, design, and regulatory activities; (2) provides dynamic feedback to

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the site characterization program; (3) implements guidance provided by the Commission in their Draft Regulatory Guide, DG-3003, entitled "Format and Content for the License Application for the High-Level Waste Repository," dated November 1990 (hereinafter referred to as "the Format and Content Reg. Guide"); (4) facilitates focused interactions with the Commission; 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.

During this reporting period, the Annotated Outline, Revision 2 (CRWMS M&O, 1993b), dated May 28, 1993, and consisting of change pages to Chapters 5, 6, and 8, was formally transmitted to the Commission, ACNW, State of Nevada, and Affected Counties. The focus of Revision 2 was setting up the framework and layout for the performance assessment and performance confirmation programs in the Annotated Outline. Revision 2 also included changes resulting from Commission comments on Revisions 0 and 1 (April 17, 1992, and September 30, 1992, respectively).

The Commission's comments on Revision 2 of the Annotated Outline were formally transmitted on July 30, 1993. These comments were directed toward Chapters 6 and 8. Since Revision 3 addresses Chapter 3, the Commission comments will not be addressed in Revision 3, but will await subsequent revision of Chapters 6 and 8.

On July 20, 1993, the Department provided the Commission with a second set of comments (DOE, 1993h) on the Format and Content Reg. Guide. These comments were developed during the Annotated Outline process, and provide the Commission with feedback on the Format and Content Reg. Guide based on its use and annotation by the Department and its Participants. The comments included suggestions for improvement of the text as well as proposed enhancements to the cross-index between the Format and Content Reg. Guide and 10 CFR Part 60 found in the Reg. Guide, Appendix A. The Department had previously provided comments on the Format and Content Reg. Guide to the Commission on September 26, 1991.

In a related activity, a draft letter report entitled "Feedback to the Site Characterization Program" was completed September 30, 1993. The report summarized experience gained during development of Revision 3 of the Annotated Outline and provided feedback to the site characterization program resulting from the attempt to write sections of a potential license application. In effect, the letter report is the mechanism to initiate formal site characterization program change requests to ensure that information needed for licensing is acquired during site characterization. This is the first in a series of reports that will follow each Annotated Outline revision.

Forecast: Annotated Outline Revision 3 development continues and consists of extensive changes to Chapter 3, The Natural Systems of the Geologic Setting. Revision 3 is scheduled to be delivered to the Commission on November 30, 1993. The letter report providing feedback to the site characterization program based on Revision 3 will be completed in January 1994.

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Subsequent to Revision 3, revisions to the Annotated Outline are planned to be issued on an annual basis. Revision 4 is, therefore, scheduled to be transmitted to the Commission in November 1994. The letter report providing feedback to the site characterization program based on Annotated Outline Revision 4 will be completed in January 1995.

2.1.4 Permits

2.1.4.1 Compliance with Federal Environmental Requirements

The Project uses three Free-Use areas on Bureau of Land Management (hereinafter referred to as "BLM" or "Bureau") land as sources of sand, gravel, and fill material for construction activities. During this reporting period, the Bureau conducted a field inspection of these Free-Use areas. All activities were found to be in compliance with permit requirements.

Consultations continue with Native American tribes and organizations, as specified in the Programmatic Agreement with the Advisory Council on Historic Preservation. One visit to the Yucca Mountain site was conducted for the Native American tribes and organizations.

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: Within the next six months, two additional site visits will be conducted for the Native Americans. There is a potential need for another Free-Use permit for the excavation of sand and gravel for use in conjunction with a concrete batch plant for ESF construction activities.

2.1.4.2 Compliance with State Environmental Requirements.

Water Quality

A permit request for a potable water supply system for the ESF was submitted to, and approved by, the State of Nevada.

Three temporary water appropriation permits, changing the place of use and allowing for testing and pumping at the C-Well Complex, were issued to the Yucca Mountain Site Characterization Project Office (YMPO) by the State of Nevada. These temporary permits did not request any additional water allocation. The total combined appropriation of these three temporary permits, along with the existing permits for USW VH-1, UE-25 J#12, and UE-25 J#13, will still not exceed the annual limit of $5.3 \times 10^5 \text{ m}^3$.

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A request for permit to construct a sewage disposal system for the ESF was also submitted to the State. This request was subsequently put on hold by YMPO because of a change in location of the proposed leachate field.

Air Quality

Air Quality Permits to Construct and modifications to those permits were issued for air compressors and the following drill rig/dust collector systems: the LM-300, the Failing-500, and the CME-850. Air Quality Permits to Construct were submitted, and are pending, for the ESF Rock Conveyor System and for a Failing Stratmaster Drill Rig/Dust Collection system. The Air Quality Permit to Construct and Operate the Kolburg Plant at the Fortymile Wash borrow area was not renewed. The need to sort material was no longer required at that location. Material will be sorted at Borrow Area #1.

Drilling and Tracers

Waivers to drill were issued for monitoring wells USW SD-12 and USW SRG-5/USW SD-11. Underground Injection Control tracer permit modifications were received for the C-Well Complex. Approvals were received for the use of tracers in boreholes UE-25 NRG#2b, USW SRG-5/USW SD-11 (phases 1 and 2), UE-25 NRG#7, and USW SD-12.

Forecast: The YMP permit applications projected over the next six months include: five air quality permits including a permit for the concrete batch plant, four tracer injection approvals under the Underground Injection Control permit, a sewage disposal permit, and approval for use of a portable holding tank for sewage disposal.

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 activity. A Participant request to initiate site characterization activity is a prerequisite for the activity and requires Land Acquisition personnel review, processing, and granting of access authorization.

A number of right-of-way applications have been filed with the Bureau for site characterization activities, and an extension application has been filed for N-48602, the largest right-of-way on the Nellis Air Force Range, which expires June 30, 1994.

Twenty-eight Participant requests to initiate site characterization activity were processed during the period. Twenty-five of these requests have been completed and access authorization granted. Of the remaining three requests, one is awaiting the receipt of a right-of-way reservation from the BLM, one is awaiting an operations permit from the Nevada Test Site Office, and one is awaiting additional information from the Participant. Additionally, one Participant request from the last reporting period was completed. This request consisted of five right-of-way applications for seismic stations that were received from the Tonopah

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Resource Area BLM 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 right-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 offices for pump tests in 42 existing wells, and two right-of-way reservations from the Caliente Resource Area office for volcanism studies at both Sleeping Butte and Crater Flat.

2.1.6 Quality Assurance Program

2.1.6.1 Program Activity

During the reporting period, the DOE/Office of Geologic Disposal Yucca Mountain Quality Assurance Division conducted nine audits. The audits were conducted of YMPO, Raytheon Services Nevada (RSN), LLNL, Los Alamos, Reynolds Electrical & Engineering Co., Inc., Sandia National Laboratories, Technical and Management Support Services/Science Applications International Corporation, M&O/TRW Environmental Safety Systems Inc., and U.S. Geological Survey (USGS). The audits evaluated the QA programs for compliance with Program requirements and effectiveness of QA program implementation.

The DOE/Office of Geologic Disposal Yucca Mountain Quality Assurance Division also conducted 24 surveillances. The surveillances were conducted to evaluate specific site characterization related activities and as follow-up to verify corrective actions taken to close open deficiencies.

To ensure that the Commission is kept informed of the status of the QA program, bimonthly QA meetings continue to be held with the Commission. These meetings provide a forum for the NRC, OCRWM, Edison Electric Institute, State of Nevada, local governments, and other affected parties to identify and participate in resolution of QA issues. These meetings also provide information on the status, development, and progress of QA-related actions.

As a result of the issuance of the QARD which more specifically defined the applicability of the QA program, and earlier changes made to the process for developing and maintaining the Q-List and the Quality Activities List, the need for a Project-level Quality Activities List was eliminated; selection of QA controls is now determined based on the importance of the item(s) to which the activity is related. The transition to this methodology, along with the direction established in the Determination of Importance and Grading Enhancement Management Plan that Participants are responsible for performing their own classification analyses, led to the development of the Determination of Importance Evaluation process. This process provides for the evaluation of ESF design elements, including the activities associated with their construction and use, to conclude the importance of the item to radiological safety or waste isolation and provide controls appropriate to these conclusions.

2.1.6.2 Management & Operating Contractor Determination of Importance Evaluations

The philosophy for the Determination of Importance Evaluation program is consistent with the QARD and is derived from NRC guidance found in NUREG-1318 (NRC, 1988) (which defines Q-list items based on permanence) and the methods used to ensure that other Q items and activities are subject to appropriate QA controls.

The Determination of Importance Evaluation program consists of methodology for: the evaluation of permanent (e.g., potential repository) or temporary (e.g., ESF) items relative to their importance to radiological safety or importance to waste isolation; the evaluation of potential impacts of activities on items important to safety or waste isolation; and a method for applying appropriate QA controls to these items and activities. The evaluations are performed in accordance with the M&O Design Analysis procedure, Quality Administrative Procedure-3-9, 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).

Input documentation for Determination of Importance Evaluations is provided by the Site Characterization Group (for Test Interference Evaluations), Performance Assessment Group (for Waste Isolation Evaluations), and ESF Design Organizations (for design configuration packages). The interfaces between these organizations are established in accordance with QA procedures for transmittal of design input. Waste Isolation and Test Interference Evaluations are used as a basis for concluding the importance of items and subsequent controls. Completed evaluations, which document this basis information and provide the controls, are transmitted to the design organization for inclusion of these controls within the Basis for Design document. From the document, these controls flow down into design outputs (specifications and drawings) for implementation by the construction contractor.

Prior to the transition of this function from RSN to the M&O, RSN Classification Analyses were completed for the ESF Topsoil Storage Area and Access Roads. Since that transition (December 1992) eight other design elements have been evaluated:

- ESF North Portal Pad
- ESF Stormwater System
- ESF Rock Storage Area
- ESF Starter Tunnel - Steel Arch Section
- ESF Starter Tunnel - Drill and Blast Section (incorporating the North Ramp Test Alcove #1)
- ESF Switchgear Building

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- ESF Water Supply System
- ESF Water Distribution System

Determination of Importance Evaluations are required prior to implementation of a particular design element. Most of the evaluations listed above were prepared for ESF Package 1A; as a result of the timing of the evaluations, they were prepared, reviewed, and approved after the 1A 90% Design Review. These evaluations were used as justification for removing "To-Be-Verified" indications from the 1A design (these indications were placed to prevent implementation of a given design element prior to completion of its classification analysis or Determination of Importance Evaluation). For subsequent design elements, the evaluations are intended to be presented for review as part of the 50% and 90% design reviews for the associated design packages.

Forecast: Work is in progress on revisions to the M&O QA classification procedure (Quality Administrative Procedure-2-3) to allow for its use on the MGDS. This procedure will provide the basis for the M&O QA classification process, which is currently performed according to YMPO procedure Administrative Procedure-6.17Q.

Also anticipated in this fiscal year is a revision to the Determination of Importance Evaluation Plan to incorporate additional evaluation methodologies as they are required and developed to support QA classification analyses. Upon revision, this document will be renamed the QA Classification Methodology Document.

2.1.6.3 Q-List and Management Control-List

The Project Q-List (DOE, 1990a) and Management Control (MC)-List (DOE, 1993i) are used to tabulate permanent items. The Q-List describes those permanent items determined to be important to radiological safety or waste isolation and, therefore, subject to the requirements of the QARD; the MC-List describes those permanent items determined not to be important to radiological safety or waste isolation and subject only to normal management and design controls. Each document describes the basis for the conclusion of a specific item's importance.

An initial evaluation of the natural barriers was performed. This evaluation utilized a systematic approach to provide justifications consistent with the current progress of site characterization. The approach involved evaluating each barrier for its capability to perform one or more potential waste isolation functions, determining the characteristics of that barrier which are needed to perform these functions, and identifying a lateral extent over which these functions would be important to the overall performance of the MGDS. This information was then added to each natural barrier as part of Section 2 of the Q-List. The Q-List will continue to be updated as site characterization data becomes available for use in more detailed performance analyses.

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Both documents reflect the conclusions of Determination of Importance Evaluations performed during this reporting period; the Q-List also still contains items originally placed there by direct inclusion in the original version of the document. Items currently on the Q-List by direct inclusion require documented analysis to warrant their removal. An Assessment Team made up of technical experts from the various Project Participants evaluates recommended changes to the Q-List.

The changes made to the Q- and MC-Lists during this reporting period include:

Q-List (Revision 1)

- Revision and clarification of the introduction and definitions sections
- Revisions to format for Section 1 (Engineered Items Important to Safety) and Section 2 (Items Important To Waste Isolation)
- Clarification of the importance of specific components of the ESF Starter Tunnel and associated ground support system in response to that item's Determination of Importance Evaluation
- Deletion of Exploratory Shaft Facility and its replacement with Exploratory Studies Facility Optional Access

Q-List (Revision 2)

- Moved the natural barriers to items important to waste isolation, defined the lateral extent of each barrier, added functions and characteristics to each barrier, and removed alluvium from the Q-List

MC-List (Revision 0)

- Initial issue

MC-List (Revision 1)

- Added unconsolidated surficial materials, including alluvium

The revisions to the Q-list were based in part on recommendations for change as a result of the Determination of Importance Evaluations performed during this reporting period. In addition, Revision 2 of the Q-List is currently in review. Recommendations for changes to these lists are evaluated in accordance with Administrative Procedure-6.17Q.

Forecast: Acceptance of the M&O Classification procedure (Quality Administrative Procedure-2-3) by OCRWM QA is anticipated in the first half of FY 1994. In-progress Determination of Importance Evaluations for ESF design packages will be completed and development of evaluations for subsequent design packages will continue. The QA

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Classification Methodology Document will be developed for description of subsequent methodologies for supporting analyses.

2.1.6.4 Design Control Improvement Plan

During this reporting period the need to evaluate the M&O design control process and procedures was identified. This evaluation was initiated to coordinate and document corrective actions planned in response to QA verification and deficiency documents dated from January 1993 to the present. As part of this evaluation, various areas were identified where process improvement was necessary. The specific evaluation and improvement actions are documented in the "M&O MGDS Design Control Improvement Plan" (CRWMS M&O, 1993c).

The purpose of the improvement plan is to coordinate the implementation of corrective actions to: provide immediate response to open Corrective Action Reports, ensure that conditions immediately adverse to quality (if any) are 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 are divided into three areas: near-term or immediate actions; longer-term, broader process improvement actions; and improvement verification or confirmation actions. It is the intent of these action items to provide for a broad review of the entire design control process to identify weaknesses and resolve them in order to prevent future problems. During the reporting period, the majority of the near-term action items were resolved and closed out, the longer-term improvement actions were initiated, and preliminary scope and schedules were developed for verification activities. The status of the action items associated with the improvement plan is as follows:

	Identified	Complete	Pending	Ongoing*
Immediate Actions	33	23	7	3
Process Improvement Actions	16	6	6	4
Verification/Confirmation Actions	5	N/A	3	2

* Ongoing signifies those actions which will continue indefinitely (e.g., verification of root cause of corrective action requests).

Forecast: Completion and close-out of the Design Control Improvement action items, including verification of the actions and evaluation of their effectiveness, is anticipated within FY 1994. Several "ongoing" action items have resulted and will result in permanent changes to the design control process.

2.1.7 Document Hierarchy

2.1.7.1 Site Characterization Program Baseline

The Site Characterization Program Baseline (SCPB) (DOE, 1993a) identifies the baselined site characterization program and provides a means to demonstrate traceability of changes in the objectives of site characterization studies. All revisions to the SCPB are reviewed, approved, and controlled in accordance with approved change control procedures.

SCPB Revision History

Revision 0, Issued February 22, 1991

Revision 1, Issued April 5, 1991: Updated information related to the ESF 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) (hereinafter referred to as "ESF Alternatives Study")

Revision 2, Issued October 2, 1991: Documented revised plans for testing in SCP 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 Hydro-chemistry." 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 ESF 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.

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Revision 9, Issued October 2, 1992: Changed scope of SCPB to divide controlled areas between SCPB and Study Plans; place parameter tables in separate controlled document; and remove hypothesis testing tables and analyses supporting test control from SCPB. 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, 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 SCPB were issued. However, several new technical requirements documents were developed and approved. These are discussed in detail later in this section. One of these documents, the Site Design and Test Requirements Document, captures the test requirements for the site characterization program. These requirements are also contained in the SCPB. The Project is in the process of evaluating the scope and content of the SCPB and will likely revise it based on this evaluation.

2.1.7.2 Regulatory Controls

The Program must comply with a large number of requirements imposed upon it by many laws, regulations, orders, and standards. To facilitate compliance with this wide range of requirements, the Project has developed a system of identifying and documenting the requirements in "System Requirements" and "Design Requirements" documents.

The Program had in place an existing suite of documents addressing regulatory controls for the majority of the system prior to the development of the System Requirements and Design Requirements documents. The new hierarchy of requirements documents (Figure 2.1-3) provides a single top level document, the Civilian Radioactive Waste Management System Requirements Document (DOE, 1992a), and rigorously enforces a structured allocation and requirements traceability process for all technical requirements. The new hierarchy also establishes top level interface requirements in the System Requirements documents for each major system element between all other interfacing system elements. An Interface Specification serves to capture and describe interfaces between each of the major system elements.

The Project recently approved five new technical documents in the technical document hierarchy. These Design Requirements Documents are identified on the Document Hierarchy. The Design Requirements Documents are: (1) the Repository Design Requirements Document (DOE, 1993c), (2) the Site Design and Test Requirements Document (DOE, 1993j), (3) the Engineered Barrier Design Requirements Document (DOE, 1993d), (4) the Exploratory Studies Facility Design Requirements Document (DOE, 1993b), and (5) the Surface-Based Testing Facilities Requirements Document (DOE, 1993k).

OCRWMDH.086/7-14-92

Figure 2.1-3. OCRWM Document Hierarchy

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The Repository, Site Design and Test, and Engineered Barrier Design Requirements Documents derive their requirements from their parent document, the Mined Geologic Disposal System Requirements Document (DOE, 1993e), which was approved by the Change Control Board in January 1993. The Mined Geologic Disposal System Requirements Document derives its requirements in turn from the Civilian Radioactive Waste Management System Requirements Document. The Exploratory Studies Facility Design Requirements Document and the Surface-Based Test Facilities Requirements Document derive their requirements from their parent document, the Site Design and Test Requirements Document. Each Design Requirements Document provides (in Section 6) a matrix that identifies the source of every requirement contained in the document. This section also provides a cross reference for the location of each requirement in the parent document correlated to the location in the Design Requirements Document. Each Design Requirements Document serves a specific purpose in the MGDS.

Repository Design Requirements Document

This document defines the Project-level requirements for the design of a repository segment consistent with the Mined Geologic Disposal System Requirements Document. These requirements include design, operation, and decommissioning requirements to the extent that they impact the physical design and development of the repository. The document also presents an overall description of the repository segment and its functions (derived using the functional analysis documented by the Mined Geologic Disposal System Requirements Document as a starting point). In addition, the Project-level interfaces of the repository segment are identified. As such, the Repository Design Requirements Document provides the technical baseline for the design of the repository. While the repository segment may evolve and change through the design process, changes must occur in a controlled manner that ensures the Civilian Radioactive Waste Management System remains integrated. In doing so, the Civilian Radioactive Waste Management System Requirements Document, Mined Geologic Disposal System Requirements Document, and Repository Design Requirements Document will be revised to capture the changes.

The Repository Design Requirements Document captures, as appropriate, all of the requirements from the old hierarchy Repository Design Requirements Document. The retention of the old hierarchy repository design requirements is documented in a horizontal trace matrix which makes up a part of the QA records package for this document.

Site Design and Test Requirements Document

This document establishes the functional descriptions and performance requirements for all site characterization activities. The document also presents an overall description of the site segment and its functions, based on the functional analysis documented by the Mined Geologic Disposal System Requirements Document. The site characterization program requirements for investigations, studies and activities are established and presented in the form of objectives. Design requirements for test support and other facilities are established in

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this document and are allocated to the ESF in the Exploratory Studies Facility Design Requirements Document and/or the Surface-Based Testing Facilities in the Surface-Based Testing Facilities Requirements Document. The Site Design and Test Requirements Document is also the parent document for the Test Requirements Document. The scope and contents of the Test Requirements Document are to be determined. In addition, the interface requirements of the site segment to engineered barrier segment, and repository segment are defined. These interface requirements are identified and allocated to the site segment in the Mined Geologic Disposal System Requirements Document.

The Site Design and Test Requirements Document captures the testing objectives previously controlled in the SCPB (DOE, 1993a). These objectives include the original SCP section references and are included in a traceability matrix in Section 6 of the Site Design and Test Requirements Document.

Engineered Barrier Design Requirements Document

This document describes the functions to be performed by and establishes the requirements for the engineered barrier segment. The engineered barrier segment is one of the segments of the MGDS for the permanent disposal of spent nuclear fuel, commercial high-level radioactive waste, and defense high-level radioactive waste. The primary function of the engineered barrier segment is to isolate waste, first by containing waste within the waste package and then, together with the geologic setting, isolating radioactive waste from the accessible environment. The requirements for the engineered barrier segment are derived from the requirements contained in the Mined Geologic Disposal System Requirements Document. The major components of the engineered barrier segment consist of the waste packages, the underground facility, any backfill placed in emplacement drifts, and emplacement hardware used to support and protect the emplaced waste packages. The underground facility portion of the engineered barrier segment has been identified as an interface with the repository segment. The Engineered Barrier Design Requirements Document allocates the requirements from the Mined Geologic Disposal System Requirements Document, expands and interprets those requirements, and defines the segment/component level requirements for the design of the engineered barrier segment. The document also presents a description of the engineered barrier segment, its functions, its components, and the requirements of these components. In addition, the interface requirements of the engineered barrier segment to geologic setting, site segment, repository segment, waste acceptance, and transportation are defined. These interface requirements are identified and contained in the engineered barrier segment in the Mined Geologic Disposal System Requirements Document.

Exploratory Studies Facility Design Requirements Document

This document establishes the requirements and constraints imposed on the development of the design for the ESF. The purpose of this requirement document is to establish the design requirements for facilities, underground openings, utilities, and services as part of the ESF required to support the subsurface in situ tests specified in the Site Design

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and Test Requirements Document. The Exploratory Studies Facility Design Requirements Document includes requirements for both surface and underground construction, utilities, and services.

This document captures all of the appropriate requirements from the previous Exploratory Studies Facility Design Requirements Document. As with the Repository Design Requirements Document, a horizontal traceability matrix was developed and is included in the QA records package.

The latest revision to this document is Revision 0, which is the version implemented with the new hierarchy. Prior to Revision 0, two Interim Change Notices were issued to Revision 7/2/92.

Interim Change Notice-1 (March 29, 1993) - Removed the requirement for chemical tracers in surface dust suppression water to prevent meteoric precipitation from mobilizing tracers on the ground surface and depositing it elsewhere. This change was made to bring the Exploratory Studies Facility Design Requirements into conformance with the SCPB.

Interim Change Notice-2 (April 30, 1993) - Removed the requirement for chemical tracers in water used for fill compaction and general surface construction and also reinstated the requirements from the California Tunnel Safety Code.

Surface-Based Testing Facilities Requirements Document

This document establishes the requirements and basic constraints imposed on the development of the surface-based testing facilities in support of site characterization at Yucca Mountain. The surface-based testing activities will include sampling and testing to be carried out from the ground surface. This document identifies requirements for facilities needed to support these activities, as well as any other surface-based activity that may affect the geologic or waste isolation characteristics of the site. The purpose of this document is to capture the requirements from the Site Design and Test Requirements Document and define the subsystem-level requirements for the design of the surface-based testing facilities. This document also presents a description of the surface-based testing facilities, its functions, its subsystems/components, and the requirements contained in the subsystems. In addition, the interface requirements of the surface-based testing facilities are defined.

This document contains the appropriate requirements from the old hierarchy Surface-Based Testing Facilities Requirements document and documents horizontal traceability in a matrix included in the QA records package.

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2.1.7.3 Management Controls

As with the Regulatory Controls area, the Program revised the structure of the management document hierarchy, and the Program-Level Management Controls documents are in the process of being revised or new documents developed to respond to these changes.

The Project is also in the process of revising or developing new documents to respond to the above changes. The Project Plan has been developed and is in review. The Project Management Plan has been revised and is on hold pending approval of the Project Plan. The Advanced Acquisition and Assistance Plan has been revised and is also on hold pending approval of the Project Plan. The Configuration Management Plan is in the process of being revised. The Test and Evaluation Plan (CRWMS M&O, 1993d) was revised and approved. The Systems Engineering Management Plan has been revised and is in the comment resolution process.

The Test and Evaluation Plan defines the controls and process to be used for the planning, implementation, and evaluation of scientific investigations of the Yucca Mountain site.

In accordance with the Test and Evaluation Plan, planning of scientific investigations is achieved by implementing the Test Planning Process, Administrative Procedure-5.32Q.

Likewise, implementation of scientific investigations is achieved through the Field Work Activation Process, Administrative Procedure-5.21Q.

Together these two processes constitute the means by which the first two elements of the Test and Evaluation Plan are achieved. The third element, test evaluation, is performed under the specific procedures of the individual Project Participants responsible for site investigations.

2.1.8 Environmental Audit Program

2.1.8.1 Audits

In accordance with the requirements of the Environmental Regulatory Compliance Plan (DOE, 1988b) an Environmental Audit program was established. Environmental audit program activities during this reporting period consisted of comprehensive environmental audits of Desert Research Institute (Audit FY93B) June 14-18, 1993, and USGS (Audit FY93C) September 20-24, 1993. The audits were directed by the YMPO Project and Operations Control Branch and conducted by the Technical and Management Support Services Environmental Compliance and Permitting Department. The purpose of the audits is to ensure that Project Participants conduct their activities in an environmentally safe and sound manner.

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The Environmental Compliance Audit Report for Audit FY93A (SAIC, 1993a), conducted last reporting period, was issued on May 13, 1993. Audit findings for the Desert Research Institute Audit have been reported in an Environmental Compliance Audit Report for Audit FY93B (SAC, 1993b) issued July 8, 1992. A Corrective Action Plan (DRI, 1993) prepared by Desert Research Institute has been approved and is currently undergoing implementation. An Environmental Compliance Audit Report which delineates the findings of the USGS Audit is under development.

Forecast: Implementation of the Corrective Action Plan for Environmental Audit FY93A, conducted in March 1993, will be completed. Three additional comprehensive environmental audits are scheduled in the next six months. There is also one focused special interest audit planned for this period. Audits FY93A and FY93B are expected to be closed out within six months.

2.1.8.2 Surveillances

During this period, approximately 120 environmental surveillances were conducted at the Yucca Mountain site to ensure compliance with environmental, programmatic, and permit requirements. One-third of the surveillances required corrective action and follow-up work; 30 of the follow-up activities were completed.

Forecast: The number of environmental surveillances projected over the next six months is 180.

2.1.8.3 Preactivity Surveys

During the reporting period, 32 land access and environmental compliance activity reviews were completed. This effort involved a total of 96 radiological, archaeological, and biological preactivity surveys. An additional 28 requests to initiate site activity have been received this period. There are currently 18 "open/active" field activities, for which environmental preactivity surveys are being conducted.

Forecast: It is anticipated that approximately 45 land access and environmental compliance activity reviews will be completed in the next six months. This effort will involve an estimated 135 radiological, archaeological, and biological preactivity surveys.

2.1.9 Exploratory Studies Facility Design and Construction

The ESF design and construction activities have progressed significantly during this reporting period. The design change from a shaft-based concept to a drift-based concept reported in Progress Report 8 (DOE, 1993m) has been implemented. The Commission sent a letter, dated August 20, 1993, to the Department, identifying four concerns related to ESF design (NRC, 1993). A DOE-NRC Management Meeting was held on September 17, 1993,

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to discuss the ESF design issue and a DOE-NRC Technical Exchange on ESF design has been scheduled for October 5-6, 1993. In the August 20, 1993 letter, NRC requested that DOE identify the latest revision of controlled documents relevant to ESF design and construction. These documents, discussed in this and other sections of this Progress Report are:

1. SCPB (YMP/CM-0011), Revision 10 (DOE, 1993a)
2. ESF Technical Baseline (YMP/CM-0016), Revision 2 (DOE, 1993n)
3. ESF Plan (YMP/93-007), Revision 0 (DOE, 1993o)
4. Plan for Phased Approach to ESF Design, Development and Implementation (YMP/91-13) (DOE, 1991a)
5. ESF Design Requirements Document (YMP/CM-0019), Revision 0 (DOE, 1993b)
6. Site Design and Test Requirements Document (YMP/CM-0021), Revision 0 (DOE, 1993j)

As reported in Progress Report 8, changing the baseline construction logic from four Tunnel Boring Machines to two machines was considered. The sequence of excavation presented in Progress Report 8 has not changed. The plan is to continue excavation down the North Ramp, along the main Topopah Spring level drift and up the South Ramp to daylight.

2.1.9.1 Exploratory Studies Facility Design

Design Activities have been fully transitioned from RSN to the M&O. Design Package 1A was originally developed by RSN, and subsequently transitioned to the M&O, and has been released for construction. Ongoing modifications in the form of Field Change Requests and Change Requests continue to be made against Package 1A. Package 1A consists of the following elements:

- North Portal pad
- Topsoil storage area
- ESF access road
- Sewage collection and treatment system
- North Portal pad water supply system
- Tunnel Boring Machine Starter Tunnel
- Rock storage area
- Switchgear building

The balance of Package 1 was further split into Packages 1B, 1C, and 1D. This subdivision was made in an effort to support construction initiatives. Design Packages 1B, 1C, and 1D have all undergone a 50% design review during this period. At the time of the

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50% review the three Package 1 components were consolidated. Package 1B has also undergone a 90% design review during this period. It is planned for Package 1B to be released during the first quarter of FY 1994. Package 1B consists of the following elements:

- Change house building (contains other services to include portal control)
- Shop building
- Sanitary sewer system
- Power distribution
- Water distribution system
- Subsurface wastewater system
- H-road, site grading and paving

Elements of Package 1B will be constructed in FY 1994.

Package 1C, in design during this reporting period, will also be completed in FY 1994 and consists of the following elements:

- Muck storage area
- Power substation pad
- Site lighting
- Conveyor maintenance access road
- Stand-by power
- Fuel storage
- Compressed air system

Package 1D, in design during this reporting period, will be completed in FY 1995 and consists of the following elements:

- Warehouse
- Covered storage
- Off site communications system
- Operations building
- Steam cleaning system

The M&O initiated the design of Subsurface Package 2, North Ramp, during this reporting period. As with Design Package 1, Package 2 underwent a complete 50% design review and subsequently was divided into three components: Package 2A, 2B, and 2C. Package 2A underwent design and a 90% review during this reporting period and will be issued for construction in the first quarter of FY 1994. Originally, Package 2A consisted of the following elements:

- Starter Tunnel extension to Bow Ridge fault (drill and blast methodology)
- Surface and subsurface conveyor specifications including arrangement drawings
- Electrical switchgear, transformers, and power center procurement specifications
- Tunnel Boring Machine operation specification
- Transportation alternatives study

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Due to projected budget constraints in FY 1994 the Starter Tunnel extension was cancelled.

Package 2B, in design during this period, will undergo a 90% design review in the first quarter of FY 1994 and will subsequently be issued for construction. Package 2B 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

Package 2C, in design during this period, will undergo a 90% design review in the first quarter of FY 1994 and will subsequently be issued for construction. Package 2C consists of the following elements:

- Concrete and structural steel for surface and subsurface conveyors
- North Ramp to Topopah Spring Level excavation specification and drawings
- Remaining utility systems for North Ramp
- Electrical power, lighting, and grounding
- Equipment installation specifications

During this reporting period E I Design activities included a proposed enhancement of the ESF configuration, studies of the transportation of personnel, studies for the procurement of the Tunnel Boring Machine, and several trade-off studies. Title II design of the temporary 69-kV system was completed during this reporting period and was released for construction.

Forecast: It is planned for Package 1B to be released during the first quarter of FY 1994. Package 1C, in design during this reporting period, will also be completed in FY 1994. Package 1D, in design during this reporting period, will be completed in FY 1995. The analysis to demonstrate acceptability and the impacts of the ESF enhancements will be completed and dispositioned by DOE. Package 2A will be issued for construction in the first quarter of FY 1994. Package 2B will undergo a 90% design review in the first quarter of FY 1994 and will subsequently be issued for construction. Package 2C will undergo a 90% design review in the first quarter of FY 1994 and will subsequently be issued for construction.

2.1.9.2 Exploratory Studies Facility Construction

The most notable activity during this reporting period was the excavation and completion of the 60-m Starter Tunnel which will be used to launch the Tunnel Boring

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Machine. The excavation started on April 2, 1993, and was completed September 9, 1993. In conjunction with the excavation, the Principal Investigators mapped the tunnel as it progressed.

Other significant construction accomplishments include: the access road base to the North Portal pad, the drainage channel over the tunnel portal, and grading of the North Portal pad. The 69-kV power system work was initiated and is in progress during this period. Power poles and lines have been installed. Power up is planned prior to December 24, 1993.

The contract for the 7.6-m Tunnel Boring Machine was awarded to Construction and Tunneling Services, Inc. of Kent, Washington, on June 4, 1993. Delivery of the Tunnel Boring Machine is on schedule for April 1994.

During this period the underground operating contract was awarded to a joint venture of Peter Kiewit and Parsons Brinckerhoff. The operator is a subcontractor to the Constructor, Reynolds Electrical & Engineering Co., Inc. Peter Kiewit and Parsons Brinckerhoff will perform assembly and operation of the Tunnel Boring Machine as well as some of the other underground construction work.

During this period extensive planning was performed for upcoming work. The planning included a comprehensive schedule that will allow installation of adequate site infrastructure to enable assembly and startup of the Tunnel Boring Machine during the next reporting period. Excavation of the first test alcove is in progress and will be completed during the next reporting period. The approximate centerline location of the alcove is 40 m down the Starter Tunnel and the alignment of the alcove is approximately along a northeast to southwest axis.

Forecast: Infrastructure to be installed during the next reporting period will include most of the buried utilities on the south side of the portal pad and in the immediate area in front of the portal itself. In addition, the off-pad water system will be developed, as well as temporary office space for all key scientific and engineering personnel. The foundations for the switchgear building will be emplaced as well as the switchgear building and the electrical systems therein. Assembly of the Tunnel Boring Machine is planned for the third quarter of FY 1994. Operations are planned for the end of the fiscal year.

2.1.9.3 Proposed Enhancements To The Current Exploratory Studies Facility Configuration

Introduction

The current ESF design is derived from Option 30 of the ESF Alternatives Study (Dennis, 1991). One of its primary features is a main drift connecting the lower ends of the North and South Ramps in the Topopah Spring Level (see Figure 2.1-4). This main drift is oriented at N 34° E, coincident with the alignment of one of the proposed repository main access drifts as shown in the Exploratory Studies Facility Technical Baseline (DOE, 1993n).

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Figure 2.1-4. Baseline ESF Layout

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Recent work on the Advanced Conceptual Design for the potential repository, coupled with concerns on the part of the Review Board and current Project Participants has led to a proposed enhancement to the Option 30-based ESF design. The proposed change would:

- Maintain the portal location and the horizontal alignment of the North Ramp.
- Result in grades less than 3.0 percent in the initial loop formed by the North Ramp - surface to Topopah Spring Level, the main drift, and the South Ramp - Topopah Spring Level to surface. This would allow the use of conventional rail haulage for the excavation in the Topopah Spring Level ramps and main drift, and would preserve the option to use conventional rail haulage in the potential repository.
- Preserve repository layout flexibility to a much greater extent than the current orientation. Flexibility is maintained because:
 - The main drift would cross the repository block at a point stratigraphically higher in the densely welded devitrified lithophysal-poor tuff (TSw2) of the Topopah Spring Member, thereby allowing repository designers to situate drifts below this main drift if future repository design work indicates that the drift is not useful for incorporation into a repository design. This alternative would not have the performance concerns that would result from having a drift situated below potential repository drifts.
 - The main drift would be adjacent to the Ghost Dance fault along much of its length. This portion of the block may be of limited value to the potential repository if it is determined that no waste can be emplaced in the fault zone.
 - Cross drifting within the TSw2 is performed at the ends of the block - not through the center where the arrangement and orientation of potential repository main and emplacement drifts are unknown at this time.
- Better accommodate repository layouts that: (1) have flat grades in emplacement drifts and 2 percent maximum grades in all other "in-block" drifts, (2) do not require emplacement drifts to cross the Ghost Dance fault, and (3) will not eliminate repository concepts identified in the development of Option 30.
- Allow repository emplacement drifts, particularly in the primary block situated west of the Ghost Dance fault, to be placed farther above the water table. (This was identified as a Favorable Feature in the ESF Alternatives Study [Dennis, 1991]; Option 30 previously did not have this feature.)
- Maintain the full scope of site suitability and characterization testing provided in Option 30. In addition, critical characterization of the Ghost Dance fault, at multiple points along the main drift, is easily provided for without compromising potential repository flexibility. The ability to characterize the TSw2, and evaluate potential north-south trending features, is provided at both the north and south ends

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of the block, with added potential to investigate the Solitario Canyon fault within the potential repository horizon via an extension of the North Ramp.

The reoriented ESF layout would result in a longer North Ramp, a shorter South Ramp, and a main drift of about the same length as the current layout (see Figure 2.1-5). The main drift would be oriented approximately north-south and would run subparallel to, and west of, the Ghost Dance fault, with a nominal 122-m offset. The Main Test Area would be located in the same basic area as in the current layout. The initial "loop" would be approximately 7791 m in length, or about 200 m shorter than with the current layout.

Background of the Development of the Baseline ESF Concept

The ESF concept presented in the SCP consisted of two 3.6-m-diameter vertical shafts and approximately 1829 m of drifting in the Topopah Spring level. The drifting was localized in the northeast quadrant of the potential repository block.

Comments from the Commission and the Review Board centered on the excavation method (drill and blast versus mechanical excavation), the Review Board's preference for ramp access over shaft access, and the localized, limited nature of the at-depth drifting.

During 1990, the Project undertook the ESF Alternatives Study to provide a comprehensive assessment of options for development of an ESF, and how those options would fit into a potential repository. Thirty-four options were developed and evaluated. The options included shaft access, ramp access, and combinations of both. Repository concepts were developed for each option to ensure that the requirements of 10 CFR 60.21(c)(1)(ii)(D) were adequately addressed. Option 30 emerged as the highest ranked option at the conclusion of the study. Following the completion of the ESF Alternatives Study, several modifications to Option 30 were made, incorporating features of other highly ranked options. This process is described in "Documentation of the Evaluation of Findings of the ESFAS Used to Develop a Reference Design Concept" (DOE, 1991b). The resulting "Modified Option 30" formed the basis for the start of Title I Design. It is important to note that in this evaluation the following wording was included to prompt exactly the type of enhancements now being proposed:

"Option 30 did not rank high in the favorable feature of showing maximum distance from the waste emplacement level to the water table. The possibility of increasing the distance between the waste emplacement level and the water table will be addressed during the Title II Design. The favorable feature of avoiding emplacement drifts crossing Ghost Dance fault was not marked high for this option; this will be addressed in the repository design."

2.1-56

Figure 2.1-5. Enhanced ESF Layout

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Factors Contributing to a Proposed Reorientation

Repository Design Flexibility. The Advanced Conceptual Design of the potential repository began on October 1, 1992. Consideration of various conceptual repository layouts has led to the conclusion that an ESF main drift which runs parallel, and in close proximity to, the Ghost Dance fault would be advantageous from a repository design standpoint. This arrangement would allow the repository designers a large degree of flexibility with respect to alternative layouts, especially those layouts which allow flat (or nearly flat) slopes in the emplacement drifts and accesses, and those which avoid having emplacement drifts cross the fault.

Maintenance of the Conventional Rail Haulage Option. Members of the Review Board have commented frequently, most recently in their "Sixth Report To The U.S. Congress and The U.S. Secretary of Energy," (NWTRB, 1992), that they feel the gradients in the current ESF are too steep, and that steps should be taken to reduce the slopes to those that can accommodate conventional rail haulage.

Availability of New Data on Contact Elevation. The Soil and Rock Properties portion of the surface-based testing program has been under way since early 1992, and results from the drilling of the NRG holes are being incorporated into the Project's data base. Results from the USW NRG-6 hole have been incorporated into the Interactive Graphics Information System geologic model and used to project the contact elevation between the densely welded devitrified lithophysal-rich tuff (TSw1), upper portion, Topopah Spring Member and TSw2. The elevation of this contact in the north end of the potential repository block is an important factor in the underground layout, as it influences the gradient of the North Ramp; the location of repository emplacement and perimeter drifts; and the main Topopah Spring level drift. Recent information suggests that the contact elevation is somewhat higher (15 m) than that used to develop the Title I ESF layout, or a total of approximately 58 m higher than original projections which were available in 1984 when the basic orientation of the main repository access drifts (current Topopah Spring level main drift) was selected.

Descriptions of the Current Concept and Proposed Modification

Current ESF Description. The ESF design as it currently exists is shown in the Exploratory Studies Facility Technical Baseline (DOE, 1993n). The design consists of two inclined ramps, north and south, from the surface to the potential repository horizon (TSw2). The North Ramp slopes at -6.8 percent while the South Ramp is at -1.8 percent. The bottoms of these two ramps are connected by a main Topopah Spring level drift. This drift is oriented at N 34° E and slopes at +4.7 percent to the south. The Main Test Area is located in the north end of the potential repository block on the east side of the Ghost Dance fault. An exploratory drift is planned which will extend eastward from the Main Test Area to the imbricate fault zone, which is assumed to bound the potential repository block to the northeast. Two cross drifts are planned. The east cross drift will start from the Topopah Spring level main drift, penetrate the Ghost Dance fault, and extend to the eastern limit of the

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potential repository. The west drift will originate in the Topopah Spring level main drift and extend to the west side of the potential repository block.

A second set of excavations is planned for exploration and testing in the underlying Calico Hills unit. These excavations will include two ramps, north and south, which originate in the lower reaches of the North and South Ramps. These two ramps will extend down to the Calico Hills level with a gradient currently planned to be -10 percent. The lower ends of these ramps will be connected by a main drift lying directly under the overlying Topopah Spring level main drift. Four side drifts are planned to be driven off the Calico Hills main drift. The Calico Hills imbricate drift will underlie the Topopah Spring level imbricate drift. Two drifts are planned to intersect the Ghost Dance fault and one drift, located at the extreme southern end of the Calico Hills main drift, will explore the zeolitic-vitric contact in the Calico Hills unit and extend to the Solitario Canyon fault.

Table 2.1-2 shows the approximate lengths of drifting in each segment, the planned cross-sectional dimensions, the approximate tonnage of material to be excavated, and the planned excavation mechanism as it was shown in the Title I design.

Reoriented ESF Description. The reoriented ESF layout is consistent with Option 30 in all important aspects, as will be shown below. It has North and South Ramp accesses to the Topopah Spring level, a main Topopah Spring level drift, cross drifting, North and South Ramps to the Calico Hills, and fault exploratory drifting in the Calico Hills. The currently planned underground testing program can be fully implemented in the revised layout, and in some areas can be significantly enhanced.

The North Ramp, surface to Topopah Spring level, is oriented on the same azimuth as the current layout. The slope of the ramp would be -2.05 percent. The length of the ramp to the beginning of the curve is 2190 m. The length of curve is 610 m, and the radius of curvature is 305 m. The diameter of the Topopah Spring level ramps and main drift is the same as the current layout or 7.62 m. The azimuth of the main Topopah Spring level drift varies from 183.8° to 180°. The main drift will run generally parallel to the Ghost Dance fault in two straight segments connected by a short curve. The northern segment, at an azimuth of 183.8° will be 1410 m in length and the south segment, at an azimuth of 180°, will be approximately 1740 m in length. The main drift is to be located a minimum of 122 m west of the projected location of the Ghost Dance fault. The slope of the main drift will vary from +0.5 to +2.63 percent. The length of curve for the South Ramp is 470 m, with a radius of 305 m, and the distance from the curve to the surface is 1360 m. The slope of the south ramp is -2.63 percent to the west and its orientation is more east-west than the current design. The Main Test Area will be in the same area (northeast quadrant) of the potential repository block as the current layout. The main drift is located higher in the TSw2 than the current layout, so the access drifts from the main drift to the Main Test Area will slope down to the east. The imbricate fault drift will be in the same general area as in the current layout.

The east and west cross drifting in the Topopah Spring level will be arranged as follows. The east cross drift will be replaced by two or more extended alcoves driven off the main drift. These alcoves need only be approximately 200-300 m in length to penetrate the

Table 2.1-2. Summary of Baseline ESF Drifting

COMPONENT	LENGTH (METERS)	GRADIENT (%)	VOLUME (CUBIC METERS)	DRIFT CONFIG. (METERS)	DRIVEN BY
North Ramp, Surface to TSL	1,965	-6.9	89,613	7.62 Round	TBM
South Ramp, Surface to TSL	2,785	-1.6	127,009	7.62 Round	TBM
North Ramp to Calico Hills	2,049	-10/-6	48,441	5.49 Round	TBM
South Ramp to Calico Hills	2,240	-10/16	52,957	5.49 Round	TBM
TSL Main Drift	3,239	4.7	147,714	7.62 Round	TBM
TSL East Drift	981	-2.6	21,874	3.7x6.1	MM
TSL West Drift	1,082	2.1	24,126	3.7x6.1	MM
TSL Imbricate Drift	685	0.5	16,194	5.49 Round	TBM
Main Test Area	2,865	N/A	63,882	3.7x6.1	MM
CH Main Drift	3,462	3.8	81,847	5.49 Round	TBM
CH East Ghost Dance Drift	463	0.5	6,194	2.7x4.9	RH
CH West Ghost Dance Drift	328	0.5	4,388	2.7x4.9	RH
CH Imbricate Drift	658	0.5	8,803	2.7x4.9	RH
CH Solitario Drift	671	8.75/0	8,977	2.7x4.9	RH
TOTALS	23,473		702,020		

TBM: TUNNEL BORING MACHINE

MM: MOBILE MINER

RH: ROADHEADER

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Ghost Dance fault. Additional contacts with the fault are readily available because of the close proximity of the main drift to the fault. Based on available surface fault trace information, this layout has the added advantage of not having to cross the fault zone in the main drift. The west cross drifting will be executed by extending the North and South Topopah Spring level Ramps to the west. The North Ramp extension would be driven to the Solitario Canyon fault located at the west boundary of the potential repository block. The South Ramp extension would be driven 2005 m, skirting the edge of the potential repository block at its southern extremity. This will provide cross drifting to explore for north-south trending structures along the north and south extremities of the block while leaving the main body of the block unencumbered by drifting which would significantly restrict subsequent repository design flexibility. Another important aspect of these ramp extensions is that they will traverse a large percentage of the vertical extent of the TSw2, providing the opportunity to test and evaluate throughout much of the unit. This is an important feature, as almost any repository design concept, including the current baseline layout, will be forced to utilize a large portion of the thickness of the TSw2 due to the dip of the rock unit.

Drifting in the Calico Hills will be almost identical to the current layout. The concerns for restriction of the potential repository layout are not present in the Calico Hills and there is no reason to deviate significantly from the current plan. This orientation serves to transect the potential repository block in such a manner that any major north-south trending structural features not evident from the drifting carried out in the North and South Ramp extensions (described above) should be discovered. Ramp access will be provided to reach the Calico Hills from the north and south. A main Calico Hills drift will connect the ramps and provide the starting point for drifting to the imbricate fault zone, the Solitario Canyon fault, and the Ghost Dance fault. The north Calico Hills ramp would be somewhat longer than in the current layout, while the south Calico Hills ramp would be shorter. See Table 2.1-3 for tabulation of the revised drifting.

Advantages of the Reorientation

Maximizes the Vertical Distance From Emplacement Drifts to the Water Table. The location of the main Topopah Spring level drift as high as possible in the TSw2 will allow development of flat potential repository concepts which maximize the vertical distance from emplacement areas to the water table while satisfying the 200-m cover limitation. This is especially evident in the primary block west of the Ghost Dance fault. This was Favorable Feature #7 in the ESF Alternatives Study (Dennis, 1991), and was not present in the repository concept which accompanied Option 30 in the ESF Alternatives Study. This feature is desirable because it would maximize the time for ground-water travel from the emplacement area to the water table.

Allows Potential Repository Layouts Which Avoid Having Emplacement Drifts Crossing the Ghost Dance Fault. The orientation of the main Topopah Spring level drift generally parallel to the Ghost Dance fault would allow the development of repository concepts in which no emplacement drift crosses the Ghost Dance fault. This was Favorable Feature #8 in the ESF Alternatives Study, and was lacking in the repository layout which

Table 2.1-3. Enhanced Layout Drifting

COMPONENT	LENGTH (METERS)	GRADIENT (%)	VOLUME (CUBIC METERS)	DRIFT CONFIG. (METERS)	DRIVEN BY
North Ramp, Surface to TSL	2,800	-2.05	127,693	7.62 Round	TBM
South Ramp, Surface to TSL	1,835	-2.63	83,685	7.62 Round	TBM
North Ramp to Calico Hills	2,295	-10/-6	54,257	5.49 Round	TBM
South Ramp to Calico Hills	1,805	-10/-6	42,673	5.49 Round	TBM
TSL Main Drift	3,155	+0.5/2.0/+2.63	143,883	7.62 Round	TBM
TSL North Ramp Extension	1,615	-1.0/+0.5	73,652	7.62 Round	TBM
TSL South Ramp Extension	2,005	-0.89/-0.77	91,438	7.62 Round	TBM
TSL Imbricate Drift	1,275	N/A	30,143	5.49 Round	TBM
TSL Ghost Dance Drifts (2)	420	+0.5	9,365	3.7x6.1	D&B
Main Test Area	2,865	N/A	63,882	3.7x6.1	MM
CH Main Drift	3,415	3.8	80,736	5.49 Round	TBM
CH East Ghost Dance Drift	465	0.5	6,221	2.7x4.9	RH
CH West Ghost Dance Drift	330	0.5	4,415	2.7x4.9	RH
CH Imbricate Drift	655	0.5	8,763	2.7x4.9	RH
CH Solitario	670	8.75/0	8,964	2.7x4.9	RH
TOTALS	25,605		829,768		

TBM: TUNNEL BORING MACHINE MM: MOBILE MINER RH: ROADHEADER D&B: DRILL & BLAST

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supported Option 30. This feature is desirable because it would minimize the amount of excavation in the fault zone, and would result in less wasted emplacement drift footage, and would negate potential performance concerns which relate to emplacement drifts intersecting one of the more prominent faults in the area.

Preserves the Conventional Rail Haulage Option. The ability to utilize conventional rail haulage in the Topopah Spring level ramps and main drift is a distinct advantage. This would be true during the construction and operation of the ESF, and becomes an even more important consideration in the construction and operation of a potential repository. The important factor is that, by providing tunnels with gradients of less than 3 percent, the ESF would not *preclude* the use of rail haulage. It is not yet known what waste haulage concept will be selected for the potential repository, but, if the construction of ramps and drifts which could become a part of the potential repository is allowed to proceed at the currently designed gradients of 6.9 and 4.7 percent, the conventional rail haulage option will be excluded from consideration. In light of current waste package Advanced Conceptual Design work, which is evaluating very large and heavy package concepts, the use of conventional rail becomes even more appropriate because of the ability of rail to handle heavier loads. Simply stated, the use of flatter grades does not eliminate any type of standard haulage concept while the use of steeper grades does eliminate conventional rail. This idea is stated in the Review Board's Recommendation #5 in its Sixth Report to Congress.

Preserves Potential Repository Design Flexibility. The orientation of the current ESF main drift is a product of earlier potential repository design arrangements in which the main entries bisect the long axis of the block and in which the average slopes of both the main and submain drifts would be approximately the same. This allowed development of emplacement entries or panels of about the same length off each side of the mains, and tended to minimize the total length of main entry footage required. Orientation of the primary and secondary jointing systems was also a factor in the selection of the arrangement. The horizontal location of the TSw2 entry point for the waste ramp and the orientation of the main drifts can be traced back to a study on a phased approach to repository construction which was performed in 1984.

The current repository concept does not consider the Ghost Dance fault to be a constraining factor in the development of the layout. Such a concept requires the Ghost Dance fault to be penetrated at least 50 to 60 times during the construction of a potential repository. In addition to imposing potential performance concerns, the emplacement entry footage in and near the fault would be unusable if emplacement were precluded in fault areas.

A potential repository concept, developed in conjunction with the proposed refinement to the current ESF layout, and which does not require repeated penetrations of the Ghost Dance fault, is shown in Figure 2.1-6. This concept uses the western part of the potential repository block, lying between the Ghost Dance fault and the Solitario Canyon fault, as the primary emplacement area. If the local areal power density ultimately selected for the potential repository equals or exceeds 185 kW/ha (75 kW/acre), this portion of the block should suffice for the entire waste inventory. This compares to a local areal power density of approximately 173 kW/ha (70 kW/acre) in the Site Characterization Plan - Conceptual Design

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Figure 2.1-6. Single Block Repository Concept

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Report (SNL, 1987) layout, and assumes the same 65-MW spent fuel waste stream. If the east portion of the block were needed, it would be developed from main drifts driven from the North and South Ramps along the eastern side of the Ghost Dance fault, as shown in Figure 2.1-7. This two block configuration would accommodate a local areal power density of approximately 148 kW/ha (60 kW/acre). This type of concept has been generally referred to in the Program as a "step block" concept. It minimizes to a great extent the number of penetrations required through the fault, can be developed at grades which would allow conventional rail haulage, and allows the emplacement drifts to be constructed absolutely horizontal, or at whatever slope is determined to be advantageous for drainage.

An important point to consider is that the reoriented ESF layout does not preclude any known repository layout, haulage concept, or the implementation of any currently planned ESF testing activities. Conversely, the current layout does make conventional rail haulage unfeasible, it limits the ability to lay out a potential repository which avoids the Ghost Dance fault to the maximum extent, and it constrains development of potential repository layouts utilizing flat emplacement drifts, unless a large portion of the block (i.e., the area crossed by the current main Topopah Spring level drift and west cross drift) is removed from consideration.

Conclusions And Recommendations

The proposed enhancements to the layout will result in an ESF which possesses all the favorable features embodied by Option 30, plus the two features which Option 30 did not have. In addition, the primary Topopah Spring level "loop" will be arranged at grades that will allow the use of conventional rail haulage for construction and operation in the ESF, and that preserve the rail option for a potential repository. It should also be noted that the overwhelming majority of Tunnel Boring Machine-driven tunnels utilize conventional rail haulage for transport of men and materials between the surface and the working face. The enhanced layout would have approximately 9 percent more excavation footage.

In light of the added flexibility that this configuration provides for potential repository layout and haulage system selection, it has been recommended that the new layout be adopted and be added to the ESF Technical Baseline, superseding the existing arrangement. Affected documents would include the ESF Technical Baseline (DOE, 1993n), the ESF Plan (DOE, 1993o), the SCPB (DOE, 1993a), and the Plan for Phased Approach to ESF Design, Development, and Implementation (DOE, 1991a).

This change will require some replanning of the surface-based drilling program related to the ESF. A critical early need will be a borehole, roughly in the center of the proposed repository block, to acquire geotechnical data and information on the TSw1-TSw2 contact in close proximity to the Ghost Dance fault. This hole should also yield information on the suitability of the 122-m offset from the fault. Also required will be a borehole near the proposed entry point location at the end of the curve of the North Ramp to verify the TSw1-TSw2 contact in this area. The TSw1-TSw2 contact information is also needed near

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Figure 2.1-7. Two Block Repository Concept

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the south end of the main Topopah Spring level drift where the drift exits the potential repository block.

Forecast: At the end of this reporting period, the proposal for formally modifying the ESF design had not yet been acted upon by the Change Control Board but action is expected in early FY 1994. If the proposed change is accepted, the baseline ESF configuration will be changed during FY 1994.

2.1.10 Initiatives in Surface-Based and Underground Testing

2.1.10.1 Site Investigations Annual Plan

The Project, with assistance from the M&O Site Characterization Group developed a draft "Fiscal Year 1994 Annual Plan for Site Characterization." A preliminary draft plan was reviewed by Project managers, Participants, and the M&O to identify activities that address current Project goals, and that are consistent with the long-range plan. Activities proposed for implementation in FY 1994 were screened according to Project priorities and budget constraints to produce an integrated site investigations plan. Appendices to the plan summarize work scopes, budgets, schedules, logistical concerns, and expected deliverables for each activity. The status of FY 1993 activities is also summarized; incomplete FY 1993 milestones and deliverables are tracked into FY 1994 until finished.

Forecast: The Annual Plan for 1994 is expected to be issued in early FY 1994. The Site Investigations Annual Plan will be revised yearly.

2.1.10.2 Integrated Test Evaluation

The Integrated Test Evaluation (ITE) is an effort to produce a logical methodology to be used as a tool in prioritizing the testing program during site characterization. The evaluation framework is designed to be used iteratively as test results become available, costs are revised, and Department priorities change.

During this reporting period, the ITE continued its efforts to aid in the prioritization of the testing program. Initial efforts on the ITE-92 effort concentrated on evaluating the ability of tests to address the criteria of suitability of site, regulatory performance objectives, scientific consensus of the general scientific community, and cost of the tests. The ITE-93 effort has centered on adding the criterion of design, updating test costs, and adding Scientific Investigation Plans to the analysis. Costs associated with drilling were assigned to the primary tests requesting the drilling in both ITE-92 and ITE-93. In the FY 1993 effort, the cost of alcove construction in the ESF was allocated to the primary tests requesting alcoves.

Preliminary results of ITE-93 are that the design decisions that will benefit most from specific data provided by the testing program include the thermal loading and waste package decisions. Eight tests have shown to be of clear value because of the cost savings to the

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decision making process versus the cost of conducting the test. However, the overall ranking of tests established during ITE-92 is not significantly affected by adding the criterion of design.

Forecast: The final report "Integrated Test Evaluation Framework to Prioritize Tests for the Yucca Mountain Site Characterization Project" is expected to be issued in October 1993.

2.1.10.3 Test Interference and Waste Isolation Evaluations

As part of the planning process for testing and construction activity, test interference 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. The evaluations serve as input to the appropriate Test Planning Package or to the QA classification process through Determination of Importance Evaluations. Potential test interference or waste isolation concerns are addressed through imposition of controls on testing, design, construction, or operations activities.

During the current reporting period, 26 evaluations were carried out.

2.1.10.4 Technical Assessment of the Exploratory Studies Facility Seismic Design

A Technical Assessment team was assembled to evaluate the Exploratory Shaft Facility Seismic Design Working Group Report (Subramanian et al., 1990) with respect to its applicability to the current ESF configuration. The recommended seismic design basis in the Working Group Report is being assessed relative to the enhanced ESF configuration, and in light of advances in knowledge on the seismotectonic framework in the vicinity of Yucca Mountain. While the technical assessment is being carried out, a temporary conservative design basis was put in place.

Forecast: The Technical Assessment will be completed and a seismic design basis for the ESF will be recommended.

2.1.11 Planning for Site Suitability Evaluation

The response to the three NRC comments and two questions on the Early Site Suitability Evaluation report (Younker et al., 1992) was issued in June, 1993. In addition to the response to NRC, a response package was prepared for comments received from the U.S. Department of the Interior, the State of Nevada, and all affected units of local government.

Forecast: During FY 1994, DOE will be initiating two activities that are related to the process of determining site suitability. The first activity is an evaluation of the DOE Siting

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Guidelines that are codified in 10 CFR Part 960 to address changes that have occurred in the Program over the past several years. The second activity will address the methodology to be used for the determination of site suitability, and will be consistent with the results of the evaluation of 10 CFR Part 960. The first of these activities will be conducted by a team that is being formed by DOE in the first quarter of FY 1994, and which may include participation from the State of Nevada and the affected units of local government.

2.1.12 Technical Data Parameter Dictionary

In compliance with QA requirements and good scientific and engineering practices, the M&O is compiling a list of data needs in support of design, performance assessment, and licensing activities. This necessary data is being identified and defined in the Technical Data Parameter Dictionary (CRWMS M&O, 1993e). The data identification process utilizes the prescribed data needs contained in the SCPB with reviews by each Participant organization to factor in the knowledge gained since the SCPB publication.

Forecast: The Parameter Dictionary will be used to identify necessary data needs on a schedule to support the site suitability determination and the License Application development processes. It will be published in early FY 1994.

2.1.13 Energy Policy Act of 1992, Section 803 Report

The U.S. Congress, in the Energy Policy Act of 1992 (U.S. Congress, 1992), instructed DOE to evaluate whether its current programs and plans for management of nuclear waste were adequate to deal with volumes or categories that might be generated through new nuclear power plants. The Congress also asked the Secretary to report on additional transportation, interim storage, and geologic repositories needed for these new wastes.

The Department was given one year to perform this study, to write an analysis, and to present its findings to the public for review and comment.

An annotated outline was developed and distributed among interested parties for comment and discussion at a public meeting held in February 1993.

The Department evaluated existing plans, as specified in the Nuclear Waste Policy Act (NWPA, 1983) and ensuing regulations, and wrote the report based on scenarios that included amounts of waste higher than expected in various cases. A reference case was developed and compared with high estimates to ensure that programs and plans could handle extreme estimates over a wide range of conditions.

In addition to waste that may be generated by new nuclear power plants, the report included waste from other sources, including spent nuclear fuel and high-level radioactive waste from both commercial and defense sources.

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The analysis resulted in the conclusion that programs and plans are adequate to handle waste management into the future, based on three findings:

- Radioactive materials 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.
- Flexibility has been built into the current program and plans.
- Development of the waste management system is at an early stage, and there is ample opportunity to accommodate changing needs.

In June 1993, a draft report on "Adequacy of Management Plans for the Future Generation of Spent Nuclear Fuel and High-Level Radioactive Waste" was released for public comment. The draft followed an evaluation process that invited substantive public involvement at various stages.

Drafts of the report were discussed in two public hearings, one held in Las Vegas, Nevada, on July 20, 1993, and a second held in Washington, D.C. on July 29, 1993.

The NRC and the EPA were consulted in producing the report, as Congress had specified. Those two agencies elected not to comment on the final version of the report. Their earlier comments were incorporated or addressed in response documents.

Responses to all people who commented either at a public meeting, a hearing, or a letter to the Department were addressed in the final report, which is currently being reviewed by DOE Headquarters.

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SECTION 2.2 SITE PROGRAMS

The site characterization effort for the Yucca Mountain 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 of offsite industrial, transportation, and military installations and operations in the Yucca Mountain vicinity, and the potential impacts of these installations and operations on the site area (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).

These programs are discussed in detail in the referenced sections.

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

The study plan received U.S. Nuclear Regulatory Commission (NRC) acceptance on October 21, 1991.

Activity 8.3.1.2.1.1.1 - Precipitation and meteorological monitoring. Data collection continued during the reporting period. Site meteorological data from five weather stations plus two remote tipping-bucket rain gauge locations were downloaded, reviewed, and archived weekly. Additional precipitation data were collected from the network of 134 nonrecording (storage) rain gauges deployed on and around Yucca Mountain. This network expands the automated network and fills in gaps. Three types of storage gauges were deployed: plastic wedges, 4-in-diameter plastic canisters, and 8-in-diameter National Weather Service gauges. Mineral oil was used in these gauges to minimize evaporation. During the reporting period, there were only five distinct precipitation events affecting Yucca Mountain, resulting in a relatively dry spring and summer following a very wet winter. The exception was an anomalous storm June 5-6, 1993, that quadrupled the mean monthly rainfall and was the largest of the spring and summer. This storm was unusual in that June is typically the driest month of the year in southern Nevada. A thunderstorm struck the southern half of Yucca Mountain on August 27, 1993. Meteoric water samples were taken from the storage gauge network, when possible, for stable isotope analysis.

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Collection and archival 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.

Statistical analysis of precipitation data obtained from the tipping-bucket gauges for the period 1990 through 1993 was initiated. These data are important for characterizing the temporal distribution of precipitation events, including the probability of storm occurrence, storm duration, and storm intensity. The preliminary analysis included a comparison of the tipping-bucket data with daily accumulations obtained using the storage gauge network. Lightning strike data, meteorological data (wind, air temperature, humidity), satellite data (cloud cover and storm type), and the video record were all used to more accurately characterize daily and seasonal storm types. Results of this work are needed to characterize natural infiltration at Yucca Mountain using rainfall-runoff models.

Work continued on a U.S. Geological Survey (USGS) Open-File Report entitled "Precipitation Data from the USGS Storage Gauge Network at Yucca Mountain, Nevada, 1992-93" (Ambos). Work continued to reformat weather station data into daily files and summaries of daily precipitation.

Forecast: Continue to collect and analyze data from the precipitation networks. Complete the 1992-93 data report.

2.2.1.2 Study 8.3.1.2.1.2 - Characterization of Runoff and Streamflow

The study plan received NRC acceptance on May 14, 1991.

Activity 8.3.1.2.1.2.1 - Surface-water runoff monitoring. Monitoring activities continued at 11 continuous-recording stream gauges, 12 peak-flow sites, and 26 storage-type precipitation gauges. In August and September, new continuous-recording streamflow gauges were installed on the Amargosa River near the California-Nevada state line, on Upper Split Wash in Yucca Mountain, and on Split Wash between Antler Ridge and Live Yucca Ridge. Data collected from these sites will be used to support studies associated with the Unsaturated Zone Infiltration Study and other regional hydrologic activities. Peak-flow gauges for documenting cross-sectional, high-water profiles at these new gauges were also installed. Reference marks were established at the three new sites and verified at other selected sites.

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 approved for publication as a USGS Open-File Report. A draft report entitled "Streamflow and Selected Precipitation Data for Yucca Mountain Region, Southern Nevada, and Eastern California, Water Years 1986-90" (Kane et al.) has been technically reviewed and submitted for approval.

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Intermittent precipitation events occurred within southern Nevada during the reporting period resulting in minor flows at some regional and Yucca Mountain monitoring gauges. Reduction of the surface-water and precipitation records for water years 1991-93 continued.

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.

Forecast: Monitoring will continue at 14 continuous-recording stream gauges, 12 peak-flow sites, and 29 storage-type precipitation gauges. Two to 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 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

The State of Nevada sent 58 comments on the study plan to the Office of Civilian Radioactive Waste Management (OCRWM) on March 16, 1993. Responses to these comments were returned to the State on September 22, 1993.

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

Activity 8.3.1.2.1.3.2 - Regional potentiometric-level distribution and hydrogeologic framework studies. Hydrochemical sampling was performed in three deep 2-in-diameter piezometers in the central Amargosa Desert using a pump jack assembly. Installation of the pump was accomplished through the use of a modular tripod and electric truck winch, permitting installation depths as great as 213 m. Additional samples were obtained from five piezometers which were bailed. These piezometers were constructed to permit sampling and water-level monitoring of the uppermost saturated zone, for subsequent comparison with deeper screened intervals in adjacent piezometers within the same boreholes. Gas bubbles were observed during the removal of the pump jack tubing, which led to resampling of two deep boreholes using a thief sampler so that the gas could be kept in solution long enough to be captured and analyzed.

Several wells in the northwest Amargosa Desert that are being monitored by LAC Bullfrog Mine, Beatty, Nevada, were visited. Discussions with LAC personnel took place and water-level records for 12 monitoring wells obtained. LAC records indicated that elevation surveys were made for all 12 wells. Quarterly water-level data from these 12 wells were

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obtained from National Park Service personnel. Measurements are planned by Project staff to corroborate values obtained by LAC personnel. Plans are in process to obtain water samples from various LAC wells and from the underground workings of the LAC Bullfrog Mine.

A report entitled "Lithologic and Geophysical Logs of Drill Holes Felderhoff Federal 5-1 and 25-1, Amargosa Desert, Nye County, Nevada" (Carr et al.) was submitted for internal USGS review.

An abstract entitled "Spreadsheets for Field Analyses of Hydrochemical Samples" (Czarnecki et al.) was prepared for inclusion at the Fall Meeting of the American Geophysical Union in San Francisco, California, December 6-10, 1993. The abstract discusses two computer spreadsheets used to evaluate the representativeness of a hydrochemical sample and to calculate the field alkalinity through incremental acid titration.

Hydraulic testing and hydrochemical sampling were conducted at drillhole USW UZ-14 at Yucca Mountain. A datalogger program was developed for storing selected water-level data obtained by using a pressure transducer. The program stores these data based on a specified change between current and previously stored values of pressure. The program (HYDTEST) was supplied to Site Saturated-Zone Studies personnel for evaluation and testing. Also, hydraulic test results for a 25-hour hydraulic test of USW UZ-14 were analyzed to estimate transmissivity.

Activity 8.3.1.2.1.3.3 - Fortymile Wash recharge study. Soil-moisture measurements 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.

A draft report entitled "Selected Hydrologic Data from Fortymile Wash in the Yucca Mountain Area, Nevada, Water Year 1992" (Savard) was prepared. Precipitation, streamflow, unsaturated-zone, and saturated-zone data were compiled in the report to document ground-water recharge in Fortymile Canyon during 1992.

Precipitation, streamflow, unsaturated-zone, and saturated-zone data for the Water Years 1992 and 1993 were compiled for inclusion in an extended summary which was submitted for inclusion at the 1994 International High-Level Radioactive Waste Management Conference in Las Vegas, Nevada, May 22-27, 1994. The objectives of the summary were to document ground-water recharge in Fortymile Canyon and to describe water movement through unsaturated volcanic and alluvial strata.

Results of a study that applied chaos theory to time series of streamflow data were presented in an all-day seminar at USGS Headquarters in Reston, Virginia. These results and their possible significance for Yucca Mountain hydrology were discussed with other participants in the seminar, which focussed on the application of nonlinear theory to hydrologic investigations.

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Activity 8.3.1.2.1.3.4 - Evapotranspiration studies. A CR-10 datalogger routine for running Bowen-ratio equipment was modified to incorporate regression equations for pairs of humidity and temperature sensors. The program and equipment were deployed at the Central Site at Franklin Lake Playa for further testing and evapotranspiration estimation. Initial data analyses indicated a possible reversal in equipment wiring which required a site visit to verify. Further analyses indicated variations in dew-point sensor response.

Two data dumps were made on a trial setup of Bowen station equipment designed to estimate evapotranspiration at a central site on Franklin Lake Playa. Humidity sensors were placed side by side to determine if the sensors were capable of producing comparable results over a 20-day period.

Forecast: Hydrochemical sampling will continue in deep wells in the Amargosa Desert using a small-diameter jack pump. Water levels will be measured in several strategic wells throughout the flow system. Recharge data from Fortymile Wash will be compiled and prepared as a draft report. Hydrologic and hydrochemical testing of USW G-2 will occur. Implementation of a 2-arm aspirated chilled mirror/thermocouple system will be incorporated into a Bowen-ratio station for deployment at Franklin Lake Playa. Further testing of a dew-cell Bowen ratio station will also continue.

2.2.1.4 Study 8.3.1.2.1.4 - Regional Hydrologic System Synthesis and Modeling

The NRC completed a detailed technical review of the study plan on April 6, 1993, and sent three comments and two questions to OCRWM. The USGS was asked on April 16, 1993, to assess the impact on the study. The OCRWM responded to NRC comments and questions on August 30, 1993. The State of Nevada sent 18 comments to OCRWM on January 22, 1993. OCRWM responded to the State's comments on April 2, 1993.

Activity 8.3.1.2.1.4.1 - Conceptualization of regional hydrologic flow models. Seminars on characterization of the regional ground-water flow system of Yucca Mountain and vicinity were presented at the USGS District Office in Boston and in the Water Resources Department of the Department of Civil Engineering at the Massachusetts Institute of Technology. Discussions were held with personnel from each group regarding various strategies for site characterization. A paper entitled "Conceptual Models of Regional Ground-Water Flow and Planned Studies at Yucca Mountain, Nevada" (Czarnecki and Wilson, 1993) has been published.

Project staff discussed sampling of carbonate and hydrogenic deposits with USGS Geologic Studies Program staff and attended a meeting to discuss hydrogenic deposits at Site 199 in Crater Flat. A follow-up visit to look at hand specimens resulted in agreement that hydrogenic deposits west of Stateline, Nevada, in the Amargosa Desert were very similar to those at Site 199.

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Activity 8.3.1.2.1.4.2 - Subregional two-dimensional areal hydrologic modeling.

Activity staff continued to run simulations which examined the removal of the barrier to ground-water flow responsible for representing the large-hydraulic gradient north of Yucca Mountain on the SUN computer. Initial hydraulic head was set to 20,000-year 15x-increased-recharge conditions. Mass balances were typically five to six orders of magnitude smaller than the maximum specified fluxes within the model indicating excellent mass balance. A breakthrough was made in automatic plotting of head-difference contours for each reported time step.

Refinements to a two-dimensional finite element mesh of the subregional flow system were made using the Grid Builder software package. A refined mesh was produced around the Yucca Mountain site with adjusted nodal locations corresponding to actual well locations. A disk file of this mesh was developed for incorporation into the regional Geoscientific Information System data base for establishing land-surface elevations and hydrogeologic properties at the nodal locations.

Personnel from USGS and the M&O met to discuss interfacing a subregional two-dimensional finite-element model domain and hydrogeologic property designations with a two-dimensional boundary-element model being developed for performance assessment by the M&O. A map of the finite-element nodal locations and node numbers and a key for going from local coordinates to central Nevada coordinates was provided to the M&O.

Project staff met to discuss the priority of water table holes that may be selected by Nye County for construction of adjacent monitor wells to be used during the hydraulic testing/sampling of the water table holes. USW WT-1 was considered to be the most desirable of these.

An abstract entitled "Automatic Editing and Graphical Postprocessing of Output from the MODular Finite Element (MODFE) Model" (Czarnecki) was written for the 7th National Computer Technology Meeting of USGS to be held in New Orleans, Louisiana in April 1994.

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 regional flow system at Yucca Mountain continued. Digital point files describing locations of hydrogeologic units and faults were developed from three-dimensional cross sections. Digital grids of each of the ten hydrogeologic units were developed using major regional faults as discontinuities. These faulted surfaces were visualized as two-dimensional cross sections to evaluate validity and then edited. From these gridded surfaces, preliminary three-dimensional models of the area were developed in both Intergraph's Modular Geographic Information System Environment Voxel Analyst and Dynamic Graphics' Earth Vision software. These preliminary visualizations indicated that some of the regional data would need to be simplified to be used effectively in current three-dimensional modeling software. As a result, modifications were made to refine and simplify cross-section data. Arrangements were made to visualize refined

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data sets in LYNX Geosystem's Geologic Modeling System and Stratamodel's Stratigraphic Geocellular Modeling and Geocellular Template Modeling software. A paper entitled "Geoscientific Information Systems and 3-D Hydrogeologic Framework Models for the Yucca Mountain Area, Southern Nevada and California, USA" has been published (Faunt et al., 1993).

A paper entitled "Hydrogeologic Characterization of Structural Discontinuities in the Death Valley Region, Nevada and California" (Faunt, 1993) was modified as a result of further work on the analysis of structural control of regional ground-water flow. Earthquake epicenters, regional discharge areas, and regional spring discharge locations were incorporated into the data sets for this task. Data were analyzed with the stress and fault data, areas where structural control was evident were delineated, and final maps and figures were prepared.

A report entitled "Preliminary Digital Geologic Maps of the Mariposa, Kingman, Trona, and Death Valley Sheets, California" (Faunt et al.), which includes data used to construct the hydrogeologic map for the study, was completed and began USGS internal review.

A series of Geographic Information System maps was developed by synthesizing and interpreting much of the regional hydrogeologic data of the Death Valley region. Map coverages were used to develop numerical arrays for the three-dimensional MODFLOW model. A vegetation map of the regional model area from Thematic Mapper satellite images was developed. Field verification was conducted and used to enhance accuracy of the map. Water use estimates were developed for the study area based on earlier investigations and additional data from the Nevada State Engineer. A map showing location, type, and estimated volume of ground-water withdrawal was developed.

Present-day discharge areas and previously estimated flux rates were analyzed. This task, conducted in conjunction with the Past Discharge Activity, resulted in the development of a map of areas showing discharge from free-water, bare soils, wetlands/marshes, and phreatophyte areas. Comparisons were made with historical estimates and published models. Discrete discharge from regional springs was also examined. This included analyzing spring discharge rates, temperature and chemistry to determine if a spring was, indeed, a regional discharge component. Additional spring localities in the northern portion of Death Valley were located. A map showing regional springs location, temperature, and discharge rate was developed to be used as a three-dimensional MODFLOW model array for ground-water discharge.

A regional potentiometric-surface map of the regional model area using well, spring, and surface hydrography data was developed. The map was compared to other published maps and topographic data. Additional changes will be made through the end of fiscal year (FY) 1994. Preparation of a USGS report entitled "A Regional Potentiometric-Surface Map of the Death Valley Region, Nevada and California" (D'Agnese) will be deferred until FY 1995 because of lack of funds. Previous ground-water recharge estimates based on the Eakin "first approximation" method were modified. The estimate was the second of three refinements to regional recharge estimation.

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A report summarizing all the work on hydrologic conceptualization for modeling purposes entitled "Hydrology of the Death Valley Region, Nevada and California" (D'Agnese et al.) was begun. However, preparation of this report will be deferred until FY 1995 because of lack of funds.

In conjunction with the Regional Hydrochemistry Activity, regional water chemistry data were sorted by lithology, and basic statistics were run for each lithologic group. Piper plots were made for each lithologic group. The data set was then analyzed in Statistical Analysis System using the method of cluster analysis. Cluster analyses of the chemical data were reviewed and interpreted. The clusters were compared with spatial and geologic information. Preliminary t-tests were run to test for separation of the nine cluster groups that were defined. These clusters were interpreted for hydrochemical significance.

A paper entitled "Using GIS for Three-Dimensional Ground-Water Flow Modeling, Death Valley Region, Nevada and California" (D'Agnese et al.) was presented at a Conference/Workshop on Integrating the Geographic Information System and Environmental Modeling, in Breckenridge, Colorado, on September 28, 1993. The paper discussed the utility and efficiency of using the Geoscientific Information System for regional ground-water modeling.

Forecast: No subregional two-dimensional areal or cross-sectional modeling will be done in FY 1994. Planned work will include finishing modifications to the three-dimensional Hydrogeologic Framework Model and completing preliminary runs of the three-dimensional MODFLOW model.

2.2.1.5 Study 8.3.1.2.2.1 - Characterization of Unsaturated-Zone Infiltration

Revision 2 of the study plan was sent to the Commission on April 5, 1993.

Activity 8.3.1.2.2.1.1 - Characterization of hydrologic properties of surficial materials. To determine the surface flux at Yucca Mountain, characterization of the hydrologic and physical properties of the surficial materials was performed. Monthly surficial grab samples, tensiometer transects, mapping programs, and geophysical logging programs were used in an effort to measure temporal and spatial changes in hydrologic and physical properties of unconsolidated sediments.

A monthly surficial sampling project, which collected grab samples of the surface materials near each neutron hole, was continued. The samples were sieved in the field and only the less-than-2-mm fraction was used for determination of soil moisture potential and gravimetric moisture content. All the moisture data have been placed into a data base. Preliminary analysis of the data showed that surficial moisture potentials ranged from 2000 bars to 0 bars and gravimetric moisture contents ranged from 0.02 to 0.20 g/g.

Preliminary map unit descriptions for geomorphic surfaces, depth to bedrock, and soil classification have been defined and evaluated in the field. A preliminary landscape position

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map for WT-2 Wash and most of Split Wash has been completed. A first attempt to determine what information will be placed in the Geographic Information System data base has been carried out. The Geographic Information System will serve as the central data base for all characterization data and mapping information. This information, combined with the surficial sampling data, will be used to create a first order surface moisture flux map.

Three transects of tensiometers (60 tensiometers total) were installed in WT-2 Wash. The tensiometers were installed at two depths (15 and 30 cm) at each of the sampling locations. Samples for gravimetric water content, volumetric water content, and soil moisture potential were collected once a month at selected locations along the transects. Bulk samples from each of the tensiometer sites have been sieved into two fractions (<2 mm and >2 mm). Determination of the different size separates of each sample has been completed.

Calibration techniques have been developed for all of the probes used with the geophysical logging van. The calibration techniques are consistent and repeatable for each of the given tools. Software was developed that allowed for time-based logging and proper sensor alignment for each of the tools. The geophysical logging van (neutron, natural gamma, and density tools) has been used in three neutron access holes and at USW UZ-14 and UE-25 UZ#16. The natural gamma and density logs differentiated the caliche and boulder layers found in the alluvial profiles. This permitted determination of layers that may inhibit or control the downward movement of water.

Activity 8.3.1.2.2.1.2. - Evaluation of natural infiltration. Numerical modeling of a small scale watershed, water content and water potential measurements in boreholes and from surface samples, water balance studies, and evaluation of shallow/deep infiltration processes were used to characterize the net present-day infiltration at Yucca Mountain.

The water contents in the existing 99 neutron-access boreholes were monitored on a monthly basis with a neutron probe. All the collected neutron probe data from July 1984 through September 1993, were organized into a functional PARADOX data base with 431,992 measurements. The data have been validated to assure that the data are consistent with the borehole measurement depths. The standard ten counts taken before field measurements indicate that the neutron probes were working properly. Work was begun organizing the measured gravimetric water contents from the drilling of the neutron calibration boreholes. Laboratory analysis of the cores from the last neutron probe boreholes was started. These data will be combined with the initial neutron probe measurements to provide data for calibration. The lithology for each neutron probe measurement depth of the boreholes drilled before November 1991 was identified and organized.

Borehole UE-25 UZN#39 was drilled through 18 m of alluvium in Jackass Flats. Drive core samples were continuously collected for the entire depth. Cuttings were collected at 60 cm intervals for eventual analysis of ^{36}Cl . This borehole completed the planned boreholes for this activity.

Tensiometer and chilled mirror psychrometer measurements of the surface water potential and gravimetric surface water content measurements were made to evaluate natural

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infiltration and surface boundary conditions. Surface water potentials ranged from -10 to -200,000 kPa and surface water contents ranged from 0.01 to 0.15 g/g. Detailed radiation load modeling of WT-2 Wash accounting for slope, aspect and blocking ridges showed average monthly radiation loads ranging from 12.7 mJ/m²/d in December to 32.8 mJ/m²/d in June. Preliminary analysis of the Bowen ratio data suggests reasonable agreement with Priestley-Taylor calculations.

Preliminary conceptual models of natural infiltration at Yucca Mountain suggest that models should incorporate four potential topographic positions: ridgetop, sideslope, alluvial terrace, and active channel. Preliminary topographic, geologic, and meteorologic factors influencing infiltration at Yucca Mountain were also identified. Measured water content profiles suggest natural infiltration and percolation of water into bedrock primarily occurs through the shallow alluvium covering the slopes and ridgetops rather than through the deep alluvium at the bottom of washes, except during extreme runoff conditions.

Modeling of the measured water content profile at UE-25 UZ#16 from the surface to the water table suggested the importance of using correct lithology. Hydraulic properties measured on outcrop samples were adequate for this modeling.

Activity 8.3.1.2.2.1.3 - Evaluation of artificial infiltration. Measurements of in situ hydrologic properties and water movement in the surficial materials of Yucca Mountain was performed. Infiltrometer measurements, large scale ponding experiments, and time domain reflectometry were all used to determine, under controlled conditions, the soil water flux in the near surface environment.

Neutron logs of water movement at the UE-25 UZN#85 prototype ponding infiltration experiment continued. The periodic readings showed that internal drainage was proceeding, but at a very slow rate. Bulk density and moisture content samples were taken at each of the time domain reflectometry probe locations. These measurements were used to refine the time domain reflectometry moisture calibration for soils containing carbonate materials. Particle size analysis (<2 mm and >2 mm fractions) were completed for each of the individual stratigraphic units. These data are being used to model the saturated hydraulic conductivity (K_{sat}) for each of these stratigraphic units.

A survey of potential field sites for infiltrometer measurements was completed. Sites were chosen that represented the greatest range in potential infiltration rates for various surficial materials. Measurements of infiltration rates were taken in selected wash locations. The double ring infiltrometer measurements of K_{sat} ranged from 2 to 20 cm/h.

Because the double ring infiltrometer may only be used on flat surfaces, work was started to develop a tension infiltrometer that may be used on sloping surfaces. Several small prototype units were developed and tested on a variety of different soil materials. Use of the tension infiltrometer, in association with the double ring infiltrometer, will allow for controlled measurements of the surface water flux for consolidated and unconsolidated surficial materials.

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A large scale time domain reflectometry calibration experiment was completed at the UE-25 UZN#14 site. A 6 x 3 block (18 blocks total), with each block containing three probe sets, was used to calibrate the time domain reflectometry at various moisture levels. Probe sets were wetted with approximately 4 L of water. At selected intervals, following the wetting, bulk density and water potential samples were collected from the material surrounding each of the probe sets. The bulk density was uniform across the site ($1.33 \text{ g/cm}^3 \pm 0.2 \text{ g/cm}^3$). An R value of 0.72 was obtained from a regression of the measured volumetric water contents vs. Topp's equation. Variability in the measured values were related to a field feature and were not a function of Topp's equation. The field feature affecting Topp's equation is most likely coarse fragment content. Analysis of the particle size fractions (including coarse fragment content) for each of the bulk density samples has been completed. This information will be used to improve Topp's equations fit of the time domain reflectometry data.

Forecast: Characterization of hydrologic properties of surficial materials: Borehole geophysical logging will be conducted in boreholes that are completed in FY 1994 to obtain in situ information prior to stemming or casing. Similar borehole geophysical logging will be conducted in the neutron-access boreholes. More intensive logging will be conducted on the 24 boreholes that were completed within the last two years. The geohydrologic/surficial/infiltration/runoff map will be refined based upon the results of field studies and the laboratory analysis of several hundred surficial-materials samples and a preliminary map will be produced.

Evaluation of natural infiltration: Logging the 99 neutron-access boreholes for the detection of changes in water content will continue as an ongoing activity. Water balance studies will continue at selected water shed basins at Yucca Mountain. Irretrievable data such as field water retention, surface-water contents, and evapotranspiration will be collected at field sites. Water-balance data collected in FY 1993 will be reviewed and organized for Technical Data Information Form submittal. Shallow and deep infiltration data, including FY 1992 and FY 1993 neutron-access borehole logging data, will be reviewed and organized. Papers will be written for presentation at the 1994 High-Level Waste Conference.

Evaluation of artificial infiltration: This activity received no funding for FY 1994, therefore no activity is planned.

2.2.1.6 Study 8.3.1.2.2.2 - Water Movement Test

Revision 1 of the study plan was submitted to the Commission for a Phase I review on February 18, 1993. It was accepted on April 8, 1993, with no comments.

Activity 8.3.1.2.2.2.1 - Chloride and chlorine-36 measurements of percolation at Yucca Mountain. Analyses of ^{36}Cl were performed on twenty samples from UE-25 UZ#16 and from several additional samples from neutron-access boreholes USW UZN-11, USW UZN-37, USW UZN-53 and USW UZN-54. These data were analyzed and a talk entitled "Distribution of Chlorine-36 in the Unsaturated Zone at Yucca Mountain: An Indicator of Fast Transport

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Paths" (Fabryka-Martin et al., 1993) was presented at the Focus '93 meeting in Las Vegas, Nevada, September 26-29, 1993. The report discussed how the $^{36}\text{Cl}/\text{Cl}$ ratios for chloride extracted from soil and ream-bit cuttings were used to provide information on characteristics of water movement through the unsaturated zone at Yucca Mountain. Bomb-pulse ^{36}Cl was found in the alluvium in two holes down to depths <20 ft; below that depth, bomb-pulse ^{36}Cl was present in the alluvium only at background levels, providing evidence for the role of deep alluvium and associated vegetation in attenuating infiltration. Elevated levels of ^{36}Cl in the underlying Paintbrush nonwelded unit were detected in three of five boreholes; this may indicate that fast transport of water via fractures through the Tiva Canyon welded unit is possible. A proceedings paper describing this work was in the Project approval process.

Forecast: Data will be collected from surface soil samples, soil profiles from pits, and cuttings from neutron access boreholes and the Exploratory Studies Facility (ESF) to determine the prebomb meteoric ^{36}Cl ratio; assess the variability in meteoric Cl/Br and $^{37}\text{Cl}/^{35}\text{Cl}$ ratios; and estimate present-day shallow infiltration.

Cuttings from deep surface-based holes in the unsaturated zone at Yucca Mountain will be collected and analyzed to determine the depth to which bomb-pulse ^{36}Cl has penetrated, and to correlate such distribution with lithology and structural features, and estimate the average residence time of infiltrating water as a function of depth.

A progress report on ^{36}Cl analysis will be prepared.

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

The study plan received NRC acceptance on March 26, 1992.

Activity 8.3.1.2.2.3.1. - Matrix hydrologic properties testing. Core samples processed for porosity, bulk density, particle density and water content included all preserved samples from neutron holes USW UZN-31 and USW UZN-32, as well as UE-25 UZ#16. The first samples processed from UE-25 UZ#16 were those close to the water table, providing data needed to interpret the various water table levels and bailing information obtained during the final drilling cycles. The processing of all core was expedited by the receipt of a large capacity relative humidity oven.

Rock physical properties were determined for all remaining surface outcrop transect samples (total 1006 samples) and a composite data set of 45 samples was developed that represents all lithologic units to be encountered in UE-25 UZ#16. These samples included additional measurements of saturated conductivity, moisture retention, and sorptivity. This data set, plus all core data from USW UZN-55, USW UZN-54 and USW UZN-53, was provided to INTRAVALE participants for development of models to predict UE-25 UZ#16 water contents. Final UE-25 UZ#16 core data were eventually provided as a validation exercise. Two reports, "Physical and Hydrologic Properties of Rock Outcrop Samples at

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Yucca Mountain, Nevada" (Flint et al.), and "Physical and Hydrologic Properties of a Two-Dimensional Transect of the Shardy Base Microstratigraphic Unit at Yucca Mountain, Nevada" (Rautman et al.), are in draft form for the transect sample data. A paper on the modeled predictions of UE-25 UZ#16 water contents was presented at the INTRAVAL international meeting in Sweden. The data set was also used for inputs in the site scale model and a two-dimensional model investigating lateral infiltration into the Paintbrush nonwelded tuff.

Over 300 samples in a series of 26 vertical transects (3000 ft [914 m] horizontal by 35 ft [10.6 m] vertical) were collected in the nonwelded shardy base of the Tiva Canyon, and were used to examine horizontal and vertical spatial variability. This particular unit exhibits strong vertical deterministic trends based on the volcanic depositional processes, while on a site scale there are few lateral differences. A paper entitled "Spatial Variability in Hydrologic Properties of a Volcanic Tuff" (Istok et al.) was submitted for Ground Water journal review.

Samples collected from UE-25 UZ#16 were received and processing began to prepare plugs for measurement of saturated hydraulic conductivity, air permeability, and particle density using the gas pycnometer, sorptivity at relative humidity dryness, moisture retention and eventually thermal conductivity and unsaturated conductivity. Unsaturated conductivity will be measured using the steady state ultra centrifuge currently in the procurement system. About 20 percent of all samples have saturated flow properties too slow to be measured in the existing permeameter. Necessary arrangements were made to construct a low flow/high pressure permeameter.

Methodology was developed using the CX-2 chilled-mirror psychrometer to measure water potential of the preserved samples from UE-25 UZ#16 samples. The instrument was used to determine moisture retention curves which were done for the 45 samples from the composite data set. Curves were fitted to all data to provide van Genuchten hydraulic parameters for estimation of unsaturated conductivity and exercises were conducted to determine the appropriate number of parameters to best estimate the data.

Another approach to estimating hydraulic parameters is through the use of an analytical solution which uses sorptivity measured at various water contents. This method, presented at the 1993 High-Level Waste Conference, assumes a linear relationship of sorptivity with initial water content and is solved analytically to predict moisture retention and unsaturated conductivity. An apparatus was designed which will provide detailed measurements of imbibition with time for up to eight samples simultaneously to provide the data for the calculation of sorptivity. Two papers entitled "Characterization of Rock Hydrologic Properties Using Model Verification" (Flint et al., 1993) and "Use of a Submersible Pressure Outflow Cell for Determination of Moisture Characteristic Curves on Rock Core" (Flint and Flint, 1993), presented in 1991, have been published.

Activity 8.3.1.2.2.3.2 - Site vertical borehole studies. A criteria letter for instrumenting the existing small diameter UZ boreholes (UE-25 UZ#4, UE-25 UZ#5, USW UZ-13, USW UZ-6s, USW UZ-7, and USW NRG-6) was prepared and submitted to the Yucca Mountain Site Characterization Project Office (YMPO) in July. Most materials and supplies

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to instrument these boreholes were acquired. Arrangements were made to fabricate 15 instrument shelters that will be needed for the unsaturated zone borehole instrumentation program. Work on these shelters will begin in October 1993. Testing of the first instrument shelter that was delivered in December 1992, was conducted throughout the reporting period. This unit appears to be functioning satisfactorily. Arrangements were also made to refurbish two instrument shelters that were fabricated in 1989/1990. These shelters will be used on the small diameter borehole sites (USW NRG-6 and UE-25 UZ#4 and UE-25 UZ#5).

All UE-25 UZ#16 fracture data were compiled and a completion report is presently in preparation.

Two reports entitled "Borehole and Geohydrologic Data for Test Hole USW UZ-6, Yucca Mountain, Nevada" (Whitfield et al., 1993) and "Proposed Algorithm for Determining the Delta Intercept of a Thermocouple Psychrometer Curve" (Kurzmack, 1993) have been published.

Vertical Seismic Profiling

Velocity measurements (P- and S-wave) of 50 core samples from UE-25 UZ#16 were completed in July. A zero offset and vertical seismic profiling walkaway survey was conducted at the UE-25 UZ#16 borehole site in mid-August. The purpose of this survey was to confirm the feasibility of conducting vertical seismic profiling surveys in the unsaturated zone at Yucca Mountain using a multigeophone string. A single wall-locking geophone was used in the preliminary tests at UE-25 UZ#16. The walkaway survey confirmed that surface seismic energy sources could be detected in the borehole from distances as great as 1219 m, well within the range of offset needed to image the Ghost Dance fault. Data from these tests are being evaluated, with a final report of results due in December 1993.

A presentation was made to NRC in Las Vegas, Nevada, that provided an overview of the purpose, scope, and objectives of the vertical seismic profiling program at UE-25 UZ#16; and a talk, "Multi Mode Reverse Time VSP Migration Overcomplex Structures at Yucca Mountain, Nye County, Nevada" (Balch) was presented.

Integrated-Data-Acquisition System

Project staff completed the transition to a personal computer-based system. The new system performs four main functions (data acquisition, data transfer to Denver, data translation, and data display/analysis). The data acquisition function is performed by three programs (HDAS, SETHDAS, and HBASE), and was installed at the Hydrologic Research Facility borehole facility in May. An additional data acquisition system was installed in the instrument shelter at the Hydrologic Research Facility building, and is currently monitoring for testing purposes.

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Data transfer is currently handled manually using a remote control program and high speed modems. Data translation is done by a program called ICONVERT, and allows the raw data to be stored in a compact file structure. The display function is handled by the IDISPLAY program which was nearly completed.

Evaluation of data from the Hydrologic Research Facility boreholes continued throughout the reporting period. Sensors in these boreholes have been in operation for a period of 24 months and continue to provide reliable data. Sensors in the second borehole will be pulled in early FY 1994 and recalibrated.

Surface-Based Air-Permeability Testing

Construction or modification of the surface-based air-permeability testing support trailer was completed. Following reinforcement of the boom, the trailer was successfully load tested with 10,000 lbs. Staff also completed construction of the packer-assembly. The support trailer and packer assembly was field tested at the C-hole complex. Testing included: assembly of the packers, attachment of the packers to the pneumatic tubes and electrical cables, lowering the packers down borehole UE-25 c#1, and inflation of the packers. All testing was successful and the field staff received the training necessary for the operation of this equipment.

The Hydrologic Research Facility calibration lab was modified for the calibration of air-permeability instruments. Calibration of the thermistors, pressure transducers, and mass flow controllers was completed. These will be used for the air-permeability testing in UE-25 UZ#16.

The data acquisition and storage system was assembled. This system consists of power sources, data loggers, switching boxes, and a field personal computer. All instruments that require certification were sent out for calibration. The programs for activation and data collection from the data gathering instruments have been written and tested. The surface-based air-permeability testing activity is fully operational and ready to begin testing in UE-25 UZ#16.

USW UZ-14 Support

Drilling of USW UZ-14 began in mid-April 1993. As of September 30, 1993, this borehole had been dry-drilled and cored to a total depth of 396 m. In late July, water was encountered at a depth of 383 m, with a standing water level of 381 m. Drilling was temporarily suspended in early-August 1993, to test the hydraulic characteristics of the "perched water zone." Three bail-down and recovery tests were conducted as the borehole was advanced in stages to a total depth of 391 m. Four pumping tests (drawdown and recovery) were conducted after advancing the borehole to the top of the Topopah Spring basal vitrophyre. Water samples were taken to determine if the source of the water encountered could be attributed solely to fluid losses from the drilling of USW G-1 in 1980, or to

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contamination of a naturally occurring perched water zone by these drilling fluids. Analysis of these samples is still in progress. In late September, grout was injected into the perched water zone in an attempt to seal off inflow into the borehole before drilling deeper. The target depth for USW UZ-14 is approximately 610 m.

In May 1993, a talk entitled "Recent Advances in the Practical Utilization of Thermocouple Psychrometers" (Rousseau) was presented at the Fourth Technology Information Exchange Conference hosted by the U.S. Department of Energy (DOE) in Knoxville, Tennessee.

Six abstracts were prepared and submitted for presentation at the 1994 High-Level Waste Conference in Las Vegas. The titles of these papers are as follows:

1. "Evaluation of a 6-wire Thermocouple Psychrometer for Determination of In-Situ Water Potentials" - (Loskot et al.)
2. "A Gas Sampling System for Withdrawing Nearly Vapor-Saturated Gases from Deep Boreholes" - (Thordarson et al.)
3. "A Borehole Instrumentation Program for Characterization of Unsaturated-Zone Percolation" - (Kume and Rousseau)
4. "Results of Prototype Borehole Instrumentation at the Hydrologic Research Facility, Area 25" - (Rousseau et al.)
5. "Results of Air-Permeability Testing in Vertical Boreholes at Yucca Mountain" - (LeCain and Walker)
6. "Applications of Multi-Mode Imaging to Multiple Offset VSP Data" - (Balch et al.)

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: Surface-Based Borehole Studies: The drilling of Unsaturated Zone and Systematic Drilling boreholes will continue to be monitored for adherence to the drilling requirements of this activity. Sensors will be calibrated for use in the instrumentation of boreholes. Boreholes USW NRG-6, USW UZ-7, and UE-25 UZ#16 are scheduled for instrumentation in FY 1994. A second gas sampling apparatus, designed to prevent vapor condensation during gas sampling, will be assembled and tested. Downhole Instrument Station Apparatuses for instrumenting boreholes in FY 1994 will be procured, assembled, and tested. The instrumentation and stemming plan for USW NRG-6, USW UZ-7, and UE-25 UZ#16 will be completed. The UE-25 UZ#16 completion report will be completed. Papers will be written for presentation at the 1994 High-Level Waste Conference.

Vertical Seismic Profiling: Zero offset and walkaway data acquired at UE-25 UZ#16 will be analyzed and processed and a report will be written on the results. The geophone

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string will be installed in UE-25 UZ#16. Plans will be made for collection of the vertical seismic profiling data. The detailed survey will be conducted at UE-25 UZ#16 involving several hundred source offsets in multiple directions from the borehole. Special effort will be made to cover the Ghost Dance fault and other features of hydrogeologic importance. Data collected from the vertical seismic profiling production survey will be processed and interpreted. A report on the results of this work will be prepared. Cross-hole vertical seismic profiling data collected at the Colorado School of Mines experimental mine will be evaluated and reported on. Papers will be written for presentation at the 1994 High-Level Waste Conference.

Hydrologic Data Acquisition System: A program to verify the proper operation of in situ borehole sensors will be developed, coded, and tested. The Hydrologic Data Acquisition System will be installed at boreholes USW NRG-6 and USW UZ-7 for the monitoring instruments and collection and storing acquired data. Instrumentation in the Hydrologic Research Facility boreholes will be monitored in FY 1994. Data from these boreholes will be analyzed to assess the performance of the Hydrologic Data Acquisition System. Reports detailing the results of gas sampling software and the Downhole Instrument Station Apparatus Test program will be written.

Air-K & Gaseous-Tracer-Testing: Staff will prepare for surface-based air permeability testing of UE-25 UZ#16 by ensuring that all equipment is available and calibrated, all planning and quality assurance (QA) documents are in place, and reviewing hydrogeologic conditions in the borehole. Staff will conduct air-permeability testing in borehole USW SD-12, and smaller diameter boreholes, provided that equipment is available to accommodate testing in these boreholes. A second borehole packer-testing system will be constructed and tested. A report on the air-permeability testing of UE-25 UZ#16 will be written.

Matrix Hydrologic-Properties Testing: Laboratory measurements of soil and rock physical properties will be conducted on as many as 2000 surface, borehole, and ESF samples. Water potential will be determined for specially preserved samples. This activity supports many different SCP activities including the Unsaturated Zone Infiltration Study, the Unsaturated Zone Percolation Study, and the Unsaturated Zone ESF Study. Moisture characteristic curves will be determined for about 500 samples. Matrix permeability tests will be conducted on about 1000 samples to define the hydrogeologic units in the unsaturated zone for use in hydrologic models. A report on the current understanding of matrix hydrologic and physical properties based on laboratory results from core samples from seven surface transects will be prepared.

USW UZ-14 Support: Sliding screen assemblies and radio modems will be procured for instrumentation of USW UZ-14. Staff will calibrate in situ instruments for the borehole; assemble, mount sensors, and test Downhole Instrument Station Apparatuses for use in instrumenting the borehole; monitor the drilling of the borehole for adherence to drilling criteria for unsaturated-zone boreholes; conduct detailed fracture logging of core from the borehole; and conduct unsaturated-zone hydrochemistry, gaseous-phase circulation, and air-permeability testing in the borehole. The borehole will be instrumented with 16 instrument

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stations, each containing two pressure transducers, two thermistors, two thermocouple psychrometers, and gas sampling tubing. Core samples collected from the borehole will be tested in the Hydrologic Research Facility and the Unsaturated Zone Hydrochemistry Laboratory.

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

Revision 2 of the study plan (adding Activity 8.3.1.2.2.4.10) was submitted to the Project for verification of comment resolution on October 1, 1993.

Activity 8.3.1.2.2.4.1 - Intact-fracture test in the Exploratory Studies Facility.

Fabrication of a low-pressure vessel to test single fracture rock cores was completed. The vessel was assembled and tested for leaks and will be torn down to start connecting the monitoring instruments. The linear variable differential transducer calibration stand was modified and delivered in late-July 1993, and the mounts were completed and delivered in September 1993. A "blank sample" is currently being fabricated and delivery is expected in October 1993.

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). Support included the following: documenting day-to-day events concerning the Block E, core 13B, and imbibition tests and data collection; air-permeability testing of boreholes in Block E; recalibration of thermocouple psychrometers used for Block E test; coring of samples from Block E trimmings for imbibition tests (included set up for wet-drilling, glove box refurbished and two stations set up for these tests); and preparation of a draft of a technical procedure for thermocouple psychrometer calibrations.

Activity 8.3.1.2.2.4.2 - Percolation tests in the Exploratory Studies Facility. The ponding test on a large fractured welded tuff block from the Tiva Canyon columnar unit was restarted in September 1993. The block dimensions are 54.3 cm long x 47.5 cm wide x 80.6 cm high. Originally, the test was terminated, and data collection stopped in January 1993. In July 1993, and following gas injection into the fractures, the ponded water that was left on top of the block started flowing slowly into the block. Most of the remaining water drained over a three-day period. Following the gas injection in July, it was verified that the fractures were open and continuous from top to bottom of the block. Entrapped air and/or bacterial growth were suspected to have caused the water to stop flowing during the original testing period prior to January 1993. Based on the latest events, entrapped air seems to be the major mechanism that interferes with water flow in fractures. After restarting the test, water started to continuously flow through the block. Measurements are still under way.

Measurements of water-flow rates through a naturally fractured core were made at unsaturated conditions. The core dimensions were 7.0 cm long x 4.2 cm in diameter, and the fracture was axial. The measurements were made at different boundary pressures, and lasted for four weeks. A significant variability was observed in flow rates made at the same

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boundary pressures. The variability was attributed to entrapped air and bacterial growth. Both entrapped air and bacteria do occur in natural systems and may cause similar variability in the natural environment.

Two summary papers entitled "Laboratory Measurements of Water Infiltration Rates into a Block of Fractured Tuff" (Thamir et al.), and "Laboratory Measurements of Unsaturated Flow Through a Fractured Core" (Thamir et al.), were sent for consideration for presentation at the 1994 High-Level Waste Conference.

Activity 8.3.1.2.2.4.3 - Bulk permeability tests 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. Plans to use the SEAMIST borehole liner system for air-permeability testing and gas sampling in the radial boreholes were altered. The cost of the SEAMIST system was significantly greater than allocated and therefore pneumatic packers will be used. The packers will be designed and constructed by USGS staff. The system will consist of an injection string and several monitor strings. The injection string will consist of one injection interval capable of injecting 500 standard L per minute. The monitor strings will consist of 15 monitor intervals, 0.3 m in length, separated by 1.7-m packed-off intervals. Each monitor interval will be connected to the alcove with 3/8 in Teflon tubing that will be used to monitor the pressure in the interval and/or obtain gas samples.

The Apache Leap Tuff Site prototype cross-hole air-permeability testing report, "Pneumatic Testing in 45-degree Inclined Boreholes in Fractured Volcanic Tuff near Superior, Arizona," (LeCain) has been submitted for editing.

Activity 8.3.1.2.2.4.5 - Excavation effects test in the Exploratory Studies Facility. Several technical procedures from Sandia National Laboratories (SNL), Waste Isolation Pilot Plant site, were reviewed with the possibility of using them for the ESF test. The procedures discussed two types of instruments that will be used for the ESF test—hydraulic pressure cells for measuring changes in rock pressure, and extensimeters for measuring rock deformation. The SNL procedures were developed with Department funds and were subject to a QA program similar to the one being followed for this project.

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 described in revisions to ESF study plans.

Activity 8.3.1.2.2.4.7 - Perched-water test in the Exploratory Studies Facility. Monitoring for perched water in the ESF starter tunnel was performed. Supplies and equipment were purchased and prepared for use if needed. A trailer was obtained and will be set up on the ESF pad for potential perched water handling. A design of potential perched water sampling and analysis systems has been ongoing.

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Activity 8.3.1.2.2.4.8 - Hydrochemistry tests in the Exploratory Studies Facility. A scientific notebook was prepared for horizontal borehole instrumentation work in the ESF and was implemented. The location of the first alcove was determined (42.7 m) using available geologic information. A short borehole packer was designed, built and tested in a borehole installed in the right rib at 42.7 m. Gas samples (CO_2 , SF_6 , CH_4 , ^{14}C , $^{13/12}\text{C}$) were collected from this short borehole. Staff began the design of a packer system and evaluation of which, if any, of the borehole liner systems will be purchased.

Activity 8.3.1.2.2.4.9 - Multipurpose-borehole testing. This activity was intentionally deleted from the study plan in Revision 9 of the Site Characterization Program Baseline. Under the current ESF 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.

Forecast: The perched water trailer will be set up and the equipment and supplies will be installed in the trailer. A report on perched water equipment will be prepared. Monitoring for perched water will resume as soon as additional construction occurs. Hydrochemistry testing will start early and will consist of collecting samples from boreholes for gaseous and aqueous geochemical analysis. Collecting rock samples throughout the ESF to determine matrix hydrologic properties in the laboratory will start when mining begins. The packer equipment to conduct the radial borehole and major faults tests has been identified and will be procured. Procurement of equipment to support the excavation effects test has been identified, but has not been procured because this test will not be conducted until FY 1995.

Several short boreholes will be sampled during the construction of Alcove #1. Three boreholes will be drilled at the end of the alcove. Traced drilling air from the borehole construction will be evacuated and the boreholes will be monitored for temperature, humidity, moisture content, pressure conditions, air flow and gas chemistry. A packer and/or borehole liner systems will be designed, constructed and tested and used to sample gas and water chemistry from these boreholes.

2.2.1.9 Study 8.3.1.2.2.5 - Diffusion tests in the Exploratory Studies Facility

Activity 8.3.1.2.2.5.1 - Diffusion tests in the Exploratory Studies Facility. No progress during the reporting period; this was an out-year activity.

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

Revision 1 of the study plan was submitted for Project review on April 6, 1993. The Project comments were sent to USGS for response on June 8, 1993. All comments were resolved on September 21, 1993, and the approved study plan was prepared for transmittal to the Commission.

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Activity 8.3.1.2.2.6.1 - Gaseous-phase circulation study. 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-6, USW UZ-6s, USW UZ-13 and selected neutron access boreholes. Stable isotope, ^{14}C , ^{13}C , and ^3H results were received from the Southern Methodist University radiocarbon lab, the USGS Reston Isotope lab, and the Hydrologic Investigation Program Unsaturated Zone Hydrochemistry lab, respectively. Gas sampling for chlorofluorocarbon (^{11}F and ^{12}F) were conducted in USW UZ-6s. Results were received from the USGS, National Research Program laboratory. Background gas samples for CO_2 , CH_4 , SF_6 , CBrCl_2F , and $^{13/12}\text{C}$ were collected from 13 Hilti holes (small diameter, shallow boreholes) near the crest of Yucca Mountain and from USW UZ-6s on several occasions, in preparation for conducting the divergent tracer tests at those locations.

A standpipe for measuring air flow direction was designed, constructed and installed at USW UZ-6s. Flow velocity, temperature, and relative humidity data were collected using the new instrument configuration. A flow survey was conducted downhole in UE-25 UZ#16, using an anemometer, to determine the zones of origin of the gas flow. A shut-in pressure test was conducted in four isolated intervals in UE-25 UZ#16 to determine the pressure response of various lithologic units. Two papers, "The Composition CO_2 Carbon Isotope Signature of Gases from Borehole USW UZ-6, Yucca Mountain, Nevada," (Thorstenson, 1993) and "Does the Wind Blow Through Yucca Mountain?" (Weeks, 1993) were presented at a 1991 Commission meeting and have been published.

Preparation of data and interpretive reports of the physical and chemical data collected from USW UZ-6, USW UZ-6s, and select neutron holes has begun. A meeting was held with University of Nevada, Las Vegas staff to discuss lab tests needed to ascertain the tracer potential properties of various gasses proposed for use as gas tracers. Discussions were held with the M&O and other Project Participants to determine the need for an additional gas flow model for ESF test interference study and the additional data that will be needed to feed that modeling effort. Gas phase circulation model development continued. Various hydrologic procedures were prepared and updated to allow collection of temperature, humidity, pressure, flow and gas phase chemistry data.

Forecast: Periodic ongoing testing, sampling, and monitoring activities at boreholes USW UZ-6, USW UZ-6s, and selected neutron-access boreholes will continue in FY 1994. Selected boreholes completed in 1993 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, South Ramp, and Main Test Level drift will be tested as part of this study. This includes numerous North Ramp Geologic boreholes, a hole in the systematic drilling program, unsaturated zone boreholes, and existing boreholes. There will be a significant increase in the amount of samples collected and analyzed. The amount of in situ data collected and analyzed will also increase significantly.

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2.2.1.11 Study 8.3.1.2.2.7- Hydrochemical Characterization of the Unsaturated Zone.

Revision 1 of the study plan was submitted to the Project for review on November 24, 1992. The USGS received Project comments on the revision on February 8, 1993. The Department approved the study plan on September 10, 1993, and it was sent to the Commission on September 17, 1993.

Activity 8.3.1.2.2.7.1 - Gaseous-phase chemical investigations. An evaluation of existing transport models for gaseous ^{14}C in carbon dioxide showed that calculation of the partitioning of ^{13}C and ^{14}C between the gaseous, aqueous, and solid phases, even in a one-dimensional transport model, is not something that can be accomplished by incorporating a simple set of chemical equations into a transport model, nor by simple modifications of existing geochemical modeling codes. Discussions on how to proceed were held with USGS National Research Program personnel. An attempt was made to formulate equations for the distribution of ^{14}C in aqueous and solid phases. No practical solution to this problem was found. The current approach being tested involves precalculating reactions with PHREEQE and using these numerical results in the transport modeling. A manuscript entitled "Interpretation of Gaseous-Phase Isotopic and Chemical-Composition Data from Test Hole USW UZ-1" (Yang et al.) is in final stages of preparation for publication.

Laboratory analyses of gas samples included: methane, carbon dioxide, and carbon-isotopic concentrations from USW UZ-1; tritium analysis of water vapor samples from USW UZ-1; analysis for carbon dioxide concentrations in gas extracted from UE-25 UZ#16 tuff cores by one-dimensional compression; analyses for carbon dioxide, methane, and SF_6 concentrations from five depths in the open borehole UE-25 UZ#16. In addition, USW UZ-1 was monitored on five occasions for SF_6 concentrations and on one occasion for carbon dioxide concentrations to determine if concentrations changed during the drilling of USW UZ-14, which is approximately 30.5 m to the west of USW UZ-1. This was done to evaluate any fracture connection between the two boreholes.

The SF_6 tracer injection in various boreholes (USW UZ-14, UE-25 NRG#2a, UE-25 NRG#2b, UE-25 NRG#4, and UE-25 NRG#5) and sampling and monitoring of tracer concentrations in those holes continued. Drilling-air samples were collected for tracer-concentration analysis at least twice a day or whenever there was a significant change in the volume of drilling air being injected. A paper entitled "Field Testing the Effectiveness of Removing Sulfur Hexafluoride Traced Drilling Air from a Prototype Borehole near Superior, Arizona" (Peters et al., 1993) has been published.

The insertion of a lightweight, plastic, wire-rope-strung, non-rigid, eight packer string was attempted to a depth of 366 m in borehole UE-25 UZ#16. The packer handling system experienced some problems during the insertion. Due to these insertion problems, only four of the eight packers were inserted, and only to a depth of 183 m. Modifications to the packer handling system will be made in an attempt to alleviate the insertion problems. Gas samples for carbon dioxide, methane, sulfur hexafluoride, and carbon isotopic concentrations were collected from the four packed intervals. Carbon dioxide data indicate that concentration levels at UE-25 UZ#16 are similar to those in other unsaturated zone boreholes at the Nevada

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Test Site, and that concentrations of sulfur hexafluoride have decreased to near background levels.

The adsorption of carbon dioxide gas onto mineral surfaces in Yucca Mountain tuffs, especially the bedded tuff, is known to occur. The extent of adsorption onto various units of Yucca Mountain tuff under various water saturations (with alkalinity similar to the unsaturated-zone) has been investigated. These experiments are important in determining the gas-phase release of ^{14}C to the accessible environment.

Activity 8.3.1.2.2.7.2 - Aqueous-phase chemical investigations. Additional core from borehole UE-25 UZ#16 and 33 cores from USW UZ-14 were obtained for pore-water extraction by one-dimensional compression and distillation for water analysis of the pore waters. Pore-water extraction tests by one-dimensional compression were completed on 13 core samples (mostly from the Calico Hills unit) from UE-25 UZ#16. Another twenty eight core samples from UE-25 UZ#16 were prepared for one-dimensional pore-water extraction in 1994. Pore-water samples extracted from UE-25 UZ#16 core were sent for cation and anion analyses, and selected samples for ^{14}C determinations.

Pore-water extraction by distillation was accomplished on over 90 cores from USW UZN-55, UE-25 UZ#16, UE-25 UZ#4, and UE-25 UZ#5 boreholes. Selected water samples from these distillations and one-dimensional compression tests were analyzed for ^3H , ^{18}O , and $^2\text{H}/\text{H}$ ratio. Water samples from USW UZ-14 perched waters, and UE-25 UZN#2 precipitation waters were prepared and sent for analyses of ^3H , ^2H , $^{18/16}\text{O}$, $^{87/86}\text{Sr}$, ^{36}Cl , ^{14}C , $^{13/12}\text{C}$, rare earth elements, cations and anions.

Preliminary results for the USW UZ-14 perched-water chemical analyses indicated that a polymer drilling fluid component from G-1 drilling was present in USW UZ-14. Concentrations of inorganic constituents of the three perched water samples indicated that two of them were similar to the UE-25 J#13 water, and one was orders of magnitude higher than the UE-25 J#13 water compositions. The ^3H concentrations were near background level (i.e., greater than 100 year-old water). Results for other ^{14}C , $^{13/12}\text{C}$, $^{18/16}\text{O}$, $^{87/86}\text{Sr}$, and $^2\text{H}/\text{H}$ ratios have not been completed.

A manuscript entitled "Pore-Water Extraction from Unsaturated Tuff by Triaxial and One-Dimensional Compression Methods, Nevada Test Site, Nevada" (Mower et al.) was approved by the USGS for release as a Water-Resources Investigations Report. Two additional manuscripts, a journal paper, "Development of the One-Dimensional Compression Method for Extraction of Pore-Water from Unsaturated Tuff" (Higgins et al.), and a USGS Open-File Report documenting the chemistry of pore-water extracted by compression methods, are in preparation.

Forecast: Tracer injection, monitoring, and gas-sample analyses will be completed for USW UZ-14. Tracer gas injection and monitoring activities will be conducted at boreholes UE-25 NRG#5 and USW SD-12. Core samples from the existing boreholes (mostly USW UZ-14) will be compressed and distilled for pore-water extraction. Extracted water will be analyzed for cations, anions, and isotopic content. The USGS Water Resources

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Investigation Report, "Pore-Water Extraction from Unsaturated Tuff by Triaxial and One-Dimensional Compression Methods, Nevada Test Site, Nevada" (Mower et al.) will be published. Three manuscripts, "Interpretation of Gaseous-Phase Isotopic and Chemical-Composition Data from Test Hole USW UZ-1" (Yang et al.), "Development of the One-Dimensional Compression Method for Extraction of Pore-Water from Unsaturated Tuff" (Higgins et al.), and a USGS Open-File Report on pore-water chemistry, are planned for completion.

2.2.1.12 Study 8.3.1.2.2.8 - Fluid Flow in Unsaturated, Fractured Rock

Revision 0 of the study plan was submitted to the Commission on September 1, 1992, and the Phase I review was completed January 28, 1993. The Commission provided two comments and requested references cited in the study plan. The OCRWM responded in a letter dated May 27, 1993. Revision 1 is now in Project review.

Activity 8.3.1.2.2.8.1 - Development of conceptual and numerical models of fluid flow in unsaturated, fractured rock. Preliminary work testing the feasibility of deriving fracture porosity from acoustic properties of fractured core was completed. The technique was tested on data from boreholes UE-25 a#4, UE-25 a#5, UE-25 a#6, and UE-25 a#7 located in or near Drillhole Wash. Preliminary results show that core from fractured Topopah Spring partially welded tuff has an average calculated fracture porosity that is high but not unreasonable considering the wash is thought to be fault controlled. A search was started to acquire additional data from varying geologic and structural settings.

Transformation of the large volume of data from the large block percolation experiment (Activity 8.3.1.2.2.4.2) as input for numerical modeling was begun as well as formulation of modeling strategies.

Golder Associates Inc. assisted the USGS staff in adapting a fracture network model, FracMan, to unsaturated zone flow. As part of the conceptual design of this activity, fracture orientations, dip, frequency, density, size, orientation and flow rates in differential stress regimes, and fracture characterization at different scales continue to be compiled from borehole, pavement, and tunnel sources. This information will be used in the formulation of fracture networks and fracture network flow and transport models.

Meetings were held with Geologic Studies Program staff to discuss preliminary results of fracture mapping in the ESF starter tunnel, the UE-25 NRG#1 borehole, and the pavement study near UE-25 NRG#1. The data from the fracture mapping will be incorporated into developing fracture networks.

A report entitled "Numerical Investigation of Steady Liquid Flow in a Variably Saturated Fracture Network" (Kwicklis and Healy) was accepted for publication in Water Resources Research. This report examines the fundamental behavior of unsaturated fracture systems using numerical experiments. Analyses and compilation of existing fracture data from the site are under way and will continue as new information becomes available. A

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report entitled "Numerical and Laboratory Investigations of Transient and Steady-State Flow in a Fractured Core" (Kwicklis et al., 1993) was published. Additional data that were collected to help resolve uncertainties described in this report are being processed, but not yet available for modeling.

About 80 percent of the report/user's guide for the semi-analytical dual-porosity code has been written by Lawrence Berkeley Laboratory (LBL) staff. It contains discussions of dual-porosity models, fracture/matrix interaction equations, shape factors and equilibration times for matrix blocks. It also contains sample problems illustrating the use of the new code. The report has five appendices covering the following topics: numerical solutions to the Richards equation, sorptive lengths and imbibition equilibration times for matrix blocks, grid discretization, comparison between Brooks-Corey and van Genuchten sorptives, and the effect of air on the infiltration of water into matrix blocks. The LBL staff presented simulation results using the dual-porosity code at the unsaturated zone modeling meeting held in Berkeley, August 11-12, 1993.

An approximate expression for the Warren-Root alpha parameter, which governs the fracture/matrix interflow rate and equilibration time, was developed. The approximation utilizes the hydrologic parameters and surface/volume ratio of the matrix block, and seems to be more accurate than previous bounds and estimates. Several papers addressing the effect of block-size distribution, in the context of saturated flow or solute transport, have been collected from the literature and studied. Recent work was focused on developing an approach for approximating the behavior of a *distribution* of block sizes by an *equivalent* matrix block. Using both a Warren-Root and a more exact treatment of fracture/matrix interactions, the equivalent shape factors will be determined in terms of the moments of the block-size distribution function.

Roughly 50 percent of the report on semi-analytical methods, which will use previously developed LBL models to predict permeability from aperture data, has been written. Various sets of published data on aperture distributions and permeabilities of fractures were collected from the literature to use in testing the models. Preliminary results indicate that reasonable estimates of the permeability can be made based on measurements of the mean and standard deviation of the aperture distribution.

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: No activity is planned for FY 1994; this study is unfunded.

2.2.1.13 Study 8.3.1.2.2.9 - Site Unsaturated-Zone Modeling and Synthesis

The study plan was revised extensively during Project review to supply additional detail concerning numerical codes and modeling strategy to be employed by the study. The study

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plan was resubmitted on December 10, 1992, received Project approval on July 2, 1993, and was sent to the Commission on July 14, 1993.

Activity 8.3.1.2.2.9.1 - Conceptualization of the unsaturated-zone hydrogeologic system.

A report entitled "Estimation of Unsaturated Zone Liquid Water Flux at Boreholes UE-25 UZ#4, UE-25 UZ#5, USW UZ-7 and USW UZ-13, Yucca Mountain, Nevada, from Saturation and Water Potential Profiles" (Kwicklis et al.) was written and will be published in the Proceedings of Focus '93, Site Characterization and Model Validation. The report presents saturation profiles for the four named unsaturated zone boreholes, derives correlations between important unsaturated zone hydrologic parameters, and uses these correlations to calculate flux profiles at the four holes. Hydrologic interpretations made on the basis of this analysis compared favorably with interpretations made using isotope data. Shortcomings in various data used in the analysis were also discussed.

Building on the work described in the report named above, one-dimensional numerical simulations were done which attempted to reproduce the observed saturation and water potential profiles at UE-25 UZ#4 and UE-25 UZ#5 in Pagany Wash. Fair agreement between the observed and simulated profiles was obtained for UE-25 UZ#5 using a time-varying infiltration rate. The one-dimensional simulations were done as a necessary prelude to two-dimensional simulations which will examine the importance of lateral flow. A summary of this work has been submitted for acceptance to the 1994 High-Level Waste Conference.

A presentation on comparison of dual-porosity and effective continuum approaches to thermal modeling was made by Kwicklis and Bodvarsson at the Performance Assessment Thermal Modeling Meeting, June 29, 1993, in Las Vegas. The work presented demonstrated that even at high thermal loads, the relatively simple and efficient composite porosity approach to modeling fracture-matrix systems is an excellent approximation to a more complex, computationally demanding dual-porosity model.

Activity 8.3.1.2.2.9.2 - Selection, development, and testing of hydrologic-modeling computer codes. The decoupled TOUGH code has been successfully tested against the original TOUGH code for various problems of different complexity. For all of the cases tested, the decoupled code gave accurate results.

Activity 8.3.1.2.2.9.3 - Simulation of the natural hydrogeologic system. A report entitled "Development of a 3-D Site Scale Model of Yucca Mountain, Nevada" (Wittwer et al.) on moisture flow is in review at LBL and will be revised according to reviewer comments.

A study was performed addressing the accuracy of the three-dimensional site-scale model with respect to the grid spacing used. A numerical grid for one of the cross sections of the three-dimensional site scale model was developed by halving the vertical and horizontal dimensions of all elements, resulting in four times as many elements. Simulations were run to compare the results with the coarse grid. New moisture tension permeability and porosity data were received from other unsaturated zone activities. A number of reports were received from the participants and generally reviewed for relevance to the site-scale model. After

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reviewing papers on gas flow at Yucca Mountain, the existing unsaturated zone model was modified to include the gas component. In this model, the gas phase consists of both air and water vapor and has both pressure and diffusion as driving mechanism for its transport. A literature search to study the effects of alternate and more realistic surface boundary conditions was begun. Both one-dimensional and two-dimensional simulations of the effects of gas movement due to pressure gradient and diffusion on moisture flow were performed. Some of the parameters and model geometries used in the three-dimensional site-scale model were also used in a study of lateral flow in the Paintbrush unit. A paper entitled "Computer Simulation of Lateral Infiltration into the Paintbrush Unit at Yucca Mountain, Nevada" (McGraw et al., 1993) summarizing this work was accepted for presentation at Focus '93.

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: Staff at LBL will continue to develop the three-dimensional site-scale model. New geological, hydrological, and geochemical data will continuously 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. For example, areas of the mountain where moisture flow is mostly one-dimensional vertical will be identified. Conversely, other areas of the mountain where two- or three-dimensional complex flow is occurring, perhaps lateral flow in the bedded units, or flow within or near faults and offsets will also be identified. The initial moisture flow report describing the 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 and the results evaluated. Gas effects will be studied using submodels, and then incorporated into the site-scale model. Effects of the ESF 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

The study plan completed the NRC Phase I review on December 6, 1991.

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-six transducer calibrations were performed in support of the hourly monitored wells. Additional water-level measurements

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were made in support of other activities at the C-Well complex, Well UE-25 UZ#16, and Well USW UZ-14. Evaluation of the 1990-91 water-level data was completed, and a draft of a report entitled "Water Levels in the Yucca Mountain Area, Nevada, 1990-91" (Tucci et al.) documenting water levels for that period was completed. Reduction and evaluation of the 1992 water-level data were completed, and work has begun on a report entitled "Water Levels in the Yucca Mountain Area, Nevada, 1991-92" (Tucci and O'Brien). Evaluation of 1993 water-level data has begun and is continuing. Water levels have essentially remained stable during the reporting period.

Four zones in two wells were monitored continuously to detect water-level fluctuations caused by earthquakes. The region remains seismically active. Water-level fluctuations associated with earthquakes in southern California, May 17-19, 1993, were very minor and transient. All water levels returned to pre-earthquake levels within one to two hours.

Work was begun on plans for drilling two new wells, USW WT-23 and USW WT-24. The sites for these two wells were located in the field in June. Plans for cleaning, reconfiguring, and hydraulic testing of three WT-series wells were completed, as were plans for hydraulic testing of Well USW G-2.

Three reports were published during the reporting period: "Water Levels in Continuously Monitored Wells in the Yucca Mountain Area, Nevada, 1985-88" (Luckey et al., 1993); "Earthquake-Induced Water-Level Fluctuations at Yucca Mountain, Nevada, June 1992" (O'Brien, 1993); and "Hydrologic Responses to Earthquakes, June 28-29, 1992 at Yucca Mountain, Nevada" (O'Brien and Tucci, 1993).

Two reports, "Precision and Accuracy of Manual Water-Level Measurements Taken in the Yucca Mountain Area, Nye County, Nevada, 1988-90" (Boucher) and "Water Levels in Continuously Monitored Wells in the Yucca Mountain Area, Nevada, 1989" (Luckey et al.), have received USGS approval and are being processed for publication.

Activity 8.3.1.2.3.1.3 - Analysis of single- and multiple-well hydraulic-stress tests. A report entitled "Results and Interpretation of Preliminary Aquifer Tests in Boreholes UE-25 c#1, UE-25 c#2, and UE-25 c#3, Yucca Mountain, Nye County, Nevada" (Geldon) was sent out for technical review. Past C-holes test data were analyzed by using manual graphical matching techniques and are included in this report. A paper entitled "Analysis of Aquifer Tests in Miocene Tuffaceous Rocks with Layered Fracture and Matrix Permeability, Yucca Mountain, Nevada" (Geldon) was submitted to the Geological Society of America Annual Meeting in Boston, Massachusetts, October 24-29, 1993.

During June 1993, Wells UE-25 c#1, UE-25 c#2, and UE-25 c#3 were instrumented with transducers in an open-hole configuration to collect atmospheric-loading data. These data will be analyzed to obtain a barometric efficiency correction factor and hydraulic diffusivity.

Activity 8.3.1.2.3.1.4 - Multiple-well interference testing. The USGS Heat and Solute Transport three-dimensional code, written by USGS National Research Program personnel, is

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being used to develop a three-dimensional porous-medium-equivalent model of the C-hole complex (the model can be used for cross-hole test design and analysis of the eventual cross-hole test results). A preliminary run of the Heat and Solute Transport code was successfully completed, using an input file representing a geohydrologic model of the cross-section between UE-25 c#1 and UE-25 c#3.

The Department issued a "Temporary Deferral of Selected Activities" to the USGS covering all pumping activities at the C-holes until the pump power cable issue is resolved. A Department Order required the power cable to be a four-conductor cable, with one of the conductors a ground wire, and all the pump-related equipment be Underwriters' Laboratories, Inc.-listed. This requirement exceeds the National Electric Code. A formal memorandum responding to the deferral order was sent to the Department after an extensive and exhaustive market search, involving all major pump and pump cable companies, in search of a way to resolve the four-conductor/Underwriters' Laboratories, Inc.-listing dilemma.

An interim plan was developed to conduct non-pumping tests at the C-holes until the discharge pipeline is completed, and the power cable issue is resolved. The interim plan involves monitoring for hydraulic effects of barometric pressure changes with open holes and for the hydraulic effects of earth tides and seismic strain with packer-string-instrumented holes.

Activity 8.3.1.2.3.1.5 - Testing of the C-hole sites with conservative tracers. A tracer mixing tank will be required on the surface at the C-holes complex during the tracer tests at the C-holes. The tank design was discussed with Klaus Stetzenbach, Professor of Chemistry at the University of Nevada, Las Vegas, who will be preparing the tracer at the Hydrologic Research Facility, prior to placing it in the tracer tank. Topics discussed included the possibility of any harmful vapors emanating from the tank, necessity of mixing the tracer in the tank, necessity of a mixing pump in the tank, and the availability of prefabricated tanks made from specially resistant materials. Work continued on design refinement and purchasing of materials for the downhole tracer injection system.

Forecast: Routine monthly, hourly, and continuous water-level monitoring will continue with the present network. Plans will be formulated for cleaning, reconfiguring, and hydraulic testing for all WT-series wells, as well as several other wells. Specifications for the drilling of Well USW WT-23 will be completed. The 1990-91 water-level data report will be submitted for approval, and a draft of the report on the 1992 water levels will be completed. Water-level data evaluation for 1993 will continue.

Phase I of work at the C-holes will be conducted, and will involve: (1) running a "dummy packer" down the three C-holes to total depth to identify any problems that may arise when the actual packer strings are lowered; (2) lowering the pump shroud (with no pump) to the location where it would eventually be placed in Well UE-25 c#3 (this well has the worst borehole constriction problems among the three), to identify any problems that may arise when the pump and shroud unit are eventually lowered; and (3) installing the packer strings in the three C-holes with three packers in each hole, allowing for four individual zones to be tested. Actual pumping from the C-holes cannot be done until the pump power cable

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grounding issue is resolved, and the discharge pipeline and discharge pond are constructed. It is anticipated that Phase II of work at the C-holes (the pumping phase) may commence in January or February of 1994, allowing for a month or two of cross-hole testing to be done within the forecast period. The collection of data during these tests will be controlled by a computerized data acquisition system that has been developed specifically for these tests.

Activity 8.3.1.2.3.1.6 - Well testing with conservative tracers throughout the site. No progress this 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. Data collection was completed on the suite of batch sorption experiments for lithium bromide; the results were analyzed, and two reports describing this characterization work were prepared. In a report entitled "Lithium Batch Experiments" (Newman et al.), the authors discussed sorption isotherms (surface concentration versus fluid concentration) obtained using tuff from Well UE-25 c#2 in the Bullfrog Member. The second report entitled "The Influence of Temperature and the Solid-Liquid Ratio on the Adsorption of Lithium in a J-13 Well Water and a C-2 Bullfrog Tuff System" (Polzer et al.) presented information on the influence of temperature and rock-water ratio on sorption.

Tracer tests were conducted using iodide and polystyrene microsphere tracers in a natural fracture in Bandelier Tuff, in preparation for similar tests in two C-Wells fracture specimens. In preparation for field tests at the C-Wells, several sizes and types of microspheres were tested.

Software documentation and QA efforts continued for the FEHMN application, a three-dimensional, multi-phase heat and mass transfer code.

Two papers were approved by the Project, and accepted for publication by the Journal of Radioactive Waste Management: "A Strategy for Validating a Conceptual Model for Radionuclide Migration in the Saturated Zone Beneath Yucca Mountain" (Robinson) and "The Use of Selectivity Coefficients to Estimate Modified Langmuir Isotherm Parameters as a Function of Experimental Conditions" (Polzer and Essington).

B. Robinson compiled all documentation for the computer code SORBEQ and prepared a paper entitled "SORBEQ—A One-Dimensional Model for Simulating Column Transport Experiments," which was approved by the Project. The model simulates one-dimensional transport governed by the convective-dispersion equation, with equilibrium sorption. It is designed to be used to simulate column sorption data to obtain the best-fit parameter values. This paper also includes all requirements, design, verification, and user information; it will be published as a Los Alamos National Laboratory (Los Alamos) report.

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: To ensure confidence that field experiments will yield usable results (i.e., a breakthrough curve in an interwell tracer test), Los Alamos staff plans to demonstrate, using

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laboratory-scale specimens, that microspheres transport through fractures; these tests will determine which particle sizes and what quantities will be used in field tests. Staff will also determine, by comparing to dissolved tracer breakthrough curves, whether transport behavior is controlled by hydrologic mechanisms or interactions with the rock surface. All details of the design of C-Wells experiments will be developed. The choice of well and flow rates of circulation will be determined. Using numerical solutions, the test duration, injection amount, concentration and duration of tracer injection, and sampling frequency will be set. The appropriate detailed technical procedures will be written.

2.2.1.15 Study 8.3.1.2.3.2 - Characterization of the Saturated-Zone Hydrochemistry

The study plan was accepted by the Commission in a Phase 1 review letter January 4, 1993, with no comments but with a request for references. The requested references were sent to the Commission on April 20, 1993..

Activity 8.3.1.2.3.2.1 - Assessment of saturated-zone hydrochemical data availability and needs. Using lithologic data from a Geographic Information System retrieval, the previously constructed set of 2203 balanced (<10 percent) analyses was sorted by lithologic type. Basic statistics were calculated for the chemical analyses for each lithologic group. The calculated results were not reasonable, necessitating examination of the process. On finding that many retrieved data were incorrectly associated with well and spring locations, they were retrieved again, verified, the data set re-sorted, and the statistics recalculated. A set of means data calculated using this data set was subsequently used for Statistical Analysis System cluster analysis. Nine distinct clusters were defined by the analysis, which used normalized-Euclidean-distance, farthest-neighbor examination of a log-transformed and pre-clustered version of the means data set. Preliminary interpretation of relative mean concentrations and the results of basic statistics for the populations of each cluster revealed relations between water chemistry, lithology, and geologic structure. In the course of preparation of a draft report for release of the data base it was determined that some location data were incorrect. These location errors were corrected. A report, "Regional Groundwater Chemistry Data, Death Valley Region, Southwestern United States" (Perfect et al.), is in preparation.

Activity 8.3.1.2.3.2.2 - Hydrochemical characterization of water in the upper part of the saturated zone. Planning for construction of a mobile laboratory included examination of extant USGS equipment in Boulder, Colorado, maintenance of analytical equipment (ion chromatograph system) purchased for inclusion in a laboratory, and examination of a currently idle Environmental Protection Agency mobile laboratory in Las Vegas. The availability of the equipment is being pursued by staff as a possible cost- and time-saving opportunity.

Contact has been maintained with possible suppliers of equipment that will be used to discretize saturated intervals of boreholes that will, perhaps, be sampled as part of saturated zone hydrochemistry characterization efforts. The only effort toward development of a downhole data and sample collection system was contact with the manufacturer of a fiber-

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optic-based dissolved oxygen meter for consideration of inclusion in the system to be obtained when funding is allocated.

Field data and a suite of samples were collected in late August during construction of USW UZ-14. The fluid sampled is, at least in part, drilling fluid lost during construction of USW G-1. The complete set of resultant analytical data likely will be available no earlier than December 1, 1993.

Input was provided in preparation of plans to clean out selected water-table holes at the site.

Activity 8.3.1.2.3.2.3 - Regional hydrochemical tests and analyses. Samples and field data were collected at additional springs within Death Valley National Monument to provide a hydrochemical and isotopic means of evaluating the extent to which Death Valley is a boundary of the regional geohydrologic system of which Yucca Mountain area is a part. Precise locations of discrete discharges were determined and site identifications established for all sites sampled to date. A water-treatment system was installed in USGS facilities in Area 25 at the Nevada Test Site to support these and subsequent data- and sample-collection efforts. A paper entitled "Hydrochemical Monitoring Through a Thick Unsaturated Zone at Yucca Mountain, Nevada, USA" (Steinkampf, 1993) describing hydrochemical monitoring at Yucca Mountain has been published.

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 report documenting the compilation and assessment of extant hydrochemical data will be reviewed and approved for release. Preparations to conduct detailed hydrochemical characterization at and in the vicinity of Yucca Mountain will continue, but the continuing deferral of capital funding will delay the start of collection of defensible data and samples until about March of 1996. Plans to collect preliminary data and samples during the cleaning of perhaps three water-table holes will be finalized.

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

The study plan was sent to the Commission on January 28, 1993. The Commission accepted the study plan on June 16, 1993, and requested six references cited in it. The references were sent on October 25, 1993.

Activity 8.3.1.2.3.3.1 - Conceptualization of saturated-zone flow models within the boundaries of the accessible environment. Twenty-one outcrop samples were collected, using a portable 1-in-diameter drill, from the Crater Flat Tuff outcrop east of Little Skull Mountain in the Bullfrog Member. The samples were collected and analyzed for the following physical properties: bulk density, porosity, and particle density. Two methods of drying, relative humidity drying and hard drying, were used during processing of the samples. The data will

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be used for scoping calculation for preliminary ground-water modeling of the site area at Yucca Mountain.

Activity 8.3.1.2.3.3.2 - Development of fracture network model. A study on the effects of censoring on fracture data from theoretical pavement maps was done by LBL staff. A report entitled "A Forward Simulation of Pavement Maps and Censoring Effects on Determining Fracture Size Distribution" (Najita) is now in LBL review. A user's manual and tutorial for the fracture flow and transport code TRINET is in review at LBL. The largest fracture flow simulation ever run using TRINET, 250,000 elements on a Sun work station, was successfully carried out. An inversion algorithm called cluster annealing that combines variable aperture fracture to match well hydraulic test data worked successfully and converged much faster than a single element on-off annealing on a synthetic case. A journal paper entitled "Using the Jackknife, the Bootstrap, and Cross-Validation with Spatially Dependent Data" (Mauldon et al.) is in review.

A report presenting fracture data collected from outcrops, "Fracture Data from Outcrops of the Bullfrog Member of the Crater Flat Tuff near Yucca Mountain, Nevada" (Ervin and Chornack), is in the USGS review process. Data include fracture orientation, length and height dimensions, spacing, mineral fill or coating, type of fracture, and qualitative categories for expression, shape, and roughness. The data are organized in table form, and orientation data are plotted on stereonet and in rose diagrams. The data will be used to constrain the numerical fracture-network model discussed above.

Activity investigators are developing a summary of possible conceptual models for fracture flow at the C-hole complex. The model(s) will be the basis for developing the fracture-flow model at the multiple-well complex.

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 conceptual model for ground-water flow at Yucca Mountain on the site scale (tens of kilometers in x-y space) will be developed in 1994. Preliminary numerical modeling will be done to test the site-scale conceptual model. The conceptual and numerical fracture-network models that will be used to interpret results of hydraulic tests at the C-hole complex will be refined. A report containing data on fracture networks in the Bullfrog Member of the Crater Flat Tuff will be completed. Approximately 20 samples of fracture fill material from outcrops of the Crater Flat Tuff will be collected. The results of the C-hole hydraulic tests also will be examined employing both the inverse technique using the inversion scheme to calculate aquifer properties and by the forward process using the spatially correlated model to predict hydrologic results. Studies of effects of permeable matrix on flow and transport in fractured rocks will be conducted. Results of cross-hole hydraulic and tracer tests at the C-hole complex will be examined to investigate the effects of the tuff matrix. Studies on scale effects will be carried out to understand whether, and how, the findings at the well test scale can be extrapolated to larger scales. Results of cross-hole hydraulic and tracer tests at the C-hole complex will be examined to investigate scale effects.

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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

Review comments on the study plan were received in May 1992 and were being addressed during this reporting period.

Data collection on geochemical modeling of Yucca Mountain ground waters in support of the "most active ground-water" model were completed, and a letter report describing the results was in preparation. A summary report of pH and Eh conditions at Yucca Mountain was in progress.

Forecast: Staff will address additional comments to the study plan, participate in the October DOE-NRC Technical Exchange, and complete the paper on pH and Eh at Yucca Mountain.

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

The study plan was being revised during the reporting period.

Activity 8.3.1.3.2.1.1. - Petrologic stratigraphy of the Topopah Spring Member. There was little progress in this activity because efforts were deferred until samples became available from new drill core and from the ESF. New UE-25 UZ#16 samples have been received; a letter report was prepared summarizing preliminary quantitative x-ray diffraction analyses on the upper portions of the UE-25 UZ#16 core, emphasizing shallow, potentially transmissive zones. However, analysis of the remainder of the UE-25 UZ#16 core, including the Topopah Spring Member host rock, will be completed in FY 1994.

Preliminary data collection on the chemical composition of fracture calcites at Yucca Mountain was completed. A paper on this subject entitled "Combined Quantitative-XRD and Chemical Evaluation of Soil Formation at Yucca Mountain, Nevada" (Vaniman et al., 1993) was published. The results indicated that with the exception of drill core USW G-4, there is a common composition for most unsaturated-zone calcites at Yucca Mountain that is distinct from most calcites in the saturated zone.

Activity 8.3.1.3.2.1.2. - Mineral distributions between the host rock and the accessible environment. Thirty samples from five different major rock groups at Yucca Mountain were prepared for microautoradiography analysis.

Data collection was completed on instrumental neutron activation analyses of calcites from a variety of boreholes. A paper summarizing the results, "Calcite Deposits in Drill Cores USW G-2 and USW GU-3/G-3 at Yucca Mountain, Nevada" (Vaniman), was approved for publication by the Project and will be published as a Los Alamos report.

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An invited talk entitled "Applications of Advanced X-ray Powder Diffraction Methods to Natural Zeolites" (Bish, 1993a) was presented at the International Conference on Applied Mineralogy in Fremantle, Australia, May 30 to June 4, 1993. The talk emphasized the large amount of quantitative information available in the x-ray diffraction patterns of natural zeolites and used numerous examples from Yucca Mountain studies, ranging from studies of the erionite content of tuffs to the hydration/dehydration behavior of zeolites. An abstract of this talk was approved by the Project and published in the conference program.

An invited talk entitled "The Importance Of Zeolites in the Potential High-level Radioactive Waste Repository at Yucca Mountain, Nevada" (Vaniman and Bish, 1993) was presented at the 4th International Conference on the Occurrence, Properties, and Utilization of Natural Zeolites (Zeolite '93) in Boise, Idaho, June 20-28, 1993. The abstract of this talk was published in the conference program. Vaniman evaluated the role of zeolites in waste retardation, site thermal loading, and site hydrology. In particular, the paper considers the details of zeolite-radionuclide interactions in light of recent sorption data. A paper was completed for the conference proceedings volume and was in the Project approval process.

A poster entitled "Equilibrium Modeling of the Formation of Zeolites in Fractures at Yucca Mountain, Nevada" (Chipera et al., 1993) was presented at Zeolite '93. The abstract of this talk was published in the conference program. Equilibrium thermodynamic modeling was used to explain the present-day mineral assemblages at Yucca Mountain, with emphasis on the zeolitic assemblages. The model calculations suggested that silica activity is an important variable in determining the zeolite mineralogy. In addition, it was found that temperature and the dominant alkali or alkaline earth cation exert some control on the stable zeolite assemblage. A full paper was completed for the conference proceedings volume and was in the Project approval process.

Collection of x-ray diffraction and chemical analyses of unweathered tuffs grading into soil horizons was completed. A talk based on this work entitled "Combined Quantitative X-ray Diffraction and Chemical Evaluation of Soil Formation at Yucca Mountain, Nevada" (Vaniman et al., 1993) was presented at the 1993 Clay Minerals Society Meeting in San Diego, September 25-30, 1993. The abstract was approved by YMPO and published in the conference program. This study was designed to examine sources of materials and their modes of transportation, focusing on sources of silica that may be transported downward into the unsaturated zone and the effects of weathering on mafic minerals.

Data collection was completed on the effects of varying humidity on the calibration data obtained for clays and zeolites occurring at Yucca Mountain, and a talk on this subject entitled "Effects of Humidity on Clay and Zeolite Quantitative XRD Analyses" (Chipera and Bish, 1993) was presented at the 1993 Clay Minerals Society Meeting. The abstract was approved by the Project and published in the conference program.

Dust samples were collected from natural dust traps at and near Yucca Mountain and from the cyclone on the drilling rig at UE-25 UZ#16, and the samples were characterized using x-ray diffraction and scanning electron microscopy to define natural background dust levels in the Yucca Mountain area.

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Activity 8.3.1.3.2.1.3. - Fracture mineralogy. A paper entitled "Fracture-Lining Manganese Oxide Minerals in Silicic Tuff, Yucca Mountain, Nevada" (Carlos et al., 1993a) was published in Chemical Geology. The authors indicated that Mn-oxide mineralogy appears to be controlled by both stratigraphy and relationship to the static water level (water table). In fractures below the water table, Mn- and Fe-oxides are potentially the most significant minerals for retardation of some radionuclides, particularly the actinides, and the Mn-oxide minerals may form an important barrier to radionuclide migration in a waste repository. Because of the ease with which the Mn in these minerals is reduced, their contribution to sustaining oxidizing ground-water conditions should be considered.

A poster entitled "Distribution of Fracture-Lining Zeolites at Yucca Mountain, Nevada" (Carlos et al., 1993b) was presented at Zeolite '93. The author presented information on the variation in mineralogy and chemistry of fracture-lining zeolites across Yucca Mountain. An abstract of this poster was approved by the Project and published in the conference program. A full paper was completed for the conference proceedings volume and was in the Project approval process.

Forecast: The fracture mineralogy of drillholes USW UZ-14 and UE-25 UZ#16 will be determined, and these data, along with previously collected data on fracture mineralogy, will be included in a report summarizing all fracture-mineralogy studies at Yucca Mountain. The study of respirable minerals at and around Yucca Mountain, and at USW UZ-14 and ESF-related excavations will continue. Trace minerals such as Fe-Ti oxides, which may have significantly greater sorption or surface complexation potential than the bulk rock, will be quantified. The mineralogy and chemistry of calcite in fractures at Yucca Mountain will be studied to determine the origin of calcite-depositing fluids and to identify paleotransport pathways for these fluids. Using x-ray diffraction, x-ray fluorescence, scanning electron microscopy, and optical petrography, the mineralogy of rock units above and below the potential repository horizon using core from UE-25 UZ#16 will be determined. This work will focus on ties between mineralogy, unsaturated-zone hydrology, and thermal loading. Quantitative x-ray diffraction analytical methods, incorporating the effects of changing humidity on hydrous minerals and possibly incorporating compositional information will continue to be improved.

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

The study plan was completed by NRC in a Phase I review on April 27, 1992.

Activity 8.3.1.3.2.2.1 - History of mineralogic and geochemical alteration of Yucca Mountain. Sample collection in the ESF North Ramp Starter Tunnel began.

K/Ar studies of secondary minerals using the electron microprobe and scanning electron microscope continued. Zeolites from altered volcanic ashes at Barstow and Lake Tecopa were examined.

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Data collection was completed on dating zeolites from existing Yucca Mountain drillholes and from other locations in the southwest, and an invited talk on this subject entitled "K/Ar Dating of Clinoptilolites: Methods and Preliminary Results" (WoldeGabriel, 1993) was approved by YMPO and presented at Zeolite '93. An abstract of this work was published in the conference program. A full proceedings paper was also completed and approved by YMPO.

A paper entitled "Paleogeothermal and Paleohydrologic Conditions in Silicic Tuff from Yucca Mountain, Nevada" (Bish and Aronson, 1993) was approved by YMPO and published in the journal Clay and Clay Minerals. The authors used results of illite/smectite studies of clays from Yucca Mountain drill cores and K/Ar dates for some of these clays to reconstruct the paleogeothermal gradients along Yucca Mountain as they existed approximately 11 million years ago. The effects of both deep hydrothermal circulation and "rain-curtain" meteoric recharge may be discernible in the gradients.

A paper entitled "ESR Dating of Quartz from Exile Hill, Nevada" (Cowan et al., 1993) was published in Applied Radiation and Isotopes. Drusy quartz from the Tiva Canyon tuff in Trench 14 was dated using a technique that measured the gradual accumulation of paramagnetic defects produced by alpha recoil in the quartz. The calculated age of 8.7 ± 2.6 million years has a large uncertainty, but is clearly not a Quaternary age.

Data collection was completed on altered rock at Busted Butte and Yucca Mountain, and a paper entitled "Surface-Discharging Hydrothermal Systems at Yucca Mountain—Examining the Evidence" (Levy, 1993) was approved by YMPO and published in the proceedings of the Materials Research Society. The paper describes exposures of altered rock at Busted Butte and Yucca Mountain that were thought to have been formed by recent discharges of water from depth; they were examined to address a concern about hydrothermal processes that could compromise the isolation capability of a potential waste repository. Levy found that the deposits are most likely the products of hydrothermal processes engendered by infiltration of water into newly deposited and still-hot pyroclastic flows that occurred more than 12 million years ago. Data collection on petrographic analysis for an expanded study on this subject was completed, and a paper on this subject entitled "Studies of Altered and Fractured Rocks Exposed around Yucca Mountain, Nevada" (Levy) was being prepared for approval by YMPO.

Preliminary plans were completed for natural self-analog studies of alteration in the Topopah Spring tuff, in conjunction with numerical modeling, as a means of understanding potential repository hydrothermal effects. The plans were summarized in a talk entitled "Natural Alteration in the Cooling Topopah Spring Tuff, Yucca Mountain, Nevada, as an Analog to a Waste-Repository Hydrothermal Regime" (Levy and Valentine, 1993) which was presented at Focus '93. A proceedings paper on this subject was prepared and submitted for Project approval.

Activity 8.3.1.3.2.2.2 - Smectite, zeolite, manganese minerals, glass dehydration, and transformation. Long-term steam-heating experiments, which were begun one year ago, continued. The materials under investigation include devitrified tuff, vitric nonwelded tuff,

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vitrophyre, smectite-rich altered tuff, zeolitic altered nonwelded tuff, cation-exchanged clays, opal-CT, and two standard clinoptilolites.

A talk entitled "Alteration History of Yucca Mountain due to Thermal Effects: Analog for a Hot Repository?" (Bish) was presented to the Nuclear Waste Technical Review Board. The presentation highlighted the following: (1) three kinds of natural alteration at Yucca Mountain that provide insight into the thermal stability of zeolites and clays under saturated conditions; (2) the variability associated with fracture-dominated hydrothermal alteration in the unsaturated zone; and (3) changes in hydrologic properties associated with zeolitization of glassy nonwelded tuffs.

An effort to model the evolution of water from zeolitic tuffs at controlled temperatures and water vapor pressures was begun. The data will help predict the behavior of zeolitic tuffs under repository-induced thermal conditions.

Data collection on the effects of heating on zeolite crystal-lattice dimensions was completed and a talk entitled "Thermal Behavior of Natural Zeolites" (Bish, 1993b) was presented at Zeolite '93. An abstract of this talk was published in the conference program; a proceedings paper was completed and was in the YMPO approval process.

Forecast: The report on history of chemical alteration at Yucca Mountain will be supported. Textural, mineralogical, and chemical analyses of core containing alteration features, with emphasis on faults and breccia zones, transport-related features, and natural gels will be collected. Laboratory tests to collect new K/Ar data will be conducted. Using surface and subsurface samples, relationships between mineral alteration and hydrologic history, emphasizing the identification of past preferential ground-water pathways will be studied. Mineralogical and geochemical studies of Trench 14 will be completed. Short-term experiments on pure minerals to determine dehydration/rehydration behavior and volume changes will be performed. The stability of clinoptilolite, smectite, hematite, devitrified, vitric, and zeolitic tuffs, vitrophyre, and opal-CT 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 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

The draft study plan is being revised by Los Alamos staff prior to YMPO review.

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Activity 8.3.1.3.3.2.1 - Kinetic studies of zeolite and related framework silicates. No progress during the reporting period; this was an unfunded activity.

Activity 8.3.1.3.3.2.2 - Determination of end-member free energies for clinoptilolite-heulandite, albite, and analcime. No progress during the reporting period; this was an unfunded activity.

Activity 8.3.1.3.3.2.3 - Solid solution descriptions of clinoptilolite-heulandite and analcime. No progress during the reporting period; this was an unfunded activity.

Forecast: The study plan will be revised. The solubilities of mordenite, clinoptilolite, and analcime to derive improved estimates of ΔH° , for use in improving the design of kinetic experiments and for defining their equilibrium states when modeling the response of the potential repository rocks to heating will be measured and evaluated. This activity will focus on the measurement and evaluation of reaction rate constants and associated activation energies for: (1) the dissolution and precipitation of cristobalite; (2) the dissolution and precipitation of mordenite, clinoptilolite, and analcime; (3) reactions between and among mordenite, clinoptilolite, and analcime; and (4) the reaction of smectite to illite. These studies will be carried out from H3OR to 25ORC as functions of: (1) the activity of water; (2) silica activity; (3) aluminum activity; and (4) the ratio of $H^+/Na^+/K^+/Ca^{2+}$.

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.

Forecast: No activity is planned for FY 1994; this is an unfunded study.

2.2.2.7 Study 8.3.1.3.4.1 - Batch Sorption Studies

A draft of the study plan, which combines studies 8.3.1.3.4.1 and 8.3.1.3.4.3, was submitted to YMPO on October 28, 1992. Review comments on the study plan were returned to Los Alamos in February 1993. They were being addressed during this reporting period.

Activity 8.3.1.3.4.1.1 - Batch sorption measurements as a function of solid phase composition. Data collection was completed on the study of uranyl interactions in the goethite/solution interface. A report on this subject entitled "Uranyl Interactions in the Goethite/Solution Interphase Region: Formation of Binary and Ternary Surface Complexes" (Kohler, Honeyman, and Leckie) was being prepared. This report focuses on the development of an empirical data base leading to the derivation of binding constants for uranium adsorption onto goethite in the presence of CO_2 and ethylene-diamine tetraacetate using the triple-layer model to provide the necessary parameters for equilibrium models.

Data collection was completed and a paper entitled "Neptunium Retardation with Tuffs and Ground-waters from Yucca Mountain (3040)" (Triay et al., 1993a) on the role that trace

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minerals in tuff play in Np retardation was published. The results of these studies indicated that sorption of Np does not appear to correlate with the quantity of trace metal oxides in the tuff.

Data collection was completed on a study of radionuclide sorption as it relates to sample grinding, surface area, and water composition, and a paper entitled "Dependence of Radionuclide Sorption on Sample Grinding, Surface Area, and Water Composition" (Rogers and Meijer, 1993) was published. The results of this study indicated that particle grinding does not influence the sorption behavior of the tuff samples until the particle size becomes smaller than about 38 μm .

Activity 8.3.1.3.4.1.2 - Sorption as a function of sorbing element concentrations (isotherms). Data collection was completed on the study of the sorption of ^{237}Np , ^{137}Cs , ^{133}Ba , and ^{85}Sr onto tuffs from the Topopah Spring Member; from zeolitic and vitric Calico Hills; and from the following pure minerals: calcite, hematite, montmorillonite, clinoptilolite, and quartz. Sorption of these tuffs and minerals was studied as a function of radionuclide concentration and temperature (25°, 60°, and 80°C).

Activity 8.3.1.3.4.1.3 - Sorption as a function of ground-water composition. Staff studied sorption of Np onto tuffs and pure minerals (See Section 8.3.1.3.4.1.2.) as a function of ground water (UE-25 J#13, UE-25 p#1, and synthetic) and temperature (25°, 60°, and 80°C). The experimental results will be reported by Triay et al. in a report entitled "Summary Report on Np Transport through Yucca Mountain Tuffs."

The paper by Rogers and Meijer (1993) (see Activity 8.3.1.3.4.1.1 above) reported the results of studies in which devitrified and zeolitized tuffs were pretreated with a synthetic water (with a Paleozoic-rock-aquifer-type water chemical composition) and following this, the sorption experiments were performed with normal UE-25 J#13 ground water. The pretreatment step was undertaken to simulate a situation in which ground water similar to UE-25 J#13 leaked from the repository and contacted deeper layers of tuff that had been previously saturated with a Paleozoic-type ground water. The results indicated that in devitrified tuffs, where sorption is dominated by surface reactions, the sorption of Np is insensitive to adsorption of calcium and magnesium during the pretreatment step. In the case of zeolitic tuffs, the sorption coefficient decreases by a factor of three for the pretreated tuffs. This behavior might be the result of competition for Np exchange sites by the divalent cations in a Paleozoic-type water.

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

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

Activity 8.3.1.3.4.3 - Development of sorption models - (See comment in Section 2.2.2.9.) Staff studied reactions of goethite mineral surfaces with water using atomic force

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microscopy. Certain surfaces were observed to react very quickly with water, producing significantly increased surface roughness.

Data collection on atomic force microscopy images of goethite and hematite surfaces was completed and a report entitled "Atomic Force Microscopy Studies of Natural Mineral Surfaces" (Rogers), which discusses experimentally observed surface reactions with water as a function of surface structure and orientation, was being prepared.

Forecast: The following activities will be performed:

1. Whole-rock experiments to determine the effect of organic coatings on radionuclide sorption onto tuffs (with emphasis on Np and U) will be conducted. Spectroscopic techniques to determine the mechanism of radionuclide sorption onto organic coatings will be used.
2. The sorption of U and Pu as a function of radionuclide concentration using tuff samples will be determined. The effect of T on the sorption of U and Pu onto tuff at 25°, 60° and 90°C will be determined.
3. Sorption measurements will be made on U and Pu as a function of ground-water chemistry (using UE-25 J#13, UE-25 p#1, and NaHCO₃ waters) at pH 6, 7, and 8.5. Carbon dioxide overpressures will be utilized to attain the specified pH values.
4. Experiments on pure separates of the minerals found in Yucca Mountain tuffs in various solutions using all of the important radionuclides will be conducted and the results used to interpret and extrapolate the whole-rock K_d data.

Priorities will be set using Los Alamos sorption strategy. The study of Np and focus on other radionuclides such as Pu and U will be completed. Progress reports and a final report on sorption of radionuclides by single minerals will be produced. To identify the sorbing phases (in tuff) for U and Pu, sorption experiments using pure mineral separates will be conducted, and the identity of surface layers absorbed or precipitated on minerals from Yucca Mountain and their influence on sorption properties will be determined. The validity of the surface complexation model and the validity of parameters obtained from single mineral studies for predicting surface adsorption of Np and U on devitrified tuffs will be tested.

2.2.2.8 Study 8.3.1.3.4.2 - Biological Sorption and Transport

A package of references requested by the Commission in a Phase I review on March 25, 1993, was sent by OCRWM on August 5, 1993.

The principal investigator was on sabbatical leave at the University of California, Berkeley from September 15, 1992 to September 15, 1993, studying microbially enhanced mineral dissolution (goethite and hematite).

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A paper entitled "The Role of Siderophores in the Transport of Radionuclides" (Hersman et al., 1993) was published. The results indicated that actinide elements, which normally exhibit quite low solubilities in near-neutral solutions, can be complexed by carbonate ligands and form solutions of higher actinide ion concentration. The results of this study bear significantly on the transport of radioactive wastes through a soil/rock system because it is possible that siderophores produced by soil microorganisms could complex with actinide/carbonate complexes, thereby altering the transport rate of the elements.

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 has been combined with Study 8.3.1.3.4.1. A discussion and status is included in Section 2.2.2.7.

2.2.2.10 Study 8.3.1.3.5.1 - Dissolved Species Concentration Limits

Resolution of all reviewers' comments on the study plan were verified and approved by YMPO on September 9, 1993. OCRWM explained, in the transmittal letter, how the study plan addressed Site Characterization Analysis Comment 96. The study plan was sent to NRC on September 17, 1993.

Activity 8.3.1.3.5.1.1 - Solubility measurements. A Los Alamos staff member participated in the panel discussion entitled "Review of Formation of Radiocolloids" at the Yucca Mountain Site Characterization Project (YMP) Colloid Workshop in Santa Fe, New Mexico, May 3-5, 1993.

Staff completed data collection on the final undersaturation experiments for Pu at pH 8.5 and Np at pH 6 in UE-25 p#1 water. A report detailing the results of these studies was being prepared.

Staff began new Np, Pu, and Am/Nd solubility experiments from oversaturation in 0.1-molar sodium perchlorate at 25°C.

Data collection was completed on the study of actinide solubilities and speciations at pH 6, 7, and 8.5 at 25° and 60°C in two Yucca Mountain ground waters, and a paper on this subject entitled "Radionuclide Solubility and Speciation Studies for the Yucca Mountain Site Characterization Project" (Nitsche et al., 1993a) was published. The results indicated that the ground waters differ substantially in total dissolved carbonate concentration, and to a lesser extent in ionic strength. In the waters with higher carbonate content, the solubilities of Np(V) decreased, whereas those of Am(III) increased at 25°C and decreased at 60°C. Pu solubilities did not significantly change with changing water composition because the solubility-controlling solids were mostly amorphous Pu(IV) polymers that contained only small amounts of carbonate.

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A Los Alamos report entitled "Measured Solubilities and Speciations of Neptunium, Plutonium, and Americium in Typical Ground Water (J-13) from Yucca Mountain Region" (Nitsche et al., 1993b) was published. The authors discussed the solubility and oxidation-state distribution of Np, Pu, and Am in UE-25 J#13 water at 25°, 60°, and 90°C and pH 6, 7, and 8.5. Experimental results indicated the following:

1. Neptunium solubility decreased with increasing temperature and with increasing pH.
2. Plutonium concentrations decreased with increasing temperature and showed no trend with pH. Plutonium(V) and Pu(VI) were the dominant oxidation states in the supernatant solution; as the amount of Pu(V) increased with pH, Pu(VI) decreased.
3. For the Am solutions, no clear solubility trend was found with increasing temperature and increasing pH.

Activity 8.3.1.3.5.1.2 - Speciation measurements. Staff participated in the second meeting of the YMP Radionuclide Solubility Working Group in Las Vegas, Nevada, on June 16, 1993. The meeting summary identified twelve major action items and assigned lead responsibility for each item. The next meeting of this group is tentatively scheduled for January 1994.

A Los Alamos staff member presented a talk entitled "Review of Formation of Radiocolloids" (Morris, 1993) at the YMP Colloid Workshop and moderated the session, "Potential Sources of Colloids at Yucca Mountain."

Data collection was completed on characterization of actinide speciation and a report entitled "Actinide(IV) and Actinide(VI) Carbonate Speciation Studies by PAS and NMR Spectroscopies" (Clark et al.) was prepared. It was approved by YMPO and will be published as a Los Alamos report. The report describes the authors' multifaceted approach to characterizing actinide speciation using a combination of photoacoustic spectroscopy, high-field multinuclear nuclear magnetic resonance spectroscopy, and related probes. Examples were chosen from recent results in carbonate media to illustrate the utility of this approach.

Data collection was completed on photoacoustic signal processing, and a paper entitled "Evaluation of Alternative Signal Processing Schemes for Actinide Speciation Using Photoacoustic Spectroscopy" (Tait et al.) was prepared and approved by YMPO. It was in review by the journal Review of Scientific Instruments. This report compares the photoacoustic signal processing schemes that this group developed for YMPO and compares these approaches to those presently in use by other investigators.

Data collection was completed on the speciation of Pu(IV) in carbonate solution as a function of pH, carbonate concentration, temperature, and plutonium concentration; a paper entitled "Plutonium(IV) Carbonate Speciation Changes" (Tait et al.) was being prepared on this subject and will be submitted to the Project for review. It is intended for submittal to the journal Inorganic Chemistry.

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The following three talks were presented at the Actinides '93 International Conference in Santa Fe, New Mexico, September 19-24, 1993:

1. "Carbon-13 NMR Kinetics and Ligand Exchange Dynamics of Actinyl(VI) Carbonate Complexes in Aqueous Solution" (Clark et al., 1993a) described carbonate ligand self-exchange studies conducted on $\text{PuO}_2(\text{CO}_3)_3^{4-}$ and $\text{AmO}_2(\text{CO}_3)_3^{4-}$ using ^{13}C nuclear magnetic resonance spectroscopy. An abstract of this talk was approved by the Project and published in the conference program.
2. "Oxygen-17 and Carbon-13 NMR Studies of Uranyl and Neptunyl Carbonate Complexes in Near-Neutral Solution" (Clark et al., 1993b) discussed the species distribution of actinyl carbonate complexes [U(VI), Np(VI), Np(V)], which was examined using multinuclear nuclear magnetic resonance spectroscopy, for the pH ranges 6.0–9.0. An abstract of this talk was approved by the Project and published in the conference program.
3. "Speciation of Neptunium(V) Carbonates as a Function of Temperature Using Absorption Spectroscopies" (Tait et al., 1993) described recent results on the speciation of Np(V) in carbonate solutions as a function of temperature, pH, and carbonate concentration using conventional ultraviolet-visible-near infrared electronic absorption spectroscopy. An abstract of this talk was approved by the Project and published in the conference program.

Data collection continued on conventional electronic absorption spectroscopy for NpO_2^+ speciation as a function of changes in bicarbonate concentration, pH, and temperature. New experimental approaches were developed to facilitate these measurements including adaptation of new thermostatted sample and reference cells and use of deuterated water to decrease interference from water absorption.

Data collection continued on using ^{13}C and ^{17}O nuclear magnetic resonance data. Explicit speciation information and thermodynamic binding constants for U(VI) in carbonate solution have been determined.

Model development continued on the determination of speciation information from experimental data. Los Alamos staff have developed a working model for use of carbonate/bicarbonate buffers in order to determine the true hydrogen ion concentration pH as a function of ionic strength, thereby removing the uncertainty associated with the need to know the activity coefficient in pH measurements. A more accurate determination of pH will allow direct curve-fitting and extraction of thermodynamic binding constants in Np experiments.

Activity 8.3.1.3.5.1.3 - Solubility modeling. No progress during the reporting period; this was an unfunded activity.

Forecast: Using pure crystalline or amorphous phases of the radionuclides, solubility studies for Np, Pu, and Am in J-13, UE-25 p#1 waters and in neutral electrolyte solutions

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from undersaturation experiments at three temperatures and three pH values will be completed. Solubility studies for U from oversaturation and undersaturation in the same solutions will begin. Temperature-dependent, higher concentration conventional UV-Vis spectrophotometric studies of the speciation of Np(V) in synthetic carbonate ground waters will be completed. Temperature-dependent photoacoustic studies of Pu(V), Pu(VI), and Np(V) at extreme dilution in synthetic carbonate ground waters will be continued. 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 code EQ3/6 and/or other codes to model solubility and speciation of radionuclides and identify, acquire, and modify thermochemical data bases for actinides for use with these codes will be modified (if necessary).

2.2.2.11 Study 8.3.1.3.5.2 - Colloid Behavior

Resolution of all reviewers' comments on the study plan were verified and approved by YMPO on September 9, 1993. OCRWM explained, in the transmittal letter, how the study plan addressed Site Characterization Analysis Comment 96. The study plan was sent to NRC on September 17, 1993.

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

Forecast: Work will resume on Pu(IV) studies of chemical behavior and physical properties of colloids 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

Review comments on the study plan were received from YMPO in June 1993 and it was being revised to incorporate these comments.

Activity 8.3.1.3.6.1.1 - Crushed tuff column experiments. Data collection was completed on the study of elution of Np solutions using crushed-tuff columns composed of tuff from the Topopah Spring Member and zeolitic Calico Hills and UE-25 J#13 and UE-25 p#1 water. A report entitled "Summary Report on Np Transport through Yucca Mountain Tuffs" (Triay), which incorporates the results of these experiments was being prepared.

A talk was presented at Focus '93 entitled "Far-Field Transport of CO₂: Retardation Mechanisms and Possible Validation Experiments" (Meijer, 1993). Possible retardation mechanisms for ¹⁴C and delineated potential validation experiments to elucidate ¹⁴C retardation in the Yucca Mountain environment were discussed. The proceedings paper was approved by YMPO.

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A paper entitled "Transport of Neptunium through Yucca Mountain Tuffs" (Triay et al., 1993b) was published in the proceedings of the Materials Research Society. The authors found that when surface complexation was the dominant sorption mechanism, Np sorption increased as pH increased. They also found that oxide minerals in solution can cause a significant amount of Np retardation. No differences were found between the Np retardation determined under flowing conditions and Np sorption determined using batch techniques.

Activity 8.3.1.3.6.1.2 - Mass transfer kinetics. In a published paper (Triay et al., 1993a), the authors reported on results of column experiments they conducted using crushed tuff from G4-1532 in solutions of Np in UE-25 J#13 water. They found that these distribution coefficients obtained under flowing conditions agree with previously obtained Np batch sorption coefficients, and Np sorption appears to be linear, reversible, and instantaneous. Consequently, they believe that performance assessment calculations for Np releases can be made using the concept of a sorption distribution coefficient to describe retardation.

Activity 8.3.1.3.6.1.3 - Unsaturated tuff columns. Staff began eluting Np solutions using water from Wells UE-25 J#13 and UE-25 p#1 through columns of intact unsaturated G4-1531 tuff.

Staff also initiated the study of Se transport through unsaturated tuff columns in collaboration with J. Conca of Washington State University. These experiments will verify whether the sorption coefficients obtained from batch sorption experiments adequately describe radionuclide transport through unsaturated tuff.

Activity 8.3.1.3.6.1.4 - Fractured tuff columns. Staff completed characterizing the hydrological parameters and mineralogy of a column of fractured tuff from drillhole USW G-1. They set up the experiments and began eluting an Np solution in UE-25 J#13 water through the fractured-tuff column.

Activity 8.3.1.3.6.1.5 - Filtration. Los Alamos staff organized and hosted the YMP Colloid Workshop. Its objective was to evaluate whether colloids will significantly increase radionuclide releases to the accessible environment at Yucca Mountain. Speakers reviewed the state of knowledge in colloid transport and its applicability to the conditions at Yucca Mountain. A strategy for future YMP colloid transport research was developed. A report on this subject was prepared entitled "Colloid-Facilitated Radionuclide Transport at Yucca Mountain" (Triay). The report described ongoing YMP colloid research, which will evaluate whether colloids will significantly increase radionuclide release from a potential high-level nuclear waste repository at Yucca Mountain to the accessible environment. The report also reviewed the evidence for the existence of colloids, both from sampling studies and from observation of colloid transport at field scale. The relevance of laboratory and field experiments on colloid transport to the conditions at Yucca Mountain were discussed. Research needs were identified in the following areas: colloid sampling, colloid generation, colloid stability, radionuclide sorption onto colloids, and colloid migration. Colloid transport calculations were presented. This report was in the YMP review process.

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

2.2.2.13 Study 8.3.1.3.6.2 - Diffusion

Resolution of all comments was verified on June 28, 1993. The study plan was approved by the Project on August 6, 1993, and sent to the Commission on August 12, 1993.

Activity 8.3.1.3.6.2.1 - Uptake of radionuclides on rock beakers in a saturated system. In a published paper entitled "Diffusion of Sorbing and Nonsorbing Radionuclides in Tuff (3065)" (Triay et al., 1993c), the authors reported on their experiments in which the cavity of a tuff beaker was filled with a solution of the radionuclide of interest, and the uptake of the radionuclide by the tuff was measured as a function of time. The authors found that the diffusion coefficient for nonsorbing radionuclides into saturated Yucca Mountain tuff was on the order of 10^{-6} cm²/s. They also found that large anions, such as pertechnetate, were excluded from tuff pores and their diffusion coefficients were on the order of 10^{-7} cm²/s.

Activity 8.3.1.3.6.2.2 - Diffusion through a saturated tuff slab. Data collection was completed on the study of Np diffusion, using intact tuffs G4-270 and G4-1532 and UE-25 J#13 or UE-25 p#1 water. A report on these results was being prepared.

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 and the diffusion of conservative and nonconservative tracers in unsaturated tuff blocks will be determined.

2.2.2.14 Study 8.3.1.3.7.1 - Retardation Sensitivity Analysis

The study plan was accepted by the Commission in a Phase I review on January 19, 1993. No comments were made, but a request was made for references cited in the study plan. The requested references were sent to the Commission on June 17, 1993.

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Activity 8.3.1.3.7.1.1 - Analysis of physical/chemical processes affecting transport. The dual porosity/dual permeability coding for air/water/heat was completed. More verification is needed as well as a more efficient solution procedure. The six unknowns per grid cell limits the problem size to several thousand nodes.

Activity 8.3.1.3.7.1.2 - Geochemical/geophysical model of Yucca Mountain and integrated geochemical transport calculations. A method for generating computational meshes for Yucca mountain flow and transport simulations was developed. This computer code, which employs triangles or tetrahedrals to accurately portray underground features in two or three dimensions, uses the hydrogeologic information contained in the SNL data base (Ortiz et al., 1985). Representations of Yucca Mountain containing up to one million nodes have been generated. The primary computational mesh for the FY 1993 runs contains 56,600 nodes and is on 76-m by 152-m centers with 35 nodes in the vertical direction.

A new version of FEHM, which incorporates dynamic memory allocation, was completed, and initial tests show an order of magnitude improvement in real performance on large memory intensive problems.

Activity 8.3.1.3.7.1.3 - Transport models and related support. Work was completed on FEHM enhancements that allow two-dimensional triangular elements in three-dimensional space. Testing of this capability is in progress.

Forecast: A locally refined model based on high-flow areas identified in previous coarser grid models will be produced. These transport calculations will reveal new sensitivities to k_d values of the hydrologic units in those over previous calculations because of the distributed flow through the repository. If time permits, transport studies with time varying flow will begin. These runs will reflect evolving climate conditions and will be the first of their kind. To support simplifying assumptions made by performance assessment for transport models, processes that affect the transport of radionuclides at Yucca Mountain will be studied. Computer codes will be developed; the development of algorithms for various processes and for optimization of the transport codes, TRACRN, FEHMN, and CTCN will be supported. Baseline documentation will be produced and the work necessary to bring codes TRACRN and FEHMN into compliance with the Software Quality Assurance Program will be performed.

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

This study plan has been deferred because no funds were allocated.

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

Activity 8.3.1.3.7.2.2 - Field-scale experiments to study radionuclide transport at Yucca Mountain. No progress during the reporting period; this was an unfunded activity.

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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.

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: In conjunction with LBL, a preliminary design of field tests at the Calico Hills geologic unit at Yucca Mountain will be prepared. Using this design, new data from the surface-based testing program and current radionuclide transport data on Calico Hills from the ESF will be evaluated. The study plan for this activity will be initiated.

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 out-year study.

Forecast: No activity is planned for FY 1994.

2.2.3 Rock Characteristics (SCP Section 8.3.1.4)

Several strategic planning meetings were held with USGS staff to discuss inter-relationships and integration among several site characterization and three-dimensional modeling activities. Issues raised regarding potential duplication and overlap of characterization activities were resolved with several agreements-in-principle that expand the collaborative activities. The increasing emphasis on ESF design requirements predicated upon ramp access rather than on earlier shaft concepts has markedly increased the importance of the site-oriented systematic drilling program. This change in application of information has led to a larger role of the systematic drilling program in this early stage of overall site characterization, rather than to an expansion of plans for the drilling program.

The discussion also indicated that the modeling efforts described in Section 2.2.3.7 were largely synergistic, mostly due to ongoing development efforts by staff from both organizations. Under the idealized scenario, the geometric model developed by USGS using the LYNX Geotechnical Modeling System software package will be used to constrain geostatistical modeling of material properties. This latter activity will continue to be tightly focused on the "performance" uses of those models in both detailed "process" modeling and more limited "total systems" assessments. Increased consistency in interpretation of site characterization data is anticipated as a result.

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2.2.3.1 Activity 8.3.1.4.1.1 - Development of an Integrated Drilling Program

Description of prototype drilling activities is discussed in Section 2.2.1.7, Study 8.3.1.2.2.3.

Catalog of Planned Boreholes for Surface-Based Testing

This catalog is an update and modification of drilling program information originally compiled in the Surface-Based Investigation Plan (DOE, 1988c). The Surface-Based Investigation Plan drew upon study descriptions contained in the SCP (DOE, 1988a). Since that time, detailed study plans have been developed for many surface-based testing activities. In addition, the catalog includes information from two drilling integration meetings held in early FY 1993. These meetings served as a forum for identifying the data needs and requirements of the various planned drilling activities. In particular, coring requirements were scrutinized and potential overlap with ESF testing was explored. Opportunities were sought to produce a more streamlined, cost-efficient program by consolidating multiple planned boreholes into single holes addressing multiple purposes. The results of these meetings, and subsequent discussions, are included in the catalog.

The catalog is a working compilation of borehole information for the surface-based testing program as currently envisioned. It provides a reference for planning, integration, and coordination of site investigation activities.

Forecast: The Catalog of Planned Boreholes will be updated twice each year. The next planned update is in December 1993.

2.2.3.2 Activity 8.3.1.4.1.2 - Integration of Geophysical Activities

Following the publication of the Geophysics White Paper (Oliver et al., 1990), the need was recognized for continued enhanced and coordinated integration of geophysical testing within the site characterization program. The Geophysics Integration Team was established within the YMPO Regulatory and Site Evaluation Division as part of the Geophysics Integration Initiative. The Geophysics Integration Team will oversee the geophysical testing program and ensure implementation of the integration initiative. The Geophysics Integration Team consists of highly trained geoscientists from YMP contractor and participant organizations and is chaired by a member of the Regulatory and Site Evaluation Division.

The YMPO has begun a concerted integration activity for geophysical testing during site characterization. This integration was designed to ensure:

- The early implementation of the currently proposed geophysical testing program
- The application of geophysical test results within the site characterization program
- Advance planning, scheduling, budgeting, and sequencing of geophysical tests

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- Consideration of technological advances in order to plan for
 - incorporation of new and potentially useful geophysical test methods into existing study plans
 - establishment of new geophysical study plans
- That objectives, scope, and methods for geophysical tests are well defined, with geophysical and nongeophysical testing programs fully integrated, test linkages and information needs established
- That the technical need and adequacy for all proposed geophysical tests is well understood and conduct of the tests is justified
- That implementation of a test will contribute to the development of models and assessments to be used for the determination of site suitability and license application.

The Geophysics Integration Team met several times during this reporting period to discuss the possible use of geophysics to aid in ESF design. Specifically, the Geophysics Integration Team discussed possible geophysical exploration techniques that could aid in the delineation of the Ghost Dance fault at the depth of the proposed repository (approximately 305 m below the Yucca Mountain crest), in order that the Tunnel Boring Machine might avoid encountering the fault along the Main Test Level. A recommendation was made by the Geophysics Integration Team to try two acoustical techniques: seismic reflection profiling across the Ghost Dance fault over the Main Test Level area, and vertical seismic profiling in boreholes near the proposed Main Test Level. The seismic reflection profiling has been budgeted, and is planned to be run by LBL in late October 1993. In addition, vertical seismic profiling was recommended, budgeted, and performed by LBL in boreholes USW NRG-6 and USW WT-2, to aid in the delineation of the Ghost Dance fault at the north and south ends of the Main Test Level. Results from these two surveys should be available in time to aid in the design of the Main Test Level. An additional vertical seismic profiling walkaway survey was performed by USGS in borehole UE-25 UZ#16 (Vertical Seismic Profiling-2) for hydrology studies, which may also aid in delineation of this fault.

The Geophysics Integration Team appointed several reviewers to review three USGS-developed draft Requests for Proposals for additional intermediate and deep seismic reflection services. The Requests for Proposals have gone back to USGS with Geophysics Integration Team comments (M&O comments and other members' comments), and may be reissued in FY 1994.

A Preliminary Draft Geophysics Catalog for FY 1993-1994 was submitted to YMPO and all Technical Project Officers for review and comment. This document is currently undergoing revision to account for reviewer comments, budgeting changes, and additional geophysical tests, and will be reissued in early FY 1994.

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An extensive geophysics section was compiled for the Site Characterization Activities Catalog, which will be issued in draft form in early FY 1994. This section includes all known planned geophysics tests, and cites relevant sections from both the SCP and the various study plans. This is the first time that all proposed geophysical tests have been compiled in one document.

A bibliography of all relevant geophysical publications related to work at the Yucca Mountain site has been compiled and will be issued in draft form in early FY 1994 for review and comment.

Monthly summaries of geophysical activities at the Yucca Mountain site are currently being compiled and informally transmitted to the Geophysics Integration Team and YMPO.

The Geophysics Integration Team met recently with the M&O to discuss the compilation of a Geophysics Integration Plan. Discussions are under way and are focusing on whether to issue this plan as a new study plan, or as a management integration plan.

Budgeting of all geophysical tests to be performed during FY 1994 was performed by the Geophysics Integration Team, and a new Work Breakdown Structure number was proposed for Geophysical Testing - 1.2.3.11. The following subheadings were proposed: 1.2.3.11.1 - Borehole Geophysics; 1.2.3.11.2 - Surface-Based Geophysical Tests; and 1.2.3.11.3 - ESF Geophysical Tests. Several new geophysical tests were proposed by the Geophysics Integration Team to be included in the FY 1994 budget, but could not be approved due to budget constraints.

The Geophysics White Paper (Oliver et al., 1990) was being updated during FY 1993 to include all geophysical surveys that have been performed by USGS in support of YMPO. This work was being done in preparation for issuance of the white paper by USGS in FY 1994. Due to budgeting constraints, this work has been postponed.

Forecast: The USGS Request for Proposals for seismic reflection services will be revised and reissued. The Geophysics Catalog for FY 1993-1994 will be finalized and issued. A draft Site Characterization Activities Catalog will be issued. A Geophysics Catalog for FY 1995-1999 is currently undergoing compilation and will be issued in draft form for review and comment in mid- to late-FY 1994. A draft bibliography of all relevant geophysical publications will be issued.

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

Revision 3 of the study plan was sent to NRC on August 30, 1993. The NRC sent two questions on the study plan in a letter dated June 22, 1993. The OCRWM responded to the NRC questions on August 30, 1993.

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Activity 8.3.1.4.2.1.1 - Surface and subsurface stratigraphic studies of the host rock and surrounding units. Rock characteristics staff worked throughout the second half of FY 1993 on partial and preliminary descriptions, and detailed logging of core from UE-25 UZ#16, USW UZ-14, UE-25 NRG#1, UE-25 NRG#2, UE-25 NRG#2A, UE-25 NRG#2B, UE-25 NRG#3, UE-25 NRG#4, UE-25 NRG#5, UE-25 NRG#6, UE-25 RF#8, UE-25 RF#3, and USW GU-3. This work was in support of studies of the USGS and the Soil Designation and Rock study conducted by SNL.

An Open-File Report entitled "Revised Stratigraphic Nomenclature and Macroscopic Identification of Lithostratigraphic Units Exposed at Yucca Mountain, Nevada" (Buesch et al.) was submitted for review. This report summarizes the newly revised stratigraphic nomenclature for the southwestern Nevada volcanic field, of which Yucca Mountain is included, and presents a detailed division of the Tiva Canyon and Topopah Spring Tuffs based on depositional, welding, and crystallization criteria. These divisions represent a compilation of descriptive characteristics of lithologic units in core from all holes listed above and a comparison with surface exposures, especially those determined for the Tiva Canyon Tuff in the Ghost Dance fault mapping activity.

Core logging activities by USGS staff of the North Ramp Geotechnical and Repository Facility (#3 and #8) drillholes directly interfaced with the Soil and Rock group of SNL in support of the evaluation of the ESF North Ramp. The logs and resulting geologic interpretations were used to interpret stratigraphic intervals which are poorly to not lithified, evaluating the location of existing and inferred faults, and for planning of successive North Ramp Geologic drillholes. USGS staff reviewed cross sections along the ESF North Ramp alignment and the lithologic and structural logs compiled by SNL.

The USGS participated in the collection of downhole video logs for UE-25 UZ#16 and UE-25 NRG#2. In UE-25 UZ#16, the video log was completed from surface to standing water. The video images showed thick coating of the walls with dust and water-saturated mud covering the walls at several intervals in the Calico Hills Formation and Prow Pass Formation. In UE-25 NRG#2, the video log is of the lower part of the hole in the Tiva Canyon Tuff to a depth of 65.5 m. Downhole video logs from UE-25 NRG#1 and UE-25 NRG#6 were provided to the USGS and have been reviewed.

The Isotope Geochemical Support Group analytical data base contains all available major-element, trace-element and radiogenic isotope data for Tertiary volcanics and Paleozoic sedimentary rocks at Yucca Mountain and surrounding areas. All analytical values in the data base have been quality checked and Project personnel have been trained in its use. All geochemical and isotopic data collected over the last six months have been entered into the data base. In addition, the most current lithostratigraphic nomenclature for the Tertiary volcanic rocks is now being used in order to more effectively correlate different sections.

Available lead and neodymium isotope data on whole rock samples of Tertiary volcanic rocks have been compiled in preparation for their addition to the data base. It was concluded that additional data are required in order to systematically characterize the primary and secondary geochemical behavior of these elements in unaltered and altered tuffs.

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Construction of isopach and structural contour maps continued. In April, USGS demonstrated a model of an integrated computer-interactive lithostratigraphic synthesis (LYNX Geosystems, Inc. software) of the subdivided Topopah Spring Member at Yucca Mountain including documentation on creation and interpretation of the synthesis to DOE/YMP, NRC onsite staff, and SNL. Staff traveled to LYNX Geosystems, Inc. in May 1993 to use their facilities to obtain output from the lithostratigraphic model. This output, consisting of 24 separate cross sections throughout the modeled area, was delivered to the engineers performing conceptual ramp design calculations. Staff received further training on the LYNX Geosystems software and software upgrades were installed on the work station.

Updates to the lithostratigraphic model continued. Isopach maps for each subdivision of the Topopah Spring Tuff were entered, and work began on a structure contour map of the top of the Topopah Spring Tuff. Staff conducted a review of the data used in the modeling process. This review performed on drillholes and isopach maps resulted in an overall increase in the precision of modeling near the North Ramp. Preliminary cross sections from the LYNX software were prepared and supplied to ESF designers for use in conceptual design.

The isopachs for each subdivision of the Topopah Spring Tuff were refined with the inclusion of additional measured sections data from the geologic mappers. The new 20-ft contour interval topographic data tape from EG&G was received and was included in the model. A request for four additional cross sections through the project area was processed in July.

USGS staff created a series of geologic cross sections along the new North Ramp alignment, with several cross sections cross-cutting the main North Ramp cross section. All these new cross sections were based on the latest isopach data, new borehole data, and recent geophysical data. A new structural interpretation of Drill Hole Wash was completed that incorporated all the new borehole data up through July 1993 and reconciled it with past surface and subsurface geological and geophysical data. This new structural interpretation was incorporated into the latest North Ramp cross sections.

Activity 8.3.1.4.2.1.2 - Surface-based geophysical surveys. USGS audits of seismic reflection proposals were completed in April. Negotiations continued with potential bidders. Planning discussions also continued with DOE/M&O staff regarding issues of safety and test interference. Analysis of bids continued through June, including interactions between Rock Characteristics and Contracts Sections and DOE/M&O staff. The anticipated FY 1993 award of the seismic contract was dropped in July due to high costs and difficulties with available bids. The process will be started with a revised proposal, with award scheduled for FY 1994.

New gravity and ground magnetic data sets obtained in Yucca Wash were reduced to obtain anomaly values. Both gravity and magnetic profiles of Midway Valley were reduced utilizing newly written computer programs.

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A manuscript for a proposed Open-File Report entitled "Gravity and Magnetic Study of Yucca Wash, Southwest Nevada" (Langenheim et al.) was submitted for USGS internal review.

Approximately 25 percent of the preparations for the planned seismic transect that passes through the Midway Valley and Yucca Wash areas was completed. Detailed gravity/magnetic data are available for these areas. Remaining work on this task was postponed until seismic line work begins again.

The task to prepare preliminary reports on Yucca Wash and Midway Valley was completed with the submittal of the following reports: "Gravity and Magnetic Data of Midway Valley, Southwest Nevada" (Ponce et al., 1993); "Gravity and Magnetic Study of Yucca Wash, Southwest Nevada" (Langenheim et al.).

An airborne magnetic survey was performed in June. The new aeromagnetic data along the Yucca Mountain transect was reduced, compiled, plotted, and transferred to YMP September 30, 1993.

Off-road shot locations for the seismic reflection survey were staked, and adjusted locations were clarified for DOE/NTS staff in preparation for preactivity surveys. Maps for seismic field investigations were submitted to DOE.

Activity 8.3.1.4.2.1.3 - Borehole geophysical surveys. Under this activity, methods for analyzing the existing (pre-1985) borehole logs were developed; the well log data base was expanded and disseminated; and well logs were obtained in a newly drilled borehole, UE-25 UZ#16.

Good estimates of moisture content and total porosity were obtained in the WT-series of boreholes using the epithermal neutron and density logs. First, the density and epithermal neutron logs which were corrupted by the rugose borehole in the unsaturated zone were treated with an algorithm which finds the right-hand bound to the density log and the left-hand bound to the epithermal neutron log. These bounds remove high-count errors caused by an air gap between the tool and the borehole wall. Next, using calibrations established for the epithermal neutron tool by Lawrence Livermore National Laboratory staff, an estimate of water content was obtained. Finally, using the water content result, an estimate of grain density, and the density log, total porosity was computed. This procedure was applied to logs from the WT-boreholes with consistent results.

The well log data base is now fully accessible on a personal computer system, using commercial log analysis software. An optical disk drive has adequate capacity and access speed to accommodate the entire data base. Redundant traces were eliminated, trace nomenclature was improved, and the data were sent to the Technical Data Base.

Magnetic susceptibility and magnetometer logs were acquired by USGS in boreholes UE-25 UZ#16 and USW NRG-6 during April. In July, neutron, density, caliper, induction, thermal decay time, gamma-ray spectrometry, and neutron activation logs were conducted in

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UE-25 UZ#16. An experimental radar tool and a developmental nuclear tool were also run in UE-25 UZ#16.

An Open-File Report entitled "Assessment of Geophysical Logs From Borehole USW G-2, Yucca Mountain, Nevada" (Nelson and Schimschal, 1993) was published.

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: USGS will work to streamline the release of preliminary stratigraphic identifications in drillholes and the culmination of the core logging activities into Open-File Reports.

Lithostratigraphic data from newly drilled boreholes will be normalized, synthesized and integrated with existing borehole data for utilization in the construction of isopach and structural contour maps, and in the development of the three-dimensional geologic model.

Work will involve writing the requests for proposals for seismic reflection profiling in part of Crater Flat and across Yucca Mountain, evaluating the bids, and possibly revising the study plan describing the seismic work. Efforts to integrate seismic work with the needs of the other studies to utilize geophysical solutions to geological problems and provide support for the three-dimensional model will be arranged.

An interpretive report will be written in FY 1994 regarding the airborne magnetic survey data.

The task to prepare a report and map of Yucca Wash was postponed due to delay in acquisition of seismic profile. The report will contain modeled data results of seismic data and of density and magnetic susceptibilities of field samples.

Computing porosity and water content in existing (pre-1985) boreholes and merging relevant logs into the three-dimensional (LYNX) data storage and viewing system will continue in FY 1994. The USGS staff will continue acquisition of logs in newly drilled borehole USW UZ-14 and others. The missing step to correct the density logs in the unsaturated zone, a procedure that ties the logs to core measurements, will be developed. Procedures being developed on existing borehole data will be useful for data being acquired under the current drilling program.

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

The NRC accepted the study plan, with no comments, in a Phase I review letter on February 8, 1993.

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

USGS staff continued detailed stratigraphic and structural feature field mapping along the trace of the Ghost Dance fault system. The areas mapped during this period include Broken Limb Ridge, Whale Back Ridge, Split Wash, and Antler Ridge. Data were used for input into the Field Identification Summary and the Stratigraphic Column for the study area.

Work began on preliminary detailed petrographic examination of a suite of rock samples collected from subunits within the Tiva Canyon Tuff. This work was performed to determine if devitrification textures and vapor phase mineralogy (in addition to variability of pumice, crystal content, lithics, and any other characteristics observed in thin section) can be used as distinguishing criteria to better define subunit lithologies within the Tiva Canyon Tuff. Thin sections were made from outcrop samples collected from a vertical section along the south flank of Antler Ridge. Preliminary microscopic examinations of 30 thin sections from the Tiva Canyon Tuff subunits were described and documented by photomicrographs.

A table was prepared summarizing the textural petrographic variation with depth of lithostratigraphic subunits within the Tiva Canyon Tuff of the Paintbrush Group. The table summarizes criteria used to differentiate lithostratigraphic subunits within the Tiva Canyon ash flow tuff. This information was prepared for presentation at the Mineralogy/Petrology integration meeting with Los Alamos held on September 21, 1993.

Staff collected 35 rock samples from a vertical section along the southeastern flank of Whale Back Ridge (Tiva Canyon Tuff lithologies) and 49 additional samples of drill core from USW GU-3 for thin section (petrographic) and geochemical analysis. This work is being used to develop microstratigraphic criteria to better define the lithostratigraphic subunits within the Tiva Canyon Tuff of the Paintbrush Group.

Detailed geologic mapping of the northeast corner of site area continued throughout the remainder of the reporting period. Several square kilometers of the rhyolite of Calico Hills in Fortymile Canyon were mapped. Three measured sections were completed and 12 samples keyed to these measured sections were collected. Reconnaissance mapping was conducted in the rhyolite of Calico Hills exposed along the northern flank of Yucca Mountain and on the north flank of Busted Butte.

Field mapping in the Paintbrush Canyon, Fortymile Wash, adjacent canyons, and at Comb Peak revealed details of welded and nonwelded air-fall and ash-flow tuff and a possible transition zone of rheomorphic welded tuff at the base of the Comb Peak Rhyolite lava flow. Field relations defined parts of the Comb Peak crater rim, and flow foliations within the lava flows indicate the vent locations. Added map detail included definition of more outcrops of rhyolite of Delirium Canyon, and newly observed debris- and air-flow deposits which help constrain post-Rhyolite of Calico Hills paleotopography. Work in Fortymile Wash included describing post-Calico Hills and pre-Pah Canyon erosional surfaces and detailed mapping of a major fault.

The USGS staff completed mapping the Paintbrush Canyon fault to the southern end of the northeast quadrant in June and began the initial field-check of map data in Upper

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Paintbrush Canyon. The distal facies of fluvially reworked bedded tuffs and soil horizons were investigated at the northern end of Busted Butte.

Rhyolite of Calico Hills exposed along the northern flank of Yucca Mountain and on the north flank of Busted Butte sections was compared to the section exposed in upper Paintbrush Canyon to develop the architectural framework of the Calico Hills volcanic field.

Illustrations were prepared for an abstract presentation entitled "Primary and Secondary Volcaniclastics, Stream Grade Fluctuation, and Structural Events in the Rhyolite of Calico Hills, Nevada" (Buesch and Dickerson, 1993). The abstract was reviewed, approved, and presented at a meeting sponsored by the International Association of Volcanology and Chemistry of the Earth's Interior held in Canberra, Australia, September 24 - October 1, 1993.

The first draft of a paper entitled "Structural Character of the Northern Segment of the Paintbrush Canyon Fault" (Dickerson and Spengler), for presentation at the 1994 High-Level Waste Conference, was completed in August. The proposed report incorporates all of the map data recently obtained north of Yucca Wash, in addition to the most recent magnetic and gravity data along the trace of the Paintbrush Canyon fault south of Yucca Wash to the southern end of Midway Valley. Thin sections from 25 samples collected from this area were prepared for petrographic analysis.

An internal report on the current status and contents of the Isotope Geochemistry Support Group analytical data base through the end of April 1993 was completed. This report provides all spatial, geochemical and isotopic data available for samples of Tertiary volcanic rocks, Paleozoic sediments and Precambrian rocks exposed at the surface in the Yucca Mountain vicinity.

A major effort to use petrographic and chemical characteristics of the Tiva Canyon Member of the Paintbrush Tuff as potential markers for studying offsets along the Ghost Dance fault was undertaken. Samples of the Tiva Canyon Member were collected from Whale Back Ridge on the eastern flank of Yucca Mountain. These samples were crushed, powdered and prepared and x-ray fluorescence analyses were performed. Thin sections were made for petrographic study. Information may be important for determining the stratigraphic position within drillholes and tunnel excavations where the lithologic characteristics of the samples may be less distinct than in the outcrop samples.

X-ray fluorescence analyses of approximately 120 whole-rock samples of tuffs from northwestern Yucca Mountain and southern Crater Flat were completed. These data were collected for mapping studies and will be useful in correlating known stratigraphy with newly mapped areas.

Dr. Leonid A. Neymark, visiting Russian isotope geochemist from the Institute of Precambrian Studies in St. Petersburg, arrived and joined the Isotope Geochemistry Support Group staff for a temporary collaborative tenure. Dr. Neymark will focus his attention on developing procedures for the analysis of U and Th by mass spectrometry for dating

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carbonates from drill core veins. In addition, he will work with Pb, Nd and Sr isotopes in volcanic rocks and ground waters.

The following reports were published as USGS Open-File Reports: "Status of Aeromagnetic Survey Coverage of a Part of Southwestern Nevada and Southeastern California, 1992" (Sikora et al., 1993) and "Gravity and Magnetic Data of Fortymile Wash, Nevada Test Site, Nevada" (Ponce et al., 1992).

The following papers were also published in FY 1993: "Seismic Reflection Profiling Across Tertiary Extensional Structures in the Eastern Amargosa Desert, Southern Nevada, Basin and Range Province" (Brocher et al., 1993) and "Geological and Mineralogical Controls on Physical Properties of Tuffs at Yucca Mountain" (Nelson, 1993).

Activity 8.3.1.4.2.2.2 - Surface-fracture network studies. Analysis of new and previously acquired data on regional variations in fracture network parameters continued. The work describes the style and mode of fracturing of bedded tuffs at the base of the Tiva Canyon Tuff and will include a detailed fracture map of the UE-25 NRG#1 pavement. Analyses are under review by the USGS.

Approximately 46 percent of the area enclosed by pavement P2001 in the Topopah Spring Tuff exposed on Fran Ridge was mapped in an effort to analyze the ESF test-pit area in three dimensions. No further progress was accomplished in FY 1993 due to budget constraints. A Technical Data Information Form for collected data will be submitted.

An abstract entitled "Fracture Network Heterogeneity in the Tiva Canyon Member of the Paintbrush Tuff" (Fahy) was submitted for presentation at the 1994 High-Level Waste Conference.

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. Conventional and photogrammetrical mapping of the North Ramp Starter Tunnel began in April 1993, and continued through the end of FY 1993 with all excavation in the upper lithophysal zone of the Tiva Canyon Tuff. The pilot bore was mapped to station 0+97 and the upper half of the tunnel to station 1+95. The lower bench of the Starter Tunnel was also mapped to station 1+95 (the end of the Starter Tunnel). Mapping was completed in the Starter Tunnel in September 1993.

Geologists collected a total of 69 samples from the Starter Tunnel (under Job Package 92-20C) as part of the Consolidated Sampling program. Samples collected between stations 0+00 and 1+95 included fracture fillings, representative lithologic samples, smectite from lithophysae, and contaminated and uncontaminated wall rock, mineral infillings, and fault rubble. Fractures were filled with a variety of secondary materials in the portal cut and starter tunnel.

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Geologists completed a draft plan-view geologic map and detailed line surveys of the drainage channel above the portal cut.

Fracture data from the detailed line surveys were compiled and processed using the DIPS software program and stereonets generated from various stations of the Starter Tunnel. Fracture families were identified from these stereonets.

The underground mapping team provided data and support for the purposes of tunnel stability analysis. This information included fracture spacing, plan map showing occurrence of identified fractures along the right wall, lower hemisphere pole and contour plots, and family identification. Members of the mapping team attended various meetings and participated in numerous discussions with DOE representatives regarding tunnel support and excavation conditions.

Activity 8.3.1.4.2.2.5 - Seismic tomography/vertical seismic profiling. Incorporation and integration of the vertical seismic profiling model with rock characteristics work continued. In April, personnel from Los Alamos and LBL were accompanied by personnel from SNL and Morrison-Knudsen to inspect the excavations in the portal and to determine if seismic imaging measurements could be made on a timely basis to aid in the prediction of the geologic structure ahead of the tunnel face and of stability of the tunnel. A modest seismic imaging program that could be added to the existing work with minimal interference with the excavations was recommended. Recommendations were submitted including information on tomographic imaging above and off-end of the tunnel and on high-resolution surface-reflection imaging. A synopsis of tomographic modeling at the C-hole complex was presented to Rock Characteristics Section staff.

A presentation was made at the DOE-NRC Technical Exchange on Geophysical Integration on the past and present cross-hole and vertical seismic profiling work at the Nevada Test Site.

Information was prepared on the availability and applicability of seismic sources for cross-hole imaging at UE-25 UZ#16.

Work to develop and validate interpretational codes VELIN3D and ANI90 continued. Improvements were made to VELIN3D to provide for more stable inversions and to avoid local minima in the inversion using the cubic b-spline methods.

Discussions were held with Los Alamos and the M&O regarding work in the North Ramp Portal. Due to unexpected fracture content, the portal work progressed at a slower rate than planned. It was suggested that resolution of several questions regarding the extent of the fractured zone, a more precise extent of the Rainier Mesa Formation adjoining the Bow Ridge fault, and location of hidden faults may be possible by using high-resolution seismic imaging.

Forecast: Geologic mapping of the ESF work in FY 1994 will include expected completion of the geologic mapping of the test alcove in the Starter Tunnel at station 1+40. The alcove is expected to be approximately 18.3 m long and completed by the end of

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November 1993. Work through the end of January is expected to consist of completion and drafting of the geologic maps of the North Ramp Portal cut, Starter Tunnel, and drainage cut above the tunnel. Completion of the photogrammetric mapping of the Starter Tunnel is also expected during this time. Interpretation of the geologic data from excavations will culminate in a report near the end of February 1994. Technical procedures and training for mapping behind the Tunnel Boring Machine will be developed during the spring of 1994.

Underground mapping is expected to resume in mid-July 1994. Prior to the resumption of mining, geologists will be trained to Technical Procedures and familiarized with the volcanic and fracture terminology to be used in the North Ramp. Completion and assembly of the mapping gantry is also expected during this time. Underground mapping is anticipated to extend from July through September 1994.

Detailed petrographic and geochemical studies will be performed on rock samples collected from four vertical stratigraphic sections within and outside the Ghost Dance fault system. This work will be used to develop microstratigraphic criteria to better define the lithostratigraphic subunits within the Tiva Canyon Tuff of the Paintbrush Group.

The FY 1994 work for seismic tomography/vertical seismic profiling will focus on processing the vertical seismic profile data acquired in USW WT-2 and USW NRG-6. High resolution surface reflection work will be culled out and the resulting data processed for information on the Ghost Dance fault system and for structural information along the strike of the proposed ramp.

In FY 1994, mapping of the Ghost Dance fault will include selected areas northward to the northern edge of the potential repository and extend east and west of the main trace of the fault, near Whale Back Ridge and Antler Ridge. Mapping of the northeast corner of the proposed site area will involve field checking of FY 1993 data. A preliminary data base will be established and published summarizing lithologic attributes of the Paintbrush Tuff for use in unsaturated zone models.

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

The NRC accepted the study plan on July 19, 1993, and indicated that a detailed technical review would be undertaken.

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Consolidated Work Scopes

The consolidated work scope process serves as an interface between the Annual Plan for Site Investigations and the test planning package. It is carried out by the M&O upon request from YMPO 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, two consolidated work scopes were compiled: one for the drilling and testing planned in borehole USW SD-12, scheduled to be drilled in the first quarter of FY 1994; and the second for the pumping and cleaning of three WT (water table) wells that were drilled with drilling fluid or air foam in the 1980s, and never cleaned to permit the collection of water samples. In addition, work scope consolidation meetings, at which interested parties expressed their requests and requirements, were held for boreholes planned in FY 1994, to provide the input to upcoming consolidated work scope statements.

Forecast: Consolidated work scopes will be completed for boreholes to be drilled in FY 1994.

Activity 8.3.1.4.3.1.1 - Systematic drilling program. The proposed enhancement to the ESF configuration would result in the main exploration drift running north-south, subparallel to the Ghost Dance fault. The potential redesign has led to increased visibility and emphasis on the role of the site-oriented systematic drilling program. Work scope consolidation meetings and other Project-level conferences have been held for FY 1994 drillhole planning.

Specific drilling plans have undergone several iterations during the reporting period. Currently two SD-series drillholes are scheduled for FY 1994. Both drillholes are located to provide sufficient design information for the ESF main drift, including post-drilling instrumentation for monitoring of construction effects on in situ conditions (see Study 8.3.1.2.2.3, Characterization of Yucca Mountain Unsaturated Zone Percolation; Activity 8.3.1.2.2.3.2, Site Vertical Bore Holes; Section 2.2.1.7). A final surface location for the first drillhole (USW SD-12) was identified in the field and a drill pad is under construction. The location is slightly to the west of the planned ESF main-test-level drift, approximately 500 ft west of the Ghost Dance fault. Drilling is scheduled to commence early in FY 1994, following release of the LM-300 drill rig from drillhole USW UZ-14.

A tentative location was selected for a second SD hole (USW SD-9). This location is similarly located geologically, but is significantly further to the north along the trace of the main-test-level drift. Logistical constraints will be more significant in this region of steep topography and narrow drainage.

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Staff assigned to support the systematic drilling program spent a significant amount of time during the reporting period providing geologic support to the work being conducted in support of the Soil and Rock Properties Study (SCP Activities 8.3.1.14.2.1, 8.3.1.14.2.2, and 8.3.1.14.2.3; see Sections 2.2.10.1, 2.2.10.2, and 2.2.10.3). The Soil and Rock Properties Study is the basis for preparing geologic and engineering logs for the North and South Ramp geotechnical boreholes. Because the Soil and Rock Properties Study and the Systematic Acquisition of Site-Specific Subsurface Information Study both focus on engineering aspects of the immediate repository block, its access ramps, and Main Test Level drifts, close coordination between the two studies is essential. Geologic logging of core is the principal focus of the support provided under this activity. The logging was conducted under the scientific notebook procedure in use for the Soil and Rock Properties Study. This provided an opportunity to refine the technical procedure that will guide work on the systematic drilling program. The technical procedure, (TP-0162) "Geologic Description and Core Logging" was issued as a controlled document in late July.

Sample logging results were compared with the equivalent rock units now exposed in the portal excavations for the North Ramp. The comparison suggests some interesting interpretations of the cause of the "poor core recovery" observed in North Ramp Geologic Hole UE-25 NRG#1 and elsewhere. The poor core recovery may actually be the result of large (>30 cm) lithophysal cavities that have been prominently displayed in the new excavations. The implications of the core recovery in UE-25 NRG#1 and the nonconventional interpretations will be explored as additional data are gathered.

A journal paper entitled "Spatial Variability of Hydrologic Properties in Volcanic Tuff" (Istok et al.) was prepared for submission to Ground Water. It includes the results of a test of the hypotheses regarding stratigraphic control of material properties developed by the original work described in the paper, "Influence of Deterministic Geologic Trends on Spatial Variability of Hydrologic Properties in Volcanic Tuff" (Rautman et al., 1993). At the end of the reporting period, the paper had completed USGS review and was pending final resolution of comments at SNL.

Forecast: During FY 1994, any outstanding prerequisites for drilling will be completed, including (as necessary) revisions of the study plan, revision and/or preparation of technical procedures, letters of criteria, job packages, sample requests and other Project-level documents required for drilling. Additional developmental activities include: completing data reports covering entire transect data set; collecting and testing additional samples, if necessary, to resolve outstanding issues; evaluating data using statistical and geostatistical methods; and preparing a final report on the transect sampling project.

If the enhanced ESF configuration is approved, field activities will be conducted for the drillholes that are to be located near the projected trace of the revised main ESF test drift in support of site characterization activities. This work will consist of: providing onsite supervision and monitoring of drilling operations; creating detailed geologic log of core, including descriptions of lithology, units contacts, fracturing and faulting, alteration phenomena, core recovery and rock quality; and monitoring geophysical logging of drillholes,

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including downhole TV logging during drilling to determine hole conditions relevant to drilling decisions.

The systematic drilling program will continue to support field activities related to the remaining North Ramp (NRG-series) and the South Ramp Geologic (SRG-series) drillholes.

"Framework" rock properties measurements will be obtained for all SD-series drillholes. These properties include porosity, bulk density, particle density, and matrix permeability. In addition, water contents 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 under a Memorandum of Understanding between SNL and USGS.

Laboratory and field data from drillhole samples will be evaluated using traditional geostatistical techniques to summarize framework material properties for this hole and determine if changes are required in the drilling and sampling program.

Two data reports are to be published as USGS Open-File Reports, and are tentatively entitled "Physical and Hydrologic Properties of Outcrop Samples from a Nonwelded to Welded Tuff Transition, Yucca Mountain, Nevada" (Flint et al.) and "Physical and Hydrologic Properties of Surface Outcrop Samples at Yucca Mountain, Nevada" (Flint et al.). These reports will contain the laboratory results of the outcrop sampling studies that were conducted at Yucca Mountain over the past several years under this activity.

2.2.3.7 Study 8.3.1.4.3.2 - Three-Dimensional Rock Characteristics Models

Preparation was begun on the study plan using the revised DOE-NRC Level-of-Detail Agreement and Review Process for Study Plans (DOE, 1993p). Because the study will create custom models upon demand to support performance assessment and design evaluation activities, the study plan will be a listing and brief theoretical and practical description of a number of tools that can be used to create the physical property distributions necessary for a particular calculation. At the end of the reporting period, the study plan was still in draft form. However, additional staff resources were added near the end of the reporting period, and completion of the study plan is a high-priority item.

Activity 8.3.1.4.3.2.1 - Development of three-dimensional models of rock characteristics at the repository site. The geostatistical indicator simulation exercise of stochastic sequences of welded versus nonwelded tuff for Yucca Mountain that began last reporting period was completed and the results were incorporated into the ongoing Total System Performance Assessment (TSPA) 1993 (Andrews, et al. and Dockery, et al.). Ten complete stochastic realizations of the fully three-dimensional, six-million-node model were computed. Eight one-dimensional stratigraphic columns, each representing a different portion of the repository block, were extracted from these models for flow and transport computations. One-dimensional columns and similar stratigraphic models used in TSPA 1993 have stratigraphic information from multiple drillholes incorporated into each individual column in the new model. The stratigraphic models are controlled by a composite model of spatial continuity.

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Previously, drillhole information was incorporated into a stratigraphic model only if the cross section being prepared passed through the drillhole. A description of the modeling process and its results was prepared for incorporation in the TSPA 1993 report.

A modest exercise was initiated late in the reporting period to produce models of rock quality associated with the North ESF Ramp and to describe the uncertainty associated with those models. Input data consist of rock quality designator. Rock quality designator (Deere and Deere, 1989) is defined on drill core measurements obtained from the various NRG-series drillholes. The measurements are highly preliminary because rock quality designator values are not yet available from all holes. There is some difficulty with these preliminary results because it appears to be that the horizontal range of spatial correlation is extremely short compared with the (incomplete) drillhole spacing. This may, in part, be an artifact of the available data. However, it may also represent a more fundamental problem related to the dominant controls on rock quality at Yucca Mountain. The zones of poor rock quality designator are related directly to structural features which tend to be high-angle features. The difficulty of characterizing high-angle structures with vertical boreholes is well known in mining circles. Following receipt of the outstanding rock quality designator data from the North Ramp Geologic drillholes, the modeling exercise will be repeated. Depending on the outcome, the exercise will be reevaluated. Preliminary discussions have been initiated with geologists currently mapping in the ESF Starter Tunnel regarding equivalent rock quality designator data that may be obtained from horizontal line-scans in the underground workings. Incorporation of closely spaced horizontal data from the ESF might significantly add to the spatial analysis and modeling.

The annual contract-review workshop of the Stanford Center for Reservoir Forecasting was held at Stanford University. The Stanford Center for Reservoir Forecasting provides many of the geostatistical algorithms used in simulation of Yucca Mountain physical property distributions. Recent developments in geostatistical applications were presented by Stanford graduate students and by industrial affiliates. Significant topics addressed at the workshop included: (1) major work on the joint simulation of multiple spatially correlated variables using a Markov-Bayes-type model of coregionalization; (2) revisions to the sequential simulation algorithm to enhance reproduction of longer-range spatial continuity patterns; (3) a merging of fractal techniques with classic geostatistical methods; (4) an expansion of earlier work on simulating multiple-point statistics (most geostatistical methods are based on two-point continuity measures); and (5) efforts to speed simulation of very large models through probability-field techniques. Although the scope of research at the Stanford Center for Reservoir Forecasting is quite broad and many of the results are somewhat preliminary, some of these items have very direct applications to the YMP.

The Markov-Bayes approach to multiple variables is probably the most significant, because ground-water flow is inherently a multivariate problem. The material property fields used as input to flow computations must reflect properly the joint variability and continuity patterns. In all likelihood, simulating these fields separately distorts the cross-variable correlation patterns extant in nature, and these Markov-Bayes techniques may permit more reasonable simulations without the complexity and numerical problems added by a full

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coregionalization model. The technique has been applied to reservoir characterization of porosity and permeability in units in the North Sea with apparent success.

The reproduction of multiple-point connectivity statistics in simulated models also has particular application at Yucca Mountain, because the closest anticipated drillhole spacings (conditioning data) are probably close to or slightly greater than the expected range of correlation based upon surface transect sampling. The sparse nature of conditioning data relative to the correlation length can produce stochastic lithologies in conceptually and physically anomalous positions. Use of higher-order spatial statistics should alleviate this problem. Numerical artifacts induced precisely by this problem were encountered in the porosity simulations of the N-54/N-55 cross section as discussed in "Recent Developments in Stochastic Modeling and Upscaling of Hydrologic Properties in Tuff" (Rautman and Robey, 1993).

The probability-field approach to simulation may prove important to the YMP, in that stochastic approaches to uncertainty assessment require the generation of large numbers of physical property models. Experience with the six-million-node, welded-nonwelded indicator simulations conducted for TSPA 1993 (described above and in Progress Report 8) indicates that the computational effort for site-scale simulations is not trivial. Probability-field simulations take longer to produce and compute initially but, once computed, generation of alternative stochastic images is extremely rapid by comparison.

A plan for the development of software that allows explicit integration of the USGS-developed geometric model of Yucca Mountain (LYNX model) with geostatistical material properties modeling at SNL is in the initial stages. The methodology is probabilistic in nature. However, it makes use of 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 incorporation of abundant soft information from the geologic setting 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. This work is aligned with, but slightly different in approach to that being used by the Stanford Center for Reservoir Forecasting.

Several Geostatistical Software Library and User's Guide (GSLIB) software routines were modified to better meet requirements for postprocessing replicated simulations and checking the successful completion of the simulations. A copyrighted, public domain PostScript utility (Ghostscript) to display and print GSLIB output on the personal computer was obtained during July. This will allow the migration of geostatistical modeling from the work station environment to the personal computer. Although display would appear to be a minor issue in a sophisticated modeling activity, personal computer software programs to serve with the powerful graphics of the PostScript language are almost nonexistent.

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Forecast: The study plan for three-dimensional rock characteristics study will be completed and enter Project review. It is anticipated that the necessary review and revisions will be completed during FY 1994, and the study plan submitted to NRC.

Development will continue on integrated geostatistical modeling tools that can efficiently produce multiple realizations of property distribution simulations and can integrate "soft information" from ongoing geologic modeling using the LYNX GMS software package. Development of these capabilities is a prerequisite to widespread application for statistically based property distributions for use in performance assessment and design analyses. Development of integrated geostatistical modeling software will continue; the "soft-information" link between the USGS geometric (stratigraphic) model (currently constructed using LYNX GMS software) and geostatistical simulation routines to utilize stratigraphic subdivisions within major welded units to constrain the simulated values will be implemented; the main simulation algorithms to incorporate new developments from the Stanford Center for Reservoir Forecasting will be upgraded as appropriate; methods for upscaling to flow simulator block sizes, as appropriate, either within simulation module or as post-processor to rock properties simulator will be incorporated; and participation in the Stanford Center for Reservoir Forecasting industrial research consortium for development of advanced geostatistical methods and algorithms will continue.

In support of the Soil and Rocks Properties Study, ESF ramp design, and construction monitoring activities, the GSLIB- and LYNX-based geologic and material properties models to provide cross sections along developing ESF ramp alignments will be developed and updated. The SNL interaction with LYNX Geosystems, Inc. personnel to guide development of user interface and geostatistical capabilities of the LYNX GMS will continue; upgraded versions of software will be installed and tested as received; test cases and models to LYNX personnel as appropriate to facilitate development will be provided; and development of geologic and material properties cross sections and updating sections as new data become available and as model links with geostatistical subroutines are developed will continue.

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

The study plan was completed and submitted to the Project for review. It was returned to USGS with comments for resolution on August 30, 1993.

Activity 8.3.1.5.1.1.1 - Synoptic characterization of regional climate. Strontium analyses of several precipitation samples gathered from February storms at Yucca Mountain were performed.

Precipitation sample collection was initiated 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 E. Cat Canyon), Beatty, and Stateline, Nevada.

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Forecast: In the first half of FY 1994, the comments on the study plan will be resolved. No other work in this activity has been funded in FY 1994.

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

The study plan was accepted by NRC on April 27, 1993, with no comments.

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. Work was initiated that will provide the basis for reconstruction of both the amount and type of precipitation that has occurred in southern Nevada during and since the last glacial period. That work includes identifying the general fate of precipitation once it has entered the hydrosphere as to evaporation, surface runoff, or infiltration and recharge. Establishing the geological history of water as it moves through the atmospheric and hydrospheric segments of the hydrological cycle will provide the basis to integrate this work in the calcite-silica studies in Study 8.3.1.5.2.1.

To establish if modern day dry and wet playas store water, and if so, how much, during the generally wetter late Pleistocene, three playas in the vicinity of Pahrump were cored by Desert Research Institute staff with assistance from USGS. The playas included Pahrump, Peter's, and Stewart Valley. Cores from those playas were subsampled for aquatic macrofossils and microfossils as well as terrestrial pollen content. Samples from those cores are currently under study. The presence of calcareous microfossils such as ostracodes, if found, will provide the data needed to reconstruct the past water chemistry and provide material for isotopic analyses. Pollen content will provide information about changes in the terrestrial vegetation surrounding the playas through time.

Molluscs and ostracodes collected from the late Pleistocene and early Holocene marsh deposits near Corn Creek Springs, as well as from modern springs, were analyzed for stable isotopes.

Field work was conducted in the Sheep and Spring Mountain Ranges to collect modern terrestrial gastropods from different elevations. Those taxa will be identified and their shells analyzed for stable isotopes. This modern data will serve as a calibration set for evaluating how well the shells record the isotope composition of precipitation. It will also help to evaluate whether an elevational or a latitudinal climate analog model should be applied to fossil data in southern Nevada. A latitudinal model will invoke a much wetter climate reconstruction than one would obtain from an elevational model.

A summary abstract entitled "Strontium Isotope Geochemistry of Playa Deposits near Yucca Mountain, Nevada" (Marshall et al.) was prepared for the 1994 High-Level Waste Conference. The paper presents strontium isotopic data determined on fine-grained sediments from several playas in southern Nevada and utilizes these data to help characterize eolian

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components present in pedogenic carbonates at Yucca Mountain. This report reflects a continuing effort to precisely define the origin of the pedogenic carbonate in light of continued controversy regarding pedogenic carbonates at Trench 14 and elsewhere.

Twenty Sr analyses of fine-grained playa deposits from the northern Nevada Test Site and northern Death Valley were performed. A memo summarizing results was prepared.

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: The USGS will continue to subsample cores collected by Desert Research Institute from about 12 lake, playa, and marsh deposits throughout the southern Great Basin to provide dates for the deposits.

2.2.4.3 Study 8.3.1.5.1.3 - Climatic Implications of Terrestrial Paleoecology

The study plan was accepted by NRC on August 27, 1993, with no comments.

The DOE has committed grant monies to Desert Research Institute, University of Nevada, Reno to provide data concerning paleoclimatic tasks. The Desert Research Institute has agreed to follow USGS QA techniques in its studies. This will allow USGS to use data collected by Desert Research Institute in its own studies.

Activity 8.3.1.5.1.3.1 - Analysis of pack rat middens.

During the reporting period, Desert Research Institute conducted the following work:

1. Ten previously collected, but unprocessed middens were processed, sorted and analyzed. Analysis of 20 previously "archived" middens was completed as well (i.e., insects were separated and all materials counted, dried and weighed if they had not been previously). Contents sheets were updated and checked. Materials from the ten newly processed middens were separated for dating (and isotope analysis) and 20 additional middens were redated to verify the plant associations in each of the strata. The midden data base was updated and modified.
2. During the spring, cores were taken from three localities in southern Nevada including: Pahrump Playa (three localities, four cores), Stewart Playa (two localities, three cores), and Peter's Playa (one locality, one core). Desert Research Institute personnel went to Denver to sample the cores retrieved during the spring. Three hundred pollen, weight loss and ostracode samples were taken about every 20 cm from one representative core from each playa. Cores were transported to Reno where they are presently stored in the Quaternary Sciences Center cold room.

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3. Extraction of 60 pollen samples from the southern Nevada playas, woodrat middens and Summer Lake in the northern Great Basin was completed. Simultaneously, weight loss on ignition of 104 samples taken from these localities has been performed.

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: A meeting will be held with participants in this study and other climate and paleoclimate studies to evaluate progress, plan the next series of studies, or modify existing plans as needed.

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. A report (published abstract) entitled "Quaternary Allostratigraphy of Surficial Deposit Map Units at Yucca Mountain, Nevada: A Progress Report" (Lundstrom et al., 1993) was presented in the session on Recent Geoscience Advances at Yucca Mountain and Surrounding Region at the Geological Society of America Cordilleran Section Meeting in Reno, Nevada, May 19, 1993. This stratigraphy defines mappable alluvial, colluvial, and eolian units in terms of diagnostic sedimentologic, pedologic, morphologic, and surficial characteristics. Using and further characterizing this stratigraphy, three surficial deposit maps (1:12,000 scale) of the northern part of the designated surficial deposit map area were completed and are in technical review. These map reports, intended for publication as USGS Open-File Reports, are entitled "Preliminary Surficial Deposits Map of the Northeast 1/4 of the Busted Butte Quadrangle" (Lundstrom et al.), "Preliminary Surficial Deposits Map of the Southeast 1/4 of the Topopah Spring NW Quadrangle" (Lundstrom and Taylor), and "Preliminary Surficial Deposits Map of the Southwest 1/4 of the Topopah Spring NW Quadrangle" (Lundstrom and Taylor).

In the course of mapping, a lithologically distinctive older gravel was recognized and mapped along Fortymile Wash, four miles east of the proposed repository area. The position and age of this gravel are significant in constraining the geomorphic evolution and tectonic history of Fortymile Wash and Yucca Mountain, and in providing further geologic evidence for the predominance of Late Miocene geomorphic and tectonic activity relative to activity in post-Miocene time. A summary report of this topic entitled "New Geologic Data Concerning the Geomorphic Evolution of Fortymile Wash" (Lundstrom), was submitted for presentation at the 1994 High-Level Waste Conference.

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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.

U-series chemistry on a Q3 soil carbonate from Midway Valley Trench 5, a sample of rhizoliths from the stratigraphically-lowest units exposed in Midway Valley Trench 7, and a sample of rhizoliths from an eolian deposit in Fortymile Wash were completed. Analyses of additional samples (i.e., laminar soil carbonate) are needed to confirm the age dating, as well as to assess whether rhizoliths are temporally associated with the eolian deposits, or whether they were introduced into this permeable horizon at a later date.

Activity 8.3.1.5.1.4.3 - Eolian history of the Yucca Mountain region. In conjunction with surficial deposit mapping activities (Activity 8.3.1.5.1.4.2), sandy eolian deposits were mapped, including a previously unrecognized eolian unit which underlies high terrace gravels of Fortymile Wash. The eolian deposits and buried soils within the deposits were sampled for U-series disequilibrium and thermoluminescence analyses.

Sample preparation and x-ray fluorescence analyses of ten sediment samples from playas between Beatty and Tonopah were completed and an internal report was prepared. These samples provide information relevant to the Oasis Valley ground-water flow system.

Forecast: These activities are unfunded; no activity is planned in FY 1994.

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 underwent SNL internal review and was sent to YMPO for review.

A plan for the transition of global and empirical climate modeling activities (Activities 8.3.1.5.1.6.1 and 8.3.1.5.1.6.4) from Pacific Northwest Laboratory to a single, consolidated effort by SNL was prepared for issue as a YMP Controlled Document. Completion of transition actions and preparation to resume technical activity for this study in FY 1994 is essentially complete and on schedule.

A number of Corrective Action Reports were closed out. The Corrective Action Reports were generated during an October 1992 internal QA audit of activity performed for this study under a contract between SNL and the National Center for Atmospheric Research. The study plan was drafted and is presently undergoing internal reviews. Because of the

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emphasis during this reporting period on planning, corrective actions, and preparatory activity, and limited FY 1993 funding, no technical work was performed specifically for this study. A readiness review is planned for early in FY 1994 as a precedent to resuming technical activity. A presentation on Long-Term Climate Modeling, describing the planned approach to the work, was made at the April Review Board Meeting as part of a series of presentations on the Department's approach to complex problems using the effects of future climate on infiltration as an example.

Activities 8.3.1.5.1.6.1 - 8.3.1.5.1.6.4. It has been proposed that the scope of work be modified for each of the four activities identified in the SCP for this study. The former activity designations and titles are:

- 8.3.1.5.1.6.1 - Global Climate Modeling
- 8.3.1.5.1.6.2 - Regional Climate Modeling
- 8.3.1.5.1.6.3 - Linked Global-Regional Climate Modeling
- 8.3.1.5.1.6.4 - Empirical Climate Modeling

The proposed replacement activities have been tentatively entitled:

- 8.3.1.5.1.6.1 - Global Climate Modeling
- 8.3.1.5.1.6.2 - Nested Global-Regional Climate Modeling
- 8.3.1.5.1.6.3 - Empirical Interpolation
- 8.3.1.5.1.6.4 - Future Climate Synthesis.

These modifications are needed to account for recent developments in climate modeling and to focus the study more directly on Project interests. In particular, the potential impacts of climate change on postclosure repository performance will be addressed.

Forecast: Early in FY 1994, a readiness review will be performed to verify readiness to resume technical work under the controls of the QA program. Other remaining actions defined in the transition plan to consolidate future climate modeling work at SNL will also be completed, including evaluating and dispositioning products developed in preliminary efforts performed over the last several years prior to study plan approval.

A significant portion of the effort for this study in FY 1994 will focus on validating computer models selected for predicting future climate conditions. This validation activity will include the comparison of model results with current meteorological data, and the initiation of validation activities comparing model results with paleoclimate data interpretations. Validation for paleoclimate conditions will initially focus on modeling a past climate state considered representative for providing an upper bound for the future precipitation rate; the preliminary results will be provided for use in ground-water travel time and future TSPA analyses.

A second major effort in FY 1994 will focus on the initial development of methods for interpolating numerical climate modeling results in both spatial and time domains, using

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empirically derived information, and for transforming climate modeling information 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

Revision 2 of the study plan was approved by OCRWM on November 10, 1992, and sent to NRC on December 24, 1992. The NRC evaluated the responses to four comments and six questions provided by OCRWM at the December 19, 1990, detailed technical review. On the basis of these responses, NRC agreed that one comment and five questions were resolved. In a letter dated July 13, 1993, YMPO requested USGS to address the one comment and one question remaining. USGS provided responses and revised text on September 29, 1993, in response to NRC comments and questions.

Activity 8.3.1.5.2.1.1 - Regional paleoflood evaluation. Project staff reduced, analyzed, and compiled flood flow and related precipitation data for the Yucca Mountain/upper Amargosa River watershed. Arc/Info drainage basin maps of the Death Valley watershed and storm volume runoff tables of the upper Amargosa River drainage basin were completed.

A draft of a report, "Late Holocene Regional Paleoflood Evaluation of the Death Valley Watershed, Southwest United States" (Grasso), was nearly ready for review. This report presents numerical correlations between regional precipitation and peak discharge and storm runoff volumes. The numerical correlations will help to quantitatively characterize regional paleoflood conditions and provide a means for establishing the potential magnitudes and frequencies of large-scale floods and debris flows that may occur due to storms in the Yucca Mountain area.

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. Fifty-four water samples (springs and wells) were collected and analyzed for major ions and/or Sr isotopes. All of the playas in the study area (approximately 50), except those off limits on the Nellis Air Force Bombing and Gunnery Range, have been sampled and sent for ostracode, chemical, and/or Sr isotope analysis. These data, together with previously analyzed samples, are being used to help define and analyze the regional ground-water flow system.

A report entitled "Vegetation Distribution in the Amargosa Desert" (Turner et al.) was submitted for technical review. The data from this report are being compared to regional vegetation mapping developed from remote sensing imagery.

A report entitled "Water Chemistry and Ostracode Occurrence from Springs in Colorado, Kansas, and New Mexico: Basic Data" (Gutentag et al.) received USGS technical review and was awaiting USGS approval.

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A report entitled "Logs and Interpretation of Trench 14 on the Bow Ridge Fault at Exile Hill, Nye County, Nevada" (Taylor and Huckins) received USGS technical review and was awaiting USGS approval.

An abstract entitled "U-Th Dating of Climate-Controlled Water Table Fluctuations, Yucca Mountain, NV" (Paces and Taylor) was submitted for presentation at the Fall '93 American Geophysical Union Meeting.

A paper entitled "Late Quaternary History and Uranium Isotopic Compositions of Ground Water Discharge Deposits, Crater Flat, Nevada" (Paces et al., 1993) was published and presented at the 1993 High-Level Waste Conference. The young ages (19 to 45 ka) presented in this paper have been criticized as representing minimum ages reflecting physical or chemical modifications of older deposits that have been exposed at the surface. Therefore, some effort was spent addressing various mixing models and other modification processes and their effects on U-series dates. These results provide additional support for the interpretations of young ground-water discharge that were expressed in the paper. In addition, investigations in obtaining ^{14}C dates from rhizoliths from these deposits was initiated, and samples were submitted for determination of total, inorganic and organic carbon.

Strontium isotope characterization of ground-water flow systems in the Yucca Mountain region was presented at the Underground Test Area Remedial Investigation and Feasibility Study Information Exchange in Las Vegas, July 27-28, 1993. Informal discussions with Geotrans, Inc. were held concerning the possibility of improving communications and data exchange between the Yucca Mountain and environmental restoration studies at the test site.

Compilation, synthesis and interpretation of geochemical and isotopic data from waters (springs and wells) in the Ash Meadows flow system continued. Available data include major cation, anion and Sr concentrations, as well as Sr, H, O, and C isotopes. Data are also being viewed as several sub-basinal flow systems in addition to the larger Ash Meadows flow system boundaries. Correlations between isotopic systems (e.g., Sr and H) and chemical concentrations are being investigated. Additional geologic control pertaining to specific spring discharge localities is currently being compiled. These data will be used to investigate ground-water flow paths in the Ash Meadows system, as well as for the broader regional hydrologic model. The Oasis Valley Sr isotopic data base for ground-water samples including new data was compiled and evaluated.

U-Th chemistry on samples of spring discharge carbonate from the Crater Flat deposit and the Horse Tooth deposit was completed. These samples are being analyzed by alpha-emission spectrometry. The purpose of these analyses is to obtain more reliable results on previously estimated ages from these rocks of 179 ± 30 ka and 39 ± 25 ka, respectively.

Field work to investigate stratigraphic relationships and collect samples for geochronological studies was performed at the spring discharge sites near the southern end of Crater Flat. Eight samples of carbonate-rich materials were collected for U-Th disequilibrium purposes, and four samples of unconsolidated silty materials were collected for thermoluminescence studies. Stratigraphic relationships within this sample suite are much more

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clearly represented than in previously collected samples and should allow a more accurate interpretation of the depositional history of these deposits. Special attention was given to field evidence that would contribute to a better understanding of the history of deposition at Crater Flat given the concerns about secondary modification of carbonates exposed at the surface.

An informal meeting was organized to explore possible future activities at the paleo-discharge sites at the southern end of Crater Flat. Attendees from the saturated zone activity discussed various possible hypotheses for the origin of the deposits and suggestions for future work included core sampling and trenching.

U-series ages for a sample of carbonate collected from within a sequence of fine-grained palustrine deposits in Pahrump Valley were obtained to test the concordance of U-series and ^{14}C ages on these materials. A final age is difficult to interpret.

Pedogenic and spring discharge deposits at Yucca Mountain and vicinity were re-examined in the field in light of the uncertain origins of some of these deposits. Several sites, including Nevares Spring, Ash Meadows, and Ute Crossing were selected to represent deposits whose ground-water discharge origins are well-established, so that their physical, morphological and geochemical features can be compared with deposits of a more equivocal nature (e.g., deposits currently mapped as Pavits Spring in Rock Valley and elsewhere). Seven rock and water samples were collected and prepared for further Sr and U isotopic analysis. Strontium analyses from a suite of banded travertine veins and massive Tertiary/Quaternary limestone from Rock Valley were performed to test the hypothesis that the prominent rock mound in Rock Valley north of Highway 95 represents a spring discharge site.

Activity 8.3.1.5.2.1.4 - Analog recharge studies. Two field trips were conducted to the East Stewart Creek and Kawich Creek study sites. Above average snow water equivalent observed in Kawich basin resulted in above average spring runoff. Near normal snow water equivalent observed in East Stewart basin resulted in near normal spring runoff. Field work conducted in late September was directed toward discontinuing data collection activities at these analog recharge sites.

Hydrologic data for the period October 1992 through May 1993 were compiled and added to the water data management file to update watershed model applications using the precipitation-runoff modeling system. The testing of the precipitation-runoff modeling system was completed.

The synthesis of the results of the chloride ion mass balance approach to estimate effective moisture and the results derived by simulation using the precipitation-runoff modeling system was completed. It was concluded that the inconsistent results derived by application of the chloride-ion method were attributable to nonrepresentative sampling characteristics of the index site(s) as regards to water chemistry. However, useful data on chloride ion deposition from bulk precipitation collectors and chloride concentrations from periodic grab samples of streamflow yield meaningful estimates of ground-water recharge

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from a reduced form of the chloride-ion mass balance technique. A report presenting modeling results, "Estimates of Recharge for Two Small Basins in Central Nevada" (Lichty), is in preparation.

The report, "An Estimate of the Roughness Length and Displacement Height of Sonoran Desert Vegetation, South-Central Arizona" (Claassen and Riggs, 1993), was published. It describes the techniques used to measure the effect that Sonoran Desert plants have on atmospheric circulation in the planetary boundary layer.

The long-term meteorological instrumentation array was shut down for two days while: newly calibrated instruments were installed, the data logger program was corrected so that the pyranometer functions properly, and the correct offsets for the thermometer calibration curves for the newly calibrated probes were input. Other than that, the long-term meteorological data collection at all three levels on the tower at Organ Pipe Cactus National Monument was completed. The April and July bulk precipitation collections were made without incident.

At the soil monitoring sites, five instrument shelters, complete with data loggers, batteries, solar panels and voltage regulators were installed. Four soils pits were dug and another was more than half completed; all were described pedologically and one was sampled for stable isotopes. Four tipping-bucket rain gauges were installed. Stilling ponds for five v-notch weirs were dug and the weirs, stilling wells, and water-level detectors installed.

Criteria for evaluating aerial photography, surveying, and topographic mapping proposals were developed with the help of National Mapping Division staff.

Twenty-two soil samples were prepared for ion chromatograph analysis and 50 analyses were performed. Fifty-six soil-water samples and one rain-water sample were analyzed for deuterium. The top and bottom of one boulder from a debris-flow channel, two boulder samples from a fan surface and one sample from a terrace surface were analyzed for boron, uranium and major elements. The chloride analysis of soil waters was completed, as was the stable isotope analysis of soil carbonates.

Forecast: The precipitation-runoff modeling report will be completed; no other work is funded in 1994.

Activity 8.3.1.5.2.1.5 - Studies of calcite and opaline silica vein deposits. Fluid inclusion investigations were continued of fracture and vein calcite from Yucca Mountain drill core samples. This work resulted in two abstracts being submitted, one to the Geological Society of America Annual Meeting entitled "Isotopic Composition of Soil CO₂ (Carbon Dioxide) near Yucca Mountain" (McConnaughey et al.), and one to the 1994 High-Level Waste Conference entitled "Fluid Inclusion Crushing Studies of Calcite Veins from Yucca Mountain, Nevada, Tuffs: Environment of Formation" (Roedder et al.).

Laboratory space was obtained for the construction of a vacuum manifold for the extraction of CO₂ from soil gases and carbonates. This laboratory will also support isotopic aspects of unsaturated zone site characterization studies.

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Studies of the applicability of fossil molluscs to paleoclimate reconstructions were initiated with Desert Research Institute. Molluscs are widespread in terrestrial and aquatic environments of southern Nevada and provide paleoclimatic information both by the species assemblages and the isotopic composition of the shell carbonate.

A study was initiated of the geochemistry of carbon dioxide and water in the soil zone in the Yucca Mountain area. Monitoring of the isotopic compositions and concentrations of soil moisture and carbon dioxide continued at several locations spanning more than 1 km in elevation and spanning the local variations in climate/plant community. Vertical profiles through the soil typically show maximal CO₂ concentrations and minimal $\delta^{13}\text{C}$ values within 1-2 m of the surface, usually corresponding with the depth of soil wetting and extensive root development. Intra-site variations in concentration and $\delta^{13}\text{C}$ value of CO₂ as a function of season and depth often exceed inter-site variations, whereas variations in the $\delta^{18}\text{O}$ of CO₂ appear to be smaller suggesting that a non-fractionating process, such as plant transpiration, is the dominant mechanism for water loss. Preliminary results of this work will be presented at the Fall '93 American Geophysical Union Meeting and at the 1994 High-Level Waste Conference. About 370 analyses of the $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values of soil gas CO₂ (including operational checks) were performed. The values for $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ from about 575 samples of calcite from drill core, soil calcrete, spring deposits, and standards were determined.

Project personnel performed checks on U-Th chemical procedures used in the mass spectrometric technique, including chemical yields, and process blanks, and obtained additional data to further refine calibration values. In addition, system calibrations were performed by analyzing the *Acropora* marine coral standard. This represents the first reliable data collected from a natural carbonate on the Isotope Geochemistry Support Group mass spectrometer. The resulting data are encouraging: external precision on six age determinations is at a level of about 0.5 to 1 percent which is acceptable for most geochronological problems at Yucca Mountain. However, the accuracy of the resulting ages is systematically biased by Th spike calibration uncertainties which will have to be corrected by preparing and calibrating new Th spikes and standards.

Twenty-three soil samples from four locations at Yucca Mountain were collected for a ⁹⁰Sr scoping study. Sites were selected to obtain profiles through soils of different ages and pedogenic characteristics. If measurable ⁹⁰Sr concentrations are observed, results will be used to model the chemical behavior and rates of mobility of Sr in the pedogenic environment. Samples from pits in Midway Valley were submitted for ⁹⁰Sr determinations. Data are currently being evaluated in terms of analytical detection limits, world-wide post-World War II background levels in soils, and with respect to the stratigraphic relationships between radiogenic and nonradiogenic samples.

Forecast: Because the funding for this activity is less than a minimal budget to support ongoing studies, only a few reports are scheduled to be completed in FY 1994.

Research to be published in FY 1994 includes: "Isotopic Composition of Soil CO₂ (Carbon Dioxide) near Yucca Mountain (McConnaughey et al.), to be presented at the Fall '93 American Geophysical Union Meeting; "Environment of Formation of Calcite Veins

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from Yucca Mountain, Nevada, Tuffs as Evidenced by Fluid Inclusion Crushing Studies" (Roedder et al.), to be presented at the Geological Society of America Annual Meeting. The following research will be presented at the 1994 High-Level Waste Conference: "Fluid Inclusion Crushing Studies of Calcite Veins from Yucca Mountain, Nevada, Tuffs: Environment of Formation" (Roedder et al.); "Paleoclimatic and Paleohydrologic Records from Secondary Calcite: Yucca Mountain, Nevada" (Whelan et al.); "Molluscs as Climate Indicators: Preliminary Results of Stable Isotope and Species Analysis" (Sharpe et al.); "Paleohydrologic and Paleoclimatic Inferences from Calcite Petrography, Chemistry, and Stable-Isotope Studies" (Vaniman and Whelan); and "Isotopic Studies of Yucca Mountain Soil Fluids and Carbonate Pedogenesis" (McConnaughey et al.).

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

The NRC accepted the study plan in a letter dated April 5, 1993, with no comments, and requested a reference cited in the study plan.

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.

2.2.5 Erosion (SCP Section 8.3.1.6)

The Commission accepted the Erosion Topical Report (DOE, 1993g), and requested the data packages supporting the report and other review materials in a letter to OCRWM dated October 15, 1993. The Program is preparing the requested materials for transmittal to the Commission.

Forecast: Comments and questions on the topical report on erosion will be addressed when they are received early in FY 1994.

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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, which addressed Commission comments from the Phase II review, was submitted to the Project in February 1993 and approved in March 1993. The revised study plan was being reviewed by the Commission during this reporting period.

The first draft of the Los Alamos technical report, "Status of Volcanic Hazards Studies for the Yucca Mountain Site Characterization Project," was completed. A DOE-NRC Technical Exchange was held on June 9, 1993, to solicit comments from the Commission on this draft.

Activity 8.3.1.8.1.1.1 - Location and timing of volcanic events. No progress during the reporting period. Funding for this activity was scheduled to start in FY 1994; however, it will be delayed until FY 1995.

Activity 8.3.1.8.1.1.2 - Evaluation of the structural controls of basaltic volcanic activity. Field studies were conducted in Crater Flat to evaluate a geologic map and tectonic models of Crater Flat. Thirteen structural models for the controls of the distribution of basalt centers in the Yucca Mountain region were identified.

Activity 8.3.1.8.1.1.3 - Presence of magma bodies in the vicinity of the site. A contract was finalized with a consultant to review the status of geophysical data in the Yucca Mountain region as it relates to the volcanism issue.

Activity 8.3.1.8.1.1.4 - Probability calculations and assessment. The first phase of risk simulation modeling of E1 and E2 was completed. A paper entitled "Simulation Modeling of the Probability of Magmatic Disruption of the Potential Yucca Mountain Site" (Crowe, 1993) was presented at Focus '93. Using a form of a triangular distribution, cumulative probability curves for E1 were generated. The paper was in the YMPO approval process and will be published in the conference proceedings.

Forecast: For FY 1994 work will focus on the development of alternative structural models for the distribution of past basaltic centers. These models will use constraint probability ranges of E2. Data will be integrated into this activity from field geologic studies, and from aspects of the tectonics programs (seismicity, geophysical studies, studies of Quaternary faulting and fault systems, and the evaluation of tectonic models). A report on this work will be prepared.

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

The draft study plan was submitted to DOE in October 1992. Review comments were completed on June 2, 1993. All comments were resolved and verified in August 1993, and the study plan was sent to NRC on October 4, 1993.

Activity 8.3.1.8.1.2.1 - Eruptive effects. Field work, which focused on the distribution of lithic fragments in basaltic pyroclastic deposits, was begun at Alkali Butte in New Mexico. Geologic mapping of this site was completed. A paper was presented entitled "Effects of Magmatic Processes on the Potential Yucca Mountain Repository: Field and Computational Studies" (Valentine et al., 1993) at Focus '93. Initial results of field analog studies at small-volume basaltic centers where detailed measurements are being conducted of the amount of wall-rock debris that can be erupted as a function of depth in the volcanic plumbing system were described. Constraints from field evidence of wall-rock entrainment mechanisms were also discussed.

Forecast: Efforts will be continued 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. A two-part approach will be used. First, an examination will be made of the physical constraints on the amount of waste that can be carried to the surface by comparison to the total abundance of lithic fragments (country rock) in magma and the depth of derivation of the lithic fragments. If the component of the repository inventory released at the surface is sufficiently small ($<0.1R$ where R is the maximum radiological releases allowed under regulatory requirements), studies on the direct effects of future volcanic activity will be terminated. Second, work will continue on the direct effects of eruptions through the controlled area. If the released inventory is $>0.1R$, eruption modeling will be carried out to attempt to determine the partitioning of the waste inventory in surface eruptions (scoria cone, scoria-fall sheet, fine-grained component, lava flows) and the percentage of the waste that is released in the accessible environment in 10,000 years. A letter report on lithic fragment studies will be prepared.

Activity 8.3.1.8.1.2.2 - Subsurface effects of magmatic activity. Basalt intrusion forms were studied at the Nye Canyon and southern Crater Flat sites. Lucero and Rio Puerco volcanic fields in New Mexico were evaluated for field studies of subsurface geometry of basalt feeder systems. A revised dike-swarm geometry of the lava sequences of the Lathrop Wells volcanic center was completed.

Forecast: Work will continue on the potential subsurface effects of intrusion of magma into a repository, topographically below or above the repository or in the waste isolation system. The primary intrusion forms examined will be individual dikes, dike swarms and sills (grading to lopoliths). The analysis will be focused on the effects of mechanical emplacement of the intrusions, on the thermal perturbations from the intrusions, and on the effects of volatile degassing on the unsaturated and saturated zone hydrology.

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Activity 8.3.1.8.1.2.3 - Magma system dynamics. Staff revised the section on magma system dynamics in the Los Alamos technical report on the status of volcanism studies.

Forecast: The following work will be performed:

1. Attempt to bound E3, the probability of magmatic activity carrying significant quantities of waste radionuclides to the surface through direct eruption.
2. Evaluate the possible subsurface effects of magma activity through formation of dikes or sills in or below the waste isolation system.
3. Examine 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.

A letter report on magma system dynamics will be prepared.

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

The Principal Investigator completed the current draft of Study Plan 8.3.1.8.2.1, Rev. 1 in the new study plan format. It was submitted for USGS review September 30, 1993.

Forecast: Work on the combined study plan package will continue in FY 1994. The study plan will be revised after USGS review and submitted to YMPO for review by mid-year. Synthesis studies will continue to compile information on the tectonic setting and structural field relations of basalts in Crater Flat. Scenarios of tectonic disruption of the hydrologic system will be developed and analyzed.

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

Activities 8.3.1.8.3.1.1 through 8.3.1.8.3.1.7. No progress during the reporting period; these were out-year activities.

Forecast: This study will be 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

Activity 8.3.1.8.3.2.5 - Effects of faulting on water-table elevation. The Principal Investigator completed the current draft of Study Plan 8.3.1.8.2.1, Rev. 1 in the new study plan format. It was submitted for USGS review September 30, 1993.

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Forecast: This study will be 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

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

Forecast: This study will be 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

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

Forecast: This study will be combined with Study 8.3.1.8.2.1.

2.2.6.8 Study 8.3.1.8.5.1 - Characterization of Volcanic Features

Activity 8.3.1.8.5.1.1 - Volcanism drillholes. Los Alamos and USGS staff held discussions about obtaining ground-magnetic and gravity data to investigate aeromagnetic anomalies. These activities have been postponed because the drillholes will not be funded in FY 1994.

Activity 8.3.1.8.5.1.2 - Geochronology studies. New $^{39}\text{Ar}/^{40}\text{Ar}$ age determinations were obtained for the basalt of Thirsty Mesa, the Amargosa Valley aeromagnetic anomaly, the 1- and 3.7-Ma basalt centers of Crater Flat, and tuff xenoliths enclosed within basalt at Lathrop Wells. Field sites were flagged in preparation for environmental surveys of trenching sites at the 1-Ma basalt centers of Crater Flat. Trench sites at the Sleeping Butte center were surveyed. At Lathrop Wells, new age determinations were obtained using the cosmogenic He and thermoluminescence methods.

Forecast: Final assessments of the utility of the U-Th disequilibrium, the cosmogenic He, and the thermoluminescence methods for establishing the ages of Late Pleistocene and Holocene volcanic centers will be made. Age determinations using the $^{39}\text{Ar}/^{40}\text{Ar}$ method will be obtained for the basalt at Sleeping Butte, Crater Flat, Buckboard Mesa, the Thirsty Mesa Shield, and the approximately 10 Ma basalt dike intruded into the Solitario Canyon fault. Soil and geomorphic studies will continue at Lathrop Wells, Sleeping Butte, and Crater Flat and at selected localities in the Cima volcanic field. Exploratory paleomagnetic work will be extended to the basalt Sleeping Butte and the basalt units of Crater Flat.

Activity 8.3.1.8.5.1.3 - Field geologic studies. Twenty-three shallow pits were excavated at the Lathrop Wells volcanic center to investigate the distribution and clast size

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variations of the scoria-fall sheet. A revised geologic map of the lava sequences of the Lathrop Wells center was completed. Field studies of the historic eruptions of Cinder Cone in Mt. Lassen National Monument were completed. The distribution of basaltic ash in trench sites in the southern part of Yucca Mountain was examined in conjunction with USGS. Two tephra units were discovered in alluvial units north of the Lathrop Wells center.

Forecast: Geologic mapping of the basalt of Buckboard Mesa will be completed. Final topographic maps of the Lathrop Wells, Sleeping Butte, and basalt units of Crater Flat will be converted to digital data for volume calculations. Some field studies will be conducted in the Cima and Lunar Crater volcanic fields in support of geochronology, soil, and geomorphic studies. Preliminary geomaps of the Pliocene volcanic centers of Crater Flat and the Quaternary volcanic centers of Crater Flat and a revised geomap of Lathrop Wells volcanic center will be prepared.

Activity 8.3.1.8.5.1.4 - Geochemistry of scoria sequences. Major element geochemical data were obtained for the Lathrop Wells volcanic center. Microprobe studies of the mineral composition of basaltic ash in alluvial deposits were begun. Modeling of fractionation, eruption, assimilation, and recharge processes was begun to discriminate between polycyclic and monogenetic eruptive activity at Lathrop Wells.

Forecast: Petrological and isotopic studies of the basalt of Lathrop Wells, Sleeping Butte, and the 1 Ma and 3.7 Ma basalt of Crater Flat will be focused on. Isotopic analyses of Sr, Nd, and Pb will be obtained for these units. INAA data for a selected suite of trace elements will also be obtained. Petrological modeling of the isotopic and geochemical data will be conducted to examine alternative models of basalt petrogenesis. The results of the modeling will be used to test assumptions used in probability calculations. A report on the geochemistry of Lathrop Wells eruptive sequences will be prepared.

Activity 8.3.1.8.5.1.5 - Geochemical cycles of basaltic volcanic fields. Staff began geochemical evaluations of alternative models of the time-compositional variations in basalt units of the Yucca Mountain region.

Forecast: Studies of the Cima, Lunar, San Francisco Peak, and Springerville volcanic fields will be continued. New data will be gathered on the volcanic fields of Saline Valley, the Big Pine area, and selected volcanic fields in southern Arizona and southern New Mexico. A report on the evolution of volcanic fields in the southwestern United States will be prepared.

2.2.6.9 Study 8.3.1.8.5.2 - Characterization of Igneous Intrusive Features

The study plan underwent YMPO review and comments were being addressed by USGS.

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.

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Activity 8.3.1.8.5.2.2 - Chemical and physical changes around dikes. Technical activities for this report period were limited to maintaining laboratory and field capabilities and providing input to drilling plans. Temperature-calibration facilities in the laboratory were improved, a new NIST-calibrated platinum-resistance thermometer was installed, and the calibration baths were modified. An apparatus for measuring the thermal conductivity of saturated rocks at elevated temperatures was calibrated and put into service, initially for a geothermal application. The apparatus might be used for Yucca Mountain-related work to determine the conductivity of rocks from the saturated zone of newly drilled deep boreholes.

Information was provided to drilling planners regarding core hole USW G-5 and to the hydrologic staff regarding planned reconfiguration of some of the WT-series holes, to allow high-resolution temperature logs through the unsaturated zone. Information was also provided to planners of the ESF for proposed horizontal temperature logging and thermal-conductivity determinations in the ESF.

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. No field measurements were carried out due to the lack of available drillholes for thermal study. A dedicated laboratory for thermal studies was maintained and apparatus was kept calibrated.

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 ESF ramp-alignment boreholes to improve baseline data before in situ conditions are disturbed by ESF 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 ESF 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 WT holes. A summary of existing heat-flow information will be prepared for a Geophysics White Paper.

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.

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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.

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. Work began in April 1993, to assemble new information on radiometric age data from altered rocks and known mineral occurrences in the vicinity of Yucca Mountain. A report entitled "New Radiometric Ages Related to Alteration and Mineralization in the Vicinity of Yucca Mountain, Nye County, Nevada" (McKee and Bergquist), was completed and was in USGS internal review. This report contains previously unpublished information that relates ages of mineralization to volcanism and enhances our understanding of the relationship between Tertiary volcanic events and mineralization in the vicinity of Yucca Mountain. The radiometric data were verified and supporting data produced. This will be an important help in the evaluation of mineral resources at the potential repository site. The report is accompanied by a map produced in the Geographic Information System format and shows sampling sites superimposed on a generalized geologic base.

Activity 8.3.1.9.2.1.4 - Assessment of hydrocarbon resources at and near the site. Work to evaluate hydrocarbons in the Yucca Mountain region continued through September 1993. Density, resistivity, gamma ray, and caliper well logs from the Felderhoff 25-1 and 5-1 wells were analyzed; figures summarizing the logs were prepared. The analysis of lithologies of rock data from the Amargosa Valley are described in a proposed Open-File Report entitled "Lithologic and Geophysical Logs of Drill Holes Felderhoff Federal 5-1 and 25-1, Amargosa Desert, Nye County, Nevada" (Carr et al.).

Evaluation of hydrocarbons in the Railroad Valley analog area continued. Surface mapping information from field studies in the Pancake Range on the west side of Railroad Valley was analyzed. The northern end of the Pancake Range includes an east-verging overturned syncline involving Late Paleozoic sedimentary strata which is part of the Central Nevada Thrust Belt. The implications of the Pancake Range mapping are that there are

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significant differences in the timing and character of the deformation between the Central Nevada thrust belt and the Utah and Wyoming thrust belt. Proposed similarities in oil potential are extremely speculative, especially if extended southward to Yucca Mountain.

Staff visited the Nevada Bureau of Mines and Geology to collect additional cuttings/samples of Chainman Shale and Sheep Pass Formation occurrences in wells throughout Railroad Valley. Coal samples were also provided as additional possible analogs to the Area 8 peats. The USGS wells in Fish Lake Valley were sampled for recent peat which may be an analog to the Neogene peat found in Area 8 of the Nevada Test Site. A first draft of "Source Rocks and Thermal Maturity History of the Yucca Mountain Region, Southern Nye County, Nevada" (Barker) and a technical data information form were prepared for future publication.

A summary abstract entitled "Isotopic Tracers of Gold Mineralization in Paleozoic Limestones of Southern Nevada" (Peterman et al.) was submitted for the 1994 High-Level Waste Conference. This paper presents Sr and Pb isotopic results from mineralized and nonmineralized Paleozoic carbonates, and suggests a powerful exploration approach that utilizes deviations in isotopic compositions from original marine signatures.

Six dacite dike samples from the northeast part of Bare Mountain were obtained from the University of Nevada, Reno for elemental and Sr and Pb isotopic analyses. These materials are being geochemically characterized since they have commonly been assumed to represent part of the igneous system responsible for hydrothermal precious metal mineralization of Paleozoic limestones at Bare Mountain. Since much of the mineralization at Bare Mountain is thought to be associated with intrusion of Tertiary igneous bodies, these dikes may provide an opportunity to characterize, in part, the intrusive component of the hydrothermal systems.

Digital Elevation Model data was used to produce topographic base maps of Bare Mountain and the Striped Hills areas and limestone sample localities were plotted on these base maps. In addition, Sr isotopic compositions and average ages of the rock units were compiled and compared to the marine Sr isotopic evolution curve. Deviations of observed $^{87}\text{Sr}/^{86}\text{Sr}$ compositions are presumably caused by secondary alteration, and the extent of deviations and their spatial distributions are currently being evaluated. Subsequently, a contoured base map of the Bare Mountain area was prepared by digitizing a portion of the Beatty 1:100,000 sheet. This digitized map is now used as a base for computer-plotting of sample locations and geochemical parameters and will allow spatial visualization of alteration patterns in the Paleozoic carbonate section. In addition, all current sample locations were determined, verified, and plotted on the base map. Possible correlations between Sr isotopic compositions and Sr and Ba concentrations were examined from Bare Mountain carbonates. Correlations are not strong, although $\delta^{87}\text{Sr}$ does exhibit a general increase with Sr and Ba concentrations. Data may be affected by the type of carbonate analyzed, and steps were initiated to quantitatively identify the degree of dolomitization in all of the samples by x-ray fluorescence analysis of Mg/Ca ratios.

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Strontium isotopic data for Paleozoic limestones from Bare Mountain, Striped Hills, Spring Mountains, and ranges in the Indian Springs Valley have been compiled and evaluated. Samples from Bare Mountain were identified as either being mineralized or nonmineralized. Samples from the Striped Hills, Spring Mountains, and ranges in the Indian Springs Valley are from nonmineralized terranes and retain their original Paleozoic marine carbonate $\delta^{87}\text{Sr}$ signatures. In contrast, mineralized carbonates from Bare Mountain have had their $\delta^{87}\text{Sr}$ values increased dramatically through an influx of Sr which was enriched in radiogenic strontium (^{87}Sr). These results imply that mineralization included interaction with high $\delta^{87}\text{Sr}$ fluids which probably represent ascending hydrothermal fluids percolating through the Precambrian basement. Thus far, this isotopic approach appears to hold considerable promise as a tool for evaluating mineral potential of carbonate terranes.

Field work included several days in the Yucca Mountain vicinity collecting field data and samples for use in assessing the potential for mineralization in the area. The first portion of the collecting trip included an underground tour of the Sterling Gold Mine at Bare Mountain. The purpose of the trip was to examine and sample altered host rock and secondary mineralization associated with low-angle structures and associated gold deposits in Paleozoic carbonates. Approximately 15 samples were collected for geochemical and isotopic (Sr and Pb) analysis. In addition, spectacular specimens of secondary carbonate speleothems were collected from open dug and cavity surfaces for geochronological, paleohydrological and paleoclimate investigations. The second portion of the collecting trip aimed at characterizing the largely unaltered section of Paleozoic carbonates in the Specter Range. These samples may serve to verify that large areas of unmodified carbonate retaining its original sea-water isotopic signatures are preserved throughout the region. In addition to collecting approximately 15 samples of marine carbonate bedrock, abundant banded travertine veins (presumably representing calcite deposition from carbonate-saturated ground waters) were observed and sampled.

The Principal Investigator participated in a mine tour of the Round Mountain Gold Mine near Tonopah, Nevada. The purpose of this trip was to closely examine a well-exposed volcanic-hosted gold deposit. Mineralization is hosted by Oligocene felsic pyroclastic volcanics. Hydrothermal solutions were introduced around 25 Ma along zones of high permeability. Hydrogeologic transmissivity at the time of mineralization was dependent on depositional porosity and fracture density which, in turn, was controlled by the degree of welding of various different lithostratigraphic units.

The following publications were presented at Geological Society of America meetings in Reno, Nevada, May 19-21, 1993, in support of the Yucca Mountain region petroleum model: "Seismic Constraints on Fault Angles in Railroad Valley, NV" (Grow et al., 1993); "Structure and Timing of Deformation in the Central Pancake Range, Nye County, Nevada" (Perry and Grow, 1993); "Controls on Cross-Sectional Geometry of Extensional Basins -- A Seismic-Stratigraphic Approach" (Potter et al., 1993); and "The Case for Pre-Middle Cretaceous Extensional Faulting in Northern Yucca Flat, Southwestern Nevada" (Cole et al., 1993).

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Forecast: Scientists plan to analyze chemical and petrologic information from core and cuttings produced from boreholes that are scheduled to be drilled for the YMP at and near Yucca Mountain and to run transects across Yucca Mountain to analyze for soil gases that can provide information on indications of mineralization or lack thereof at depth.

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

The State of Nevada sent 25 comments on the study plan to OCRWM on December 24, 1992. DOE responded to the State's comments on April 22, 1993. No other progress during the reporting period; this was an out-year study.

Forecast: No activity is planned for FY 1994; this is an out-year study.

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 planned in FY 1994; this is an out-year study.

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 planned in FY 1994; this is an out-year study.

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

No progress during the reporting period. This study will be combined with Study 8.3.1.12.1.2 and Study 8.3.1.12.4.1.

Forecast: The study plan preparation will be initiated in FY 1994.

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

No progress during the reporting period. This study will be combined with Study 8.3.1.12.1.1 and Study 8.3.1.12.4.1.

Forecast: The study plan preparation will be initiated in FY 1994.

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

Revision 1 of the study plan was sent to NRC on August 11, 1993.

Activity 8.3.1.12.2.1.1 - Site meteorological monitoring program.

The Meteorological Monitoring Summary Report (SAIC, 1993c), for the reporting period December 1985 through December 1991, was submitted to YMPO. Two quarterly ambient air monitoring reports were submitted to the State of Nevada; this met the reporting requirements for Air Quality Permit No. 2693 during the period to allow continuation of surface disturbing activities.

Meteorological monitoring continued at nine sites. Equipment upgrades were completed at five sites, enhancing the capability to measure additional parameters and improving the reliability and quality of the existing systems. This upgrade will also provide more detailed data to be used as part of the diurnal cold air drainage study associated with the mountain terrain around Yucca Mountain.

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.

Forecast: Data collection will continue during FY 1994. The data required to maintain the State of Nevada Air Quality permit will continue to be collected and reported.

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

A scoping field study for air diffusion measurements in mountain terrain was conducted in June 1993, with support of the National Oceanic and Atmospheric Administration Turbulence and Diffusion Division, and Technical and Management Support Services personnel. Procedures for performing full-scale diffusion measurement field activities were drafted. A report entitled "Summary of Socioeconomic Data Analyses Conducted in Support of the Radiological Monitoring Program During Calendar Year 1992" (SAIC, 1993d) was prepared in May 1993. This is an annual summary report from the socioeconomic data base

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which provides population density and community characteristics for 1992 to support the "NV/YMP Site Specific Radiological Control Manual" (REECo, 1992).

Forecast: A diffusion measurement field activity will be accomplished with support of the National Oceanic and Atmospheric Administration Turbulence and Diffusion Division in the October/November time period. A report of the results will be prepared and submitted to the Project. An annual update of population density for Task 1, "Determine Population Centers," of this study plan will be obtained from the summary of socioeconomic data analyses.

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

No progress during the reporting period. This study will be combined with Study 8.3.1.12.1.1 and Study 8.3.1.12.1.2.

Forecast: The study plan preparation will be initiated in FY 1994.

2.2.9 Offsite Installations and Operations (SCP Section 8.3.1.13)

The radiological environmental monitoring program for YMP, being implemented by the Technical and Management Support Services contractor for YMP, 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 QA program began in 1990. Program activities are being reported annually (by calendar year) in the Site Environmental Report.

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 are being prepared for analysis. Data validation and reduction is in process.

Forecast: Sample collection and analysis will essentially remain at present levels through FY 1994 with the exception of biota. No biota samples will be collected for analysis.

2.2.10 Surface and Subsurface Access Characteristics (SCP Section 8.3.1.14)

The Transition Plan for Soil and Rock Properties of Potential Locations of Surface Facilities was prepared and submitted to YMPO. This plan effects the transition of the work from USGS to SNL.

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2.2.10.1 Study 8.3.1.14.2.1 - Exploration Program

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

Activity 8.3.1.14.2.1.2 - Preliminary and detailed exploration. The SNL Principal Investigator and staff met with the ESF design team, Sample Management Facility staff geologists, and DOE staff at the Sample Management Facility to review the core from UE-25 NRG#2A and to discuss further drilling along the North Ramp alignment in the vicinity of the Bow Ridge fault. As a result of these discussions, UE-25 NRG#2A was deepened to provide a lithologic contact of high confidence. UE-25 NRG#2 was deepened to ensure complete penetration of the Bow Ridge fault and to provide a lithologic contact of high confidence to the east of the fault. Another borehole, UE-25 NRG#2B, was drilled to provide additional information for a zone of no core recovery in UE-25 NRG#2.

A section map of the North Ramp Bow Ridge fault area was prepared to incorporate the information from boreholes UE-25 NRG#1, UE-25 NRG#2, UE-25 NRG#2A, UE-25 NRG#2B, UE-25 NRG#3 and UE-25 RF#8. An overview of the Soil and Rock Properties Study and the section map of the North Ramp Bow Ridge fault area was presented to NRC staff during a site visit in May.

Drilling was also completed on boreholes UE-25 NRG#4 and UE-25 NRG#5. The cored interval in UE-25 NRG#4 was increased to accommodate the enhanced ESF option. The location for an additional North Ramp borehole designated USW NRG-7 was surveyed. Criteria for the engineering design use of data from borehole USW SD-12 have been established, and the hole has been located and surveyed.

The locations for additional North Ramp boreholes designated USW NRG-8a, USW NRG-8b and USW NRG-8c were identified. These shallow boreholes will investigate the depth of alluvium to the west of Exile Hill above the North Ramp.

Forecast: The objective of the exploration program is to plan the strategy for collection and analysis of the geotechnical information that is necessary to site and design surface facilities and underground openings for the ESF. Existing data will be evaluated to determine the additional information needed to adequately address design issues for construction of the ESF. On the basis of these data needs and the expected soil and rock conditions at the site, an exploration program will be implemented using such methods as drilling, test pit excavation, sampling and geophysical investigations. Results of data collection and analysis activities will be summarized and published in an SNL report.

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2.2.10.2 Study 8.3.1.14.2.2 - Laboratory Tests and Material Property Measurements

Mechanical and Bulk Properties Testing:

Mechanical and bulk properties testing (unconfined compression, splitting tension, triaxial compression and bulk properties) has been completed for core from boreholes UE-25 NRG#2, UE-25 NRG#2A, UE-25 NRG#3, and USW NRG-6 (see Section 2.2.11.3).

Thermal Conductivity Testing:

The SNL Work Agreement for thermal conductivity testing of samples from USW NRG-6 was issued. The thermal conductivity of each sample is being measured at nominal temperatures of 30°, 50°, 70°, 110°, 155°, 200°, 245°, and 290°C. Testing of samples from eleven different depths between 0.0 m and 126.8 m has been completed at three different saturation states (air-dry, fully saturated, and oven-dry). The scientific notebooks containing these data are being reviewed and testing at temperatures above 100°C is in process. Samples from USW NRG-6 below 126.8 m were selected and are in the process of being machined.

Thermal Expansion Testing:

The SNL Work Agreement for thermal expansion testing of samples from USW NRG-6 was issued. For these samples, testing will be conducted from ambient to 300°C, and at three different saturation states (air-dry, fully saturated, and oven-dry) below 100°C (see Section 2.2.11.2).

Testing of air-dry samples from ten different depths between 0.34 and 126.8 m was completed from ambient to 110°C. Thermal expansion testing on saturated samples was delayed so that parts for the saturation test apparatus can be cloned for the additional dilatometer system (see Section 2.2.11.2). The saturation test apparatus is used to control the atmosphere (i.e., high humidity) around the sample to minimize sample dehydration at temperatures below the nominal boiling point of 100°C. Reassembly of the dilatometer system is in process. Thermal expansion testing on fully saturated samples will resume after the system is calibrated. For these tests, thermal expansion will be measured from ambient to 100°C, then the temperature will be held constant for 30 hours to allow the sample to dehydrate and the length to stabilize. Heating will then be restarted and will continue until 300°C is reached, then the sample will be cooled to ambient temperature.

Mineralogy:

The SNL Work Agreements for preparing polished thin sections and laboratory petrologic determination of samples from USW NRG-6 were issued.

Polished thin sections were made on 17 samples from depths 6.8 to 126.8 m and mesoscopic descriptions were completed for these samples. Microscopic thin section descriptions and point counts are in process. Powdered samples are being prepared for whole-rock chemical and x-ray diffraction analysis. Mineralogic, petrologic, and whole-rock

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chemistry of the samples will be used to interpret data from thermal and mechanical tests and to determine if correlations exist between these values and the physical properties of the rock.

Forecast: The objective of this program is to determine physical, mechanical, thermal, and dynamic properties of the soil and rock. Laboratory tests and material property measurements will be performed on representative samples of soil and rock. The results of this testing will provide engineering data for the design of surface structures, fills, roads, slopes, and underground openings. Testing activities on core samples from several drillholes include laboratory mechanical tests and laboratory thermal properties tests. In addition, laboratory tests will be performed on unconsolidated tuff recovered from NRG-2B, and soils testing will be performed for a booster pump station, water storage tanks, and conveyer support locations. Results of the laboratory testing will be summarized and published in an SNL report.

2.2.10.3 Study 8.3.1.14.2.3 - Field Tests and Characterization Measurements

A Scientific Notebook Procedure for Geotechnical Core Logging was developed and used to develop geologic and structural logs for core from boreholes UE-25 NRG#1, UE-25 NRG#2, UE-25 NRG#2A, UE-25 NRG#2B, UE-25 NRG#3, UE-25 NRG#4, UE-25 NRG#5 USW NRG-6 and UE-25 RF#8.

The procedures for Schmidt-Hammer tests of core from the North and South Ramp boreholes were prepared and the equipment to perform these tests was procured. Equipment to perform the soil resistivity testing was procured and calibrated. The M&O has assumed responsibility for earth resistivity testing at the North Portal and SNL will provide calibrated test equipment and limited support for these tests.

The existing open soil test pits for the North Ramp Portal and access roads were closed.

Standard Penetration Tests were performed in borehole UE-25 NRG#2B to determine the bearing capacity of the unconsolidated tuff.

Forecast: Field tests will be performed to determine the in situ physical, mechanical and dynamic properties of the soil and rock. Characterization measurements will be conducted on the rock to classify and quantitatively describe rock structure. The results of these tests and measurements will be used to develop estimates of the engineering characteristics of the soils and rock. This geotechnical information will be used for structural design and to group soil and rock into stratigraphic units with similar properties. Testing activities include preparation of structural and geologic logs for designated North Ramp Geologic and South Ramp Geologic holes, rock mass quality estimates for selected surface locations, and submission of results of the in situ soils testing forecast in Section 2.2.10.2. Results of the data collection and analysis will be summarized and published in an SNL report.

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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

Revision 1 to the study plan was reviewed, approved by YMPO on August 27, 1993, and sent to NRC on September 14, 1993. This revision updates the study plan with respect to the current configuration of the ESF. The OCRWM transmittal letter to NRC explained how this study plan addressed Site Characterization Analysis Comment 55.

In the last half of FY 1993, priority was given to thermal conductivity testing of samples from USW NRG-6 (see Section 2.2.10.2). Initiation of studies to determine baseline test conditions for thermal conductivity testing were delayed until additional test equipment was procured and calibrated.

Activity 8.3.1.15.1.1.1 - Density and porosity characterization. No progress during the reporting period; this was an unfunded activity.

Activity 8.3.1.15.1.1.2 - Volumetric heat capacity characterization. No progress during the reporting period; this was an unfunded activity.

Activity 8.3.1.15.1.1.3 - Thermal conductivity characterization. Calibration runs using moisture containment cells made from the polymer Delrin® were found to be unstable. New cells made from Kel-F® were fabricated and successful calibration runs were completed. The moisture containment cells are used for testing samples in a controlled environment (high humidity) below 100°C.

An additional low temperature instrument for measuring thermal conductivity from ambient to 100°C was procured. Component and system calibrations were completed for the low temperature instrument and the Thermal Conductivity Analyzer. The Thermal Conductivity Analyzer is used for thermal conductivity testing at temperatures above 100°C.

The SNL Work Agreement for the study of the saturation effects on thermal conductivity was issued. Three samples of welded devitrified tuff and three samples of nonwelded zeolitic tuff were selected to be used for this study. Nominal temperatures of 30°, 50°, and 70°C were selected to measure the thermal conductivity of each sample at five different saturation states (fully saturated, oven-dry, air dry, and two other intermediate states). Testing of air-dry samples was completed and the samples were saturated in preparation for the next series of tests. These experiments are necessary to determine whether thermal conductivity has a predictable dependence on the saturation state of the sample and, if so, to describe the nature of the relationship. Results from these experiments will be used to determine the optimal baseline test conditions for thermal conductivity characterization.

The SNL Work Agreement for the study on the effects of a fracture on the thermal conductivity of TSw2 was issued. Machining of samples for this study, which was delayed to give priority to samples from USW NRG-6 and UE-25 NRG#2, has proceeded. The nominal temperature of 30°C and stress levels of 0, 2.5, 5, 7.5, and 10 MPa were selected to measure

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the thermal conductivity of samples from TSw2. These measurements will be made using the comparative method before and after the intact samples are fractured. If fractures are observed to have a significant effect, samples containing natural fractures will be obtained and tested.

Rock crushing and grinding equipment was procured and installed at the University of New Mexico. The equipment will be used for preparing powdered rock samples for chemical analysis and mineralogic determination by x-ray diffraction. A petrographic photograph album of Yucca Mountain rocks was also assembled to provide a visual reference for evaluating welding, devitrification, and alterations observed in thin sections. Mineralogic and chemical analyses will be used to aid in the interpretation of thermal properties data.

Forecast: The studies on the effects of saturation on and the effects of fractures on thermal conductivity testing will be completed. Samples from North Ramp Geologic and South Ramp Geologic holes to support the Soil and Rock Properties Study (see Section 2.2.10.2); and Systematic Drilling holes to support design of the main ESF/repository drifts will be characterized by measuring saturated bulk density, dry bulk density and grain density; calculating matrix porosity; and performing mineralogic, petrologic, petrographic, and bulk chemical analyses.

Technical procedures will be developed to support activities that measure the heat capacity of tuff samples by adiabatic pulse calorimetry and to perform tests to establish baseline test conditions for measuring the heat capacity of tuff samples.

Testing will be conducted on and limited to the Topopah Spring Member of samples from North Ramp Geologic, South Ramp Geologic, and Systematic Drilling holes. Results of the tests will support the soil and rock properties study and ESF design. Tests to be conducted are heat capacity measurements and thermal conductivity measurements on several samples from various North Ramp Geologic and South Ramp Geologic holes, as well as on several samples from various Systematic Drilling holes.

In addition, analyses on heat capacity data and thermal conductivity data will be performed to include:

- Calculating the heat capacity of the solid components as a function of temperature using measured values of heat capacity heat, matrix porosity and textbook values for the heat capacity of water and air
- Calculating 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
- Calculating the thermal conductivity of the solid components as a function of temperature using measured values of thermal conductivity, matrix porosity and textbook values for thermal conductivity of water and air

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- Examining potential correlations between thermal properties and other sample characteristics
- Performing preliminary statistical analyses to examine the spatial variability of thermal conductivity and heat capacity
- Examining potential correlations between thermal properties and other sample characteristics (e.g., bulk properties, porosity, mineralogy)
- Developing preliminary three-dimensional models for thermal conductivity and heat capacity

2.2.11.2 Study 8.3.1.15.1.2 - Laboratory Thermal Expansion Testing

Revision 1 to the study plan was reviewed, approved by YMPO on August 27, 1993, and sent to NRC on September 14, 1993. This revision updates the study plan with respect to the current configuration of the ESF.

In the last half of FY 1993, priority was given to thermal expansion testing on samples from USW NRG-6 (see Section 2.2.10.2). Until additional test equipment is brought on line, the studies to establish baseline test conditions for thermal expansion measurements have been delayed.

Activity 8.3.1.15.1.2.1 - Thermal expansion characterization. Thermal expansion tests were completed using samples from USW G-1 (128.5 m) to establish the maximum heating rate ($\leq 1^\circ\text{C}$) for samples containing tridymite and cristobalite. The test results indicated that the α - β transformations of these silica polymorphs are detected at approximately the same temperatures (163°C for tridymite and 250°C for cristobalite) when heating rates of 0.25°C and 1°C are used. An irreversible shifting of the inversion temperatures was observed on repeated tests of a given sample. The inversions for tridymite and cristobalite were measured as low as 150°C and 175°C , respectively, on subsequent test runs.

An additional dilatometer and the saturation test apparatus, used for controlling the sample test environment, were procured. This equipment is undergoing operational checks and calibration.

The SNL Work Agreement for the study on the effects of sample size on thermal-expansion behavior was issued. The samples for this study were machined in right cylinders of two sizes, -0.6 cm diameter by 2.54 cm, and 2.54 cm diameter by 10.2 cm, nominally. The sample were vacuum saturated in preparation for testing. Five samples of four different lithologies (welded devitrified, welded vitric, nonwelded vitric, and nonwelded zeolitic) will be tested from ambient to 300°C . These experiments are necessary to determine whether the measured thermal expansion of tuff has a predictable dependence on the sample size, and if so, to describe the nature of the relationship. Results from these experiments will be used to determine the optimal baseline test conditions for thermal expansion characterization.

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The SNL Work Agreement for the study on the effects of sample saturation on thermal expansion behavior was issued to conduct the testing of five samples of four different lithologies (welded devitrified, welded vitric, nonwelded vitric, and nonwelded zeolitic). Three initial saturation states will be examined: fully saturated, air-dry, and oven-dry.

Forecast: Studies will be conducted to determine baseline test conditions, including completing the study on the effects of sample size on thermal expansion behavior and completing the study on the effects of sample saturation on thermal expansion behavior.

Thermal expansion will be measured on samples from North Ramp Geologic and South Ramp Geologic holes in support of the Soil and Rock Properties Study (see Section 2.2.10.2); and Systematic Drilling holes to support ESF design. The measurements will be limited to only samples from the Topopah Spring Member. The use of velocity measurements to determine if microcracking occurs due to thermal cycling during testing will also be investigated.

In addition, analyses on thermal expansion data will be performed to include:

- Performing preliminary statistical analyses to examine the spatial variability of thermal expansion
- Developing preliminary three-dimensional model for thermal expansion
- Examining potential correlations between thermal expansion and other sample characteristics
- Developing a graphical interface for integrating test locations and thermal and mechanical properties data

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

Revision 1 to the study plan was submitted to YMPO for review on July 7, 1993. Comments were returned to SNL on September 23, 1993. This revision will update the study plan to the current ESF design.

Activity 8.3.1.15.1.3.1 - Compressive mechanical properties of intact rock at baseline experiment conditions. Samples are not yet available for this testing effort; however, the prototype experiments have been completed and the technical procedures necessary for future testing at baseline conditions have been drafted in anticipation of sample availability in the next one to three years.

Testing of several rock types was conducted at eight government and private rock mechanics laboratories in support of the American Society for Testing and Materials/Institute for Standards Research Steering Committee for the Interlaboratory Testing Program for Rock

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Properties. An SNL staff member served on the committee and provided test data from contractors for the Phase I testing. The results were reported in an American Society for Testing and Materials/Institute for Standards Research report and summarized in a document published in the ASTM Geotechnical Testing Journal. The report suggested measures of precision for published rock-property standard American Society for Testing and Materials test methods. The protocols were written to accompany the standard methods being used for the testing in Phase II. The testing for the second phase was initiated in December 1992 and should be completed by late 1993.

Activity 8.3.1.15.1.3.2 - Effects of variable environmental conditions on mechanical properties. A study was conducted of the mechanical properties of tuff samples from the series of North Ramp Geologic drillholes located along the length of the planned position of the north ramp of the ESF. The samples were machined, dried, and saturated prior to testing at uniaxial and triaxial conditions. Other samples were tested in indirect tensile (Brazil) experiments and for average grain densities. Sample porosity was calculated from dry bulk density and average grain density values, compressional and shear wave velocities were measured on both the dry and saturated samples, and computerized tomography images were taken of the pretest samples. To date, a total of 82 unconfined experiments, 16 confined experiments, 63 Brazil tests, and 124 measurements of average grain density have been performed on samples from UE-25 NRG#2, UE-25 NRG#3, and USW NRG-6. These data are being analyzed.

In addition, a study of time-dependent deformation involving high-temperature experiments at creep and low strain rate conditions was conducted by SNL and subcontractors. The most recent series of experiments consisted of at least six samples of TSw2 to be 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. Three experiments have been completed. The results to date exhibited a large scatter and will be difficult to interpret until the entire series of experiments is completed.

A report entitled "Unconfined Compression Experiments on Topopah Spring Member Tuff at 22°C and a Strain Rate of 10^{-9}s^{-1} : Data Report" (Martin et al., 1993) was approved by YMPO and published.

An abstract entitled "Strength-Size-Porosity Empirical Model for Yucca Mountain Tuff" (Price) was approved by YMPO for presentation and publication at the Fall '93 American Geophysical Union Meeting.

Forecast: SNL will complete a set of experiments on samples from North Ramp Geologic and South Ramp Geologic drillhole core, and reduce, analyze, and report data to support ESF design activities. Minimal support of the American Society for Testing and Materials/Institute for Standards Research Steering Committee will also be continued.

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

Revision 1 of the study plan was submitted to YMPO on September 9, 1993.

Several SNL staff members participated in the Fracture Properties Working Group, which met seven times during the last six months. The discussions centered on revising the study plan and plans for supporting ESF design efforts.

Activity 8.3.1.15.1.4.1 - Mechanical properties of fractures at baseline experiment conditions. Samples are not yet available for this testing effort; however, studies are proceeding to define the baseline-condition test technique and the approach for future characterization of fracture topography.

Rotary friction (axial compression-torsion) was chosen as the test technique for gathering the majority of the data on the mechanical properties of fractures. In this 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 has been drafted and submitted to American Society for Testing and Materials Committee on Soil and Rock Properties (Committee D-18).

A draft of the American Society for Testing and Materials procedure, "Standard Test Method for Normal and Shear Stiffness of Rock Fractures Using a Compression/Rotary Shear Apparatus" completed the first review by the American Society for Testing and Materials Subcommittee on Rock Mechanics (Subcommittee D-18.12). This review was discussed at the committee meetings in Atlanta, Georgia, June 22-23, 1993. The draft received relatively few technical comments.

Detailed characterization and analysis of fracture surfaces will aid in the interpretation of mechanical properties (e.g., stiffness and shear strength) and transport properties. In order to accomplish this, a laser profilometer was designed, built, and tested. The existing profilometer system (profiler and software) was used to characterize the topography of all samples used in the experiments under 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 of this program is to use the surface characterizations as a predictor of the mechanical properties.

An abstract entitled "Simple Mathematical Model of a Rough Fracture Using the Concepts of Fractal Geometry" (Brown, 1993) was approved by YMPO for presentation and publication 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. Amonton's law $\tau = \mu\sigma$; where τ is the shear stress parallel to the fracture, σ is the normal stress across the fracture, and μ is called the coefficient of friction) is the most common relationship used to describe the mechanical properties of relatively

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smooth (or artificial) fractures. A study continued that addressed whether or not other variables (e.g., time-of-stationary contact, velocity of sliding, degree of saturation, temperature, and history) are important for inclusion into the constitutive description, or whether the simple formulation of Amonton's law is sufficient for most modeling efforts. The results are being analyzed and summarized.

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 was 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 include experiments on artificial (i.e., relatively smooth) fractures in rate-stepping tests and a creep experiment in triaxial compression. The data are being analyzed and future reports are being considered.

Two abstracts entitled "Joint Creep in Yucca Mountain Tuff" (Olsson) and "Effect of Roughness and Material Strength on the Mechanical Properties of Fracture Replicas" (Wibowo et al.) were approved by YMPO for presentation and publication at the Fall '93 American Geophysical Union Meeting.

Two reports entitled "Effect of Boundary Conditions on the Strength and Deformability of Replicas of Natural Fractures in Welded Tuff: Data Report" (Wibowo et al.) and "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.) were approved by YMPO and will be published in the next two months.

Forecast: SNL will continue performance of experiments on samples from North Ramp Geologic and South Ramp Geologic drillhole core, and reduce, analyze, and report data to support ESF design activities.

2.2.11.5 Study 8.3.1.15.1.5 - Excavation Investigations

Revision 1 of the study plan includes changes required by the new FSF design. Revision 1 was submitted to YMPO for review and comments were returned to SNL on May 10, 1993.

Activities 8.3.1.15.1.5.1 through 8.3.1.15.1.5.3. No activity during the reporting period; these were unfunded activities.

Forecast: During FY 1994, a sequence of measurements will be performed at stations in the North Ramp of the ESF to monitor both instantaneous and long-term response of the rock mass. These measurements will include both stress measurements and rock mass deformation measurements. The rock mass deformation measurements will be conducted using multipoint borehole extensometers and tape extensometer. Stations will be installed in

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each major thermomechanical unit encountered in the ramp access, with special emphasis on units in the Topopah Spring Member. Specific locations will be selected based on location of stratigraphic contacts and faults.

SNL will compile test documentation and early data analysis from the North Ramp and develop experiment plans for access convergence test instrumentation of North Ramp in FY 1994 and FY 1995. This plan will form the basis for the test planning package.

2.2.11.6 Study 8.3.1.15.1.6 - In Situ Thermomechanical Properties

SNL staff finished a draft of the study plan and gave a presentation that detailed the plans and objectives of the experiments which are contained in the study plan at the Nuclear Waste Technical Review Board meeting held July 13-14, 1993.

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.

Forecast: The study plan will be completed reflecting the current ESF configuration and construction method, and will be submitted to YMPO for review and comments.

Detailed analyses to support the development of the design and instrumentation layout and requirements for incorporation into the study plan will be performed. The thermomechanical tests described in this study will require development and prototyping of instrumentation that can survive the high temperature environment. Development and testing of optical sensors for high temperature work will be started. Previous instrumentation studies have identified fiber optics as a potential solution to displacement and stress measurements at elevated temperatures.

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 out-year activities.

Forecast: No activity is planned in FY 1994.

2.2.11.8 Study 8.3.1.15.1.8 - In Situ Design Verification

The NRC accepted the study plan in a letter dated April 15, 1993, with no comments.

Activities 8.3.1.15.1.8.1 through 8.3.1.15.1.8.3. The SNL staff conducted construction monitoring of the ESF North Ramp of the Starter Tunnel. The monitoring included seismic

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monitoring of blasting, blast damage assessment, rock mass quality determination, ground support system performance monitoring, and cross-drift convergence monitoring.

A summary of construction monitoring activities of the ESF North Ramp Starter Tunnel was presented at the 34th U.S. Rock Mechanics Symposium, in Madison, Wisconsin, June 27-30, 1993, at a special session on the YMP. The presentation was entitled "The Influence of Strain Rate and Sample Inhomogeneity on the Moduli and Strength of Welded Tuff" (Price et al.).

As an activity separate from construction monitoring, staff began fielding additional monitoring activities in the North Ramp Starter Tunnel to address safety concerns. Convergence measurements were made to the tunnel to monitor stability of the ramp and the rock bolt load cells for evaluating ground support were installed and monitored.

Forecast: In situ design verification experiments will be conducted in FY 1994, including evaluation of mining methods, monitoring of ground support systems, and monitoring of drift stability. Activities include:

- Evaluating mining methods by assessing induced damage of the surrounding rock mass resulting from construction using borehole television cameras.
- Monitoring ground support systems using rock mass classification indices, rock bolt load cells, and pull tests.
- Monitoring drift stability by continuing to observe the instrumentation installed in the Starter Tunnel. Additional monitoring stations will be installed as required by local ground conditions. Under the assumption that the ramp will be constructed by Tunnel Boring Machine from the Starter Tunnel, the Access Convergence Test will serve the dual role of measuring rock mass relaxation behind the mining face and monitoring long-term rock movement.

The SNL staff will also provide support to the Los Alamos Test Coordination Office in developing detailed test plans for the North Ramp.

Activity 8.3.1.15.1.8.4 - Air quality and ventilation experiment. No progress during the reporting period; this was an unfunded activity.

Forecast: No activity is planned for FY 1994.

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 activity during the reporting period, this was an out-year activity.

Forecast: No activity is planned for FY 1994.

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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.

A draft of the study plan which incorporated reviewer comments was returned to YMPO on May 19, 1993.

Forecast: Preparation of the study plan will continue in preparation for out-year activities.

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 out-year 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.

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2.2.13 Preclosure Tectonics (SCP Section 8.3.1.17)

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 8.3.1.17.1.3. 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: No activity is planned for FY 1994.

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 SCP. Responses to 32 comments from the State of Nevada, received by OCRWM on January 7, 1993, were returned to the State in a letter from YMPO dated April 21, 1993.

Activity 8.3.1.17.3.1.1 - Identify relevant earthquake sources. Participants conducted several field trips in Nevada in an effort to identify possible earthquake sources; gather current information; and update interpretations concerning Quaternary fault activities, potential earthquake magnitudes, and recurrence rates. Information was compiled from available geologic maps, reports, and reconnaissance investigations to prepare a preliminary table of source parameters for known and suspected Quaternary faults within 100 km of Yucca Mountain. The preliminary table of fault parameters was used to identify and rank the sources in terms of those that are most important to earthquake ground motion and fault displacement hazards. Participants began to examine the quality, reliability, and completeness of the fault data.

Activity 8.3.1.17.3.1.2 - Characterize 10,000-year cumulative slip earthquakes for relevant seismogenic sources. A group of seismic hazard experts held meetings to discuss and develop a methodology for seismic source characterization and hazard analysis that is appropriate for a potential repository at Yucca Mountain. The proposed probabilistic and deterministic seismic hazard methodologies were evaluated in order to update the study plan (and others), perform a technical assessment for the ESF, and contribute to the DOE topical report on Methodology to Assess Seismic Hazards at Yucca Mountain. Participants composed portions of the topical report including Appendix A, "Technical Data Base for Seismic Hazard Analyses at Yucca Mountain" and Appendix B, "Seismic Source Characterization at Yucca Mountain." A progress report entitled "Recommendations and Revisions to Seismic Source

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Characterization" (Pezzopane), was submitted as planned and accepted for revision. The study plan has been revised and submitted for review. A preliminary source characterization was completed for all known or suspected Quaternary faults, based on the revised methodology and currently available fault parameters. Participants contributed to the seismic hazard analysis for the ESF.

Forecast: Work planned for FY 1994 will focus on synthesizing new and existing data concerning the activity, magnitudes, and recurrence intervals of known or suspected seismic sources. Effort will focus on locating unrecognized, buried, or hidden seismogenic structures, characterizing the magnitudes and recurrence parameters for these sources, and estimating the impacts of alternative tectonic models towards uncertainties in the seismic source parameters. Additional effort will be placed in estimating the parameters of potential nuclear explosion sources and earthquakes related to volcanic processes, including swarms, tremors, and potential triggering of tectonic earthquakes as a result of volcanic eruptions. The preliminary table of Quaternary fault and seismic source parameters will be updated continually as new data and interpretations become available. Methods to estimate maximum magnitudes will 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. The maximum magnitudes and closest source-to-site distances will be used to complete a preliminary deterministic seismic hazard analysis in an attempt to identify with a high degree of confidence all relevant seismic sources. The deterministic analysis will be used to rank the relevant sources in order of importance, based on the level of ground motion that they can produce at frequency ranges of engineering significance, and to determine which relevant sources may call for more detailed field investigations, based on the quality and amount of paleoseismic and geologic data that are currently available.

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.

2.2.13.5 Study 8.3.1.17.3.3 - Ground Motion From Regional Earthquakes and Underground Nuclear Explosions

An internal working draft of Study Plan 8.3.1.17.3.3 was revised by SNL to reflect continued development of the ESF design and revised approaches to model development and define an approach for developing a preliminary ground motion model for Yucca Mountain.

Completion of the study plan to develop earthquake ground-motion models is delayed so that the results of collaborative research and evaluation by the Seismic Hazards Working Group, a team of seismic hazard experts assembled by YMP, to develop an appropriate methodology for seismic hazard analysis at the potential repository can be incorporated. The

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methodology relies on a hybrid approach, which incorporates both deterministic and probabilistic components, and will be described in detail in the "Topical Report on Methodology to Assess Seismic Hazards at Yucca Mountain," which is in preparation.

Activity 8.3.1.17.3.3.1 - Select or develop empirical models for earthquake ground motions. Participants worked to develop the seismic hazard methodology and contributed to the YMP topical report. Members of the Seismic Hazards Working Group and additional USGS seismic hazard experts held meetings to discuss and develop a methodology for modeling earthquake ground motions. The ground work has been laid for the study plan to commence, and work will proceed in accordance with methodologies stated in the topical report and new ground motion models based on site-specific information developed for Yucca Mountain.

Forecast: The draft study plan will be completed in the first few months of FY 1994, and comment resolution will follow in the remainder of the year. An informal tectonics conference is planned for early next year to gather seismologists and tectonicists together to discuss potential earthquake source characteristics for relevant faults and the impacts of postulated tectonic models toward ground motion models. Plans are to exchange up-to-date information concerning the paleoseismic behavior of relevant faults in an effort to build a consensus concerning the plausible earthquake sizes, locations and geometries, and to provide a prospectus for future work. The conference will provide input to the seismologists for developing ground motion models as well as be useful to direct the geologists in site characterization activities.

Activity 8.3.1.17.3.3.2 - Select or develop empirical models for ground motion from underground nuclear explosions. No progress during the reporting period; this was an unfunded activity.

Forecast: SNL will complete the development of a preliminary ground motion model for Yucca Mountain. Activities to be conducted include development of a preliminary earthquake ground motion model which utilizes available seismic data (i.e., natural seismicity and induced seismicity) for supporting a YMP topical report on Seismic Hazard Assessment Methodologies.

2.2.13.6 Study 8.3.1.17.3.4 - Effects of Local Site Geology on Surface and Subsurface Motions

Responses to 26 comments from the State of Nevada received by OCRWM on January 6, 1993, were returned to the State in a letter from YMPO dated April 27, 1993.

Activity 8.3.1.17.3.4.1 - Determine site effects from ground-motion recordings. In April 1993, Experiment 1 used 12 Reftek portable stations in and near Midway Valley to gather data for the site effects study. This experiment was conducted through June 1993. In addition, prior recordings made at Yucca Mountain were assembled for study of site effects. A preliminary one-dimensional structural model was constructed for the Yucca Mountain area.

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S-wave spectra of signals recorded in the above experiment from Little Skull Mountain aftershocks were used to determine the local site effects. A least-squares method was used to determine the seismic moment, the corner frequency, and the spectral decay parameter. A standard model spectrum was computed from the average estimates, and the site responses were computed by averaging the differences of the spectra for individual stations from this standard spectrum.

Forecast: The standard ground motion model will be updated during FY 1994 with additional data collection, analysis, and modeling studies. During FY 1994 it is anticipated that two phases of improvement will occur. The first phase will result from refining the low-frequency models based on crustal structure and teleseismic and Nevada Test Site recordings. The second phase will result from spectral ratios based on regional earthquakes and possible Nevada Test Site blasts.

In FY 1994 Experiments 2 and 3 will be conducted. Experiment 2 is a short-duration deployment to record microseisms to improve our velocity model at Yucca Mountain. Experiment 3 is a long-duration deployment to record local events and teleseisms at the surface, downhole, or underground within a three-dimensional grid to understand the three-dimensional wave propagation effects at Yucca Mountain.

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 is not funded in FY 1994, and 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 out-year activities.

Forecast: These activities are not funded in FY 1994, and are planned to start in FY 1995.

2.2.13.9 Study 8.3.1.17.4.1 - Historical and Current Seismicity

Activity 8.3.1.17.4.1.1 - Compile historical earthquake record. Surveys for precarious rocks have been continued in various parts of California and Nevada, both seismic and aseismic areas. Correlations with intensity maps for historical seismicity and, if possible, with measured or estimated ground motions have been made for precarious rock locations.

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The area around the May 17, 1993, Eureka Valley earthquake was examined for rock falls and also the area around the Utah earthquake of October 25, 1992.

The two-dimensional computer code for predicting the effect of strong motion on various rock shapes was completed and run on various cases. Results have been compared with physical models of rocks toppled in the laboratory to verify the computer code.

The Meremonte-Rogers historical earthquake catalog for the Southern Great Basin was searched for events near Yucca Mountain. One potentially important earthquake occurred in 1948, apparently at Yucca Mountain itself, and had a magnitude of 3.6. Original records at the California Institute of Technology were photographed for this and other nearby events, and analysis of them suggests that the magnitude = 3.6 event was mislocated and is, in fact, at least 10 km from Yucca Mountain.

A progress report on historical seismicity and another on precarious rocks were submitted for internal USGS review on September 30, 1993.

Activity 8.3.1.17.4.1.2 - Monitor current seismicity. Since April 1, 1993, the University of Nevada, Reno Seismic Laboratory has continuously detected events and created signal files for the Southern Great Basin Seismic Network, except for downtime that amounted to approximately 37 hours. Develocorder film was continuously recorded as a backup. The California Institute of Technology-U.S. Geologic Survey seismic processing software (CUSP) system was moved to the new VAX 4000/200 computer in August 1993, with a significant increase in the reliability and efficiency of the online recording processes.

During the reporting period, the seismicity rate due to the Little Skull Mountain aftershocks has continuously fallen to a rate of about six events per day in the Southern Great Basin. The Eureka Valley earthquake of May 17, 1993, caused a large sequence of aftershocks. Another significant sequence of events occurred in Rock Valley of the Nevada Test Site in June 1993. Portable instruments were deployed for both of these sequences and have made hundreds of additional records of these events. Calibration of the 62 stations of the Southern Great Basin Seismic Network was complete in September of 1993, except for one station in a highly secure area of Nellis Air Force Base.

Planning for the digital upgrade of the Southern Great Basin Seismic Network in this reporting period has included preparing procurement documents for a 49-station network, upgrading the microwave telemetry equipment on the link from the Southern Great Basin to Reno, and selecting seven additional sites around Yucca Mountain for digital stations.

Considerable effort was expended by the University of Nevada, Reno Seismic Laboratory in August and September 1993, to prepare for recording the nonproliferation experiment shot at the Nevada Test Site and the Ryan shot to the south of the Nevada Test Site. These shots were recorded with good to excellent quality on the permanent Southern Great Basin Seismic Network and on nearly 50 portable instruments deployed at the time. The data have been collected for analysis to refine the seismic velocity structure in the vicinity of Yucca Mountain.

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A report on 1992 seismicity for the Southern Great Basin entitled "Seismicity for the Southern Great Basin of Nevada and California in 1992" (Brune) was submitted for internal USGS review on September 30, 1993.

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: Work on historical seismicity will increase in FY 1994 with additional staff to analyze the historical record in more detail.

Work on precarious rocks in FY 1994 will involve calculation of toppling accelerations for approximately ten precarious rocks in Solitario Canyon. Actual field tests will be carried out of toppling forces in situ. Rock-varnish and geomorphic studies will be carried out to more accurately estimate the length of time for which rocks have remained in their current precarious positions.

The Southern Great Basin Seismic Network will be recorded throughout FY 1994, the bulletin for calendar year 1993 will be prepared, and signals for events recorded by the Southern Great Basin Seismic Network will be recorded. The digital upgrade work will include seven new sites in FY 1994. The Reftek network recorder will be moved to Reno and the 13 digital stations will be put on a telemetry link to Reno. The limited digital network will then be recorded continuously in Reno at the same time that signal detection will be performed by the network recorder. Software acquisition and development for the output of this system will be undertaken to provide efficient and reliable handling of the data and to provide routine bulletin preparation capabilities.

The data collected from the nonproliferation experiment and Ryan shots will be analyzed and the Little Skull Mountain aftershocks analysis will be completed in the first quarter of FY 1994. Upgrade and repair work for the portable instrumentation is required for future experiments. An array of roughly 10-12 strong-motion instruments at Yucca Mountain will be installed, pending DOE funding.

2.2.13.10 Study 8.3.1.17.4.2 - Location and Recency of Faulting Near the Prospective Surface Facilities

The NRC accepted Revision 2 of the study plan in a letter to OCRWM dated June 16, 1993, with no comments.

Activity 8.3.1.17.4.2.1 - Identify appropriate trench locations in Midway Valley. This activity is complete. The Principal Investigator reviewed map contacts, aerial photographs, descriptions of soil profiles, and reviewed field activities in preparation of the report on the mapping in Midway Valley. 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 completed and submitted for USGS internal review at the end of FY 1993.

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Activity 8.3.1.17.4.2.2 - Conduct exploratory trenching in Midway Valley. Bedrock faults exposed in the "box cut" of the ESF portal were mapped to determine their locations relative to the faults and fractures observed in trenches (now backfilled) in the construction area. Work continued to prepare and draft maps of the trench walls, and to prepare the report of the investigations of the trenches near the ESF.

Trench logs and a draft report entitled "Preliminary Report and Map of Trench MWV-T4 Across the Paintbrush Canyon Fault, Yucca Mountain Area, Nye County, Nevada" (Wesling et al.). The report was submitted for USGS internal review on September 30, 1993.

Forecast: Trench A-3 on the Paintbrush Canyon fault will be excavated and logged early in FY 1994. Results of geologic mapping and trench studies will be summarized in a final report on Midway Valley and submitted for USGS review during the first half of FY 1994.

Additional time will be required to complete the review process for publication of the final map and report on the surficial geology of Midway Valley.

2.2.13.11 Study 8.3.1.17.4.3 Quaternary Faulting Within 100 km of Yucca Mountain, Including the Walker Lane

The study plan was approved by YMPO on January 21, 1993 and sent to NRC on February 9, 1993. The NRC accepted the study plan in a letter to OCRWM dated September 2, 1993, with one comment and two questions. The USGS assessed the impact of the comment and questions in a letter to YMPO dated September 20, 1993, and a response to the NRC comment and questions is being prepared.

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.

Activity 8.3.1.17.4.3.2 - Evaluate Quaternary faults within 100 km of Yucca Mountain. The USGS staff completed a compilation of known and suspected Quaternary faults within 100 km of Yucca Mountain; two maps showing fault locations are accompanied by text and tables. This document entitled "Preliminary Surficial Geologic Map of the Bare Mountain Frontal Fault; Bureau of Reclamation" (Anderson) was submitted for USGS internal review on June 30, 1993.

To evaluate faults southwest of Yucca Mountain, the Principal Investigator interpreted low-sun-angle aerial photographs of the Amargosa Desert area and conducted reconnaissance studies of the Death Valley—Furnace Creek fault zone in the field. Several areas in Death Valley were identified where detailed geologic mapping could provide specific information on the age of the most recent surface faulting event and amount of slip on this important fault zone.

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The Los Alamos staff conducted a scoping study in preparation for dating the surface exposure of scarps along Windy Wash and Solitario Canyon faults. Samples were collected and were being processed.

Preliminary data collection was completed on a study of scarps along the Windy Wash and Solitario Canyon fault, and an abstract was prepared on this subject for the Fall '93 American Geophysical Union Meeting entitled "Preliminary Analysis of Erosionally Enhanced Scarps Associated with Faults in Crater Flat, Nevada" (Harrington). This abstract is in the YMPO approval process.

A paper entitled "Relict Colluvial Boulder Deposits as Paleoclimatic Indicators in the Yucca Mountain Region, Southern Nevada" (Whitney and Harrington, 1993) was published. The authors found that by interpreting the necessary conditions to form hillslope boulder deposits in the Yucca Mountain region, they could infer paleoclimatic conditions for the periods of their formation. They dated the deposits by cation-ratio dating of rock varnish and confirmed their early- to mid-Quaternary age. They also used the deposits as hillslope datum to calculate hillslope erosion rates and to interpret differences in climatic conditions between early Quaternary climates, those of the last full glacial (ca. 18 ka), and those of today.

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. Staff compiled a preliminary surficial geologic map of the Bare Mountain frontal fault zone based on analyses of low-sun-angle aerial photographs and reconnaissance geologic studies.

Preparations were made for the NRC field trip, which included a visit to a trench across the Bare Mountain fault zone, and preliminary findings were presented. The trench required re-excavation and shoring in July, which delayed logging and analysis until after that time. Four soil pits were excavated, and at the end of September a trench at the mouth of Tarantula Canyon (BMT-1) was excavated.

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: Detailed studies will be conducted at several localities along the Death Valley—Furnace Creek fault zone to determine the age, amount of slip, and recurrence of surface faulting events. In order to determine the age and recurrence of faulting on the Bare Mountain frontal fault zone, detailed mapping and trench analysis will be completed.

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2.2.13.12 Study 8.3.1.17.4.4 - Quaternary Faulting Proximal to the Site Within Northeast-Trending Fault Zones

The study plan was approved by YMPO on March 18, 1993, and sent to NRC on May 18, 1993. The NRC accepted the study plan in a letter to OCRWM dated September 2, 1993, with no comments.

Activity 8.3.1.17.4.4.1 - Evaluate the Rock Valley fault system. Field work was undertaken to characterize fault disruption and history of displacement among faults in Rock Valley. Parameters included location, attitude and length of fault planes, style and width of disruption of faults within the system, and amount and recurrence of displacements. Field examinations of fault exposures, lineaments, and other deformation features of inferred tectonic origin (i.e., exhibiting structural control) were guided by previous USGS mapping and recursive analysis of aerial photos. Principal structural parameters were noted, field locations described and, where feasible, recorded by Global Positioning Satellite receiver, and plotted on field maps for further annotation and analysis. Five sites of surface fractures, possibly related to fault creep, were observed. Nine samples of volcanic rocks were obtained for radiometric age dating to constrain the older displacement events and hence the cumulative offsets. Candidate trench sites were determined from field and aerial photo examination and in consultation with other Principal Investigators. An interim report entitled "Interim Report: Rock Valley Fault Zone, Nevada Test Site, Nevada" (O'Leary) was submitted at midyear. A second interim report entitled "Preliminary Fault Slip Analysis of Northeast Trending Strike-Slip Faults in Rock Valley, Nevada, Proximal to the Potential Yucca Mountain Repository Site" (O'Leary) was prepared at the end of FY 1993.

Activity 8.3.1.17.4.4.2 - Evaluate the Mine Mountain fault system. No progress during the reporting period; this was an out-year activity.

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."

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: Studies in FY 1994 will include continued evaluation of the Rock Valley fault system. A final decision on the location of one or two trench sites will be made along with preparations for excavation, logging and interpretation. Data on the history and nature of Quaternary displacement will support a final report on the Rock Valley fault zone. Field examination of the Mine Mountain fault zone will begin by aerial photographic overview and appraisal of previous mapping..

2.2.13.13 Study 8.3.1.17.4.5 - Detachment Faults at or Proximal to Yucca Mountain

The NRC accepted the study plan in a letter to OCRWM dated February 2, 1993.

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Activity 8.3.1.17.4.5.1 - Evaluate the significance of the Miocene-Paleozoic contact in the Calico Hills area to detachment faulting within the site area. The Principal Investigator spent several weeks in the field at Calico Hills examining the Miocene-Paleozoic contact and mapping low-angle faults. Exposures of Paleozoic stratigraphy were examined and a new, tectonically important breccia unit was identified. A field trip was conducted to examine detachment faults in the region of Yucca Mountain and dissimilarities were noted between regional detachment faults and the low-angle structures in the Calico Hills. Field work was compiled and a draft report was prepared. An interim report entitled "The Miocene-Paleozoic Contact at the Calico Hills" (Simonds) was prepared and submitted to USGS as an administrative report.

Activity 8.3.1.17.4.5.2 - Evaluate postulated detachment faults in the Beatty-Bare Mountain area. Field work in April brought the bedrock mapping to 75 percent completion in the Big Dune 7.5 minute quadrangle (southern Crater Flat) and 100 percent completion in the East of Beatty Mountain 7.5 minute quadrangle (northern Crater Flat). Airphoto interpretation, including photogrammetry was used to produce a final compilation map of the East of Beatty Mountain quadrangle and a map entitled "Geologic Map of the East of Beatty Mountain 7.5 Minute Quadrangle, Nye County, Nevada" (Fridrich et al.) was submitted for internal USGS review, to be an Open-File Report (uncolored) at 1:12,000 scale. A map of the middle quadrangle in Crater Flat (between the two above-mentioned quadrangles) was mapped by J. Faulds and others of the State of Nevada. USGS personnel participated in a two-day field review of this map and found that it is of excellent quality; little additional work will be required now in the middle quadrangle. An interim report entitled "The Miocene History of Extension in the Yucca Mountain Region: A Preliminary Report" (Fridrich) synthesizes the results of mapping in Crater Flat to date.

Project Participants attended a field trip to examine both upper and lower plate rocks of the major detachment faults in the region. Field work was conducted at Bare Mountain and vicinity collecting metamorphic samples for thermobarometric studies. The samples were prepared for petrographic analysis, fission track and $^{40}\text{Ar}/^{39}\text{Ar}$ dating, and thermobarometric studies. An interim report entitled "Thermobarometric and Kinematic Studies of Metamorphic Rocks at Bare Mountain and Proximal Sites" (Hoisch) was submitted to USGS as an administrative report.

Activity 8.3.1.17.4.5.3 - Evaluate potential relationship of breccia within and south of Crater Flat to detachment faulting. No progress during the reporting period; this was an out-year activity.

Forecast: Work will begin on this activity in FY 1994.

Activity 8.3.1.17.4.5.4 - Evaluate postulated detachment faults in the Specter Range and Camp Desert Rock areas. No progress during the reporting period; this was an out-year activity.

Forecast: Work will begin on this activity in FY 1994.

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Activity 8.3.1.17.4.5.5 - Evaluate the age of detachment faults using radiometric ages.

Samples were collected, primarily from lower plate rocks, to determine the ages of metamorphic minerals and thus constrain the age of metamorphism and subsequent uplift. The samples were examined petrographically and eight were selected for fission track and/or $^{40}\text{Ar}/^{39}\text{Ar}$ dating. Metamorphic minerals sphene, apatite, and zircon were separated for fission track analysis and hornblende, muscovite, and biotite were separated for $^{40}\text{Ar}/^{39}\text{Ar}$ analysis. The mineral separates were sent to the USGS isotope lab for analysis. A report was prepared describing the samples along with a map showing sample locations. The report was included as part of an administrative report entitled "Thermobarometric and Kinematic Studies of Metamorphic Rocks at Bare Mountain and Proximal Sites" (Hoisch).

Forecast: Work on the Calico Hills map and report will continue and is expected to be submitted for USGS review early in FY 1994. Mapping in Crater Flat will continue in FY 1994 with the following goals: (1) Finish mapping in the Big Dune 7.5 minute quadrangle (southern Crater Flat), and submit preliminary map for internal USGS review to be published as an Open-File Report; (2) Generalize the 1:12,000 scale map of the East of Beatty Mountain quadrangle at a 1:24,000 scale and submit for publication as an I-series map (colored); (3) make a preliminary version of a map of the volcanic rocks in the Beatty Mountain 7.5 minute quadrangle; and (4) synthesize map data into graphical formats that document extensional history, and how it varies over different parts of the Crater Flat basin and in adjacent structural domains. Thermobarometric analysis of metamorphic rocks will continue in FY 1994 and the results will be incorporated with mineral dates in a report by the end of the fiscal year.

2.2.13.14 Study 8.3.1.17.4.6 - Quaternary Faulting Within the Site Area

The NRC accepted the study plan in a letter to OCRWM dated October 3, 1991.

Activity 8.3.1.17.4.6.1 - Evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain. Compilation of field data and mapping of Quaternary faults at Yucca Mountain was completed during the reporting period. Compiled maps at 1:12,000 scale were reduced and merged to fit a 1:24,000 scale topographic base map. The 1:24,000 scale map was drafted and annotated and a descriptive text was prepared. The map and text were submitted for USGS internal review.

Activity 8.3.1.17.4.6.2 - Evaluate age and recurrence of movement on suspected and known Quaternary faults. To study the Paintbrush Canyon fault in the vicinity of Busted Butte, Project staff completed plotting contacts and structures on photographs of exposure #4.; systematically re-evaluated fault event chronology and field measurement of vertical offsets; and measured slickenside lineations on fault planes.

Study of the southern Windy Wash fault included six lines of a shallow seismic reflection survey. The seismic survey successfully imaged a buried basalt flow, thus providing evidence for the amount of offset on the Windy Wash fault.

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Study of the Stagecoach Road fault included field logging of structures and contacts on photographs of the north wall of both SCR-T1 and SCR-T3 trenches. Grids for conventional logging of the south wall, east half, of both trenches were established, and for plotting contacts and structures. Results were presented on Stagecoach Road trenches, and on the southern trench of the Solitario Canyon fault, to NRC during a field trip.

A talk entitled "Stratigraphic Evidence for Multiple Small Quaternary Displacement on the Bow Ridge Fault at Northeast Yucca Mountain, Nye County, Nevada" (Menges et al., 1993) was presented at a regional Geological Society of America meeting.

To evaluate scarp evolution in north Windy Wash, field work was conducted and potential sites for cosmogenic isotopic dating were examined and sampled on the Windy Wash and Solitario Canyon fault scarps. An interim report entitled "Progress Report on Study of Scarp Evolution Along the Solitario Canyon and Windy Wash Faults, Crater Flat, Nevada" (Harrington) was submitted to USGS on the potential application of the dating technique.

Excavation on four new trenches and exposures on Solitario Canyon fault, and two new or modified trenches at Alice Ridge on the Northern Paintbrush Canyon faults were almost completed by the end of the reporting period. Existing trenches and fault scarps near those trenches were examined on North Solitario Canyon and Pagany Wash fault to prepare for future relogging.

Forecast: Continued work on each of the major faults at Yucca Mountain will include both trench and scarp studies. Trench logging activities will continue at new trenches on the Solitario Canyon fault and Paintbrush Canyon faults, and at old trenches on the southern Windy Wash fault and Fatigue Wash fault. A cosmogenic dating study will attempt to establish faulting ages on the Ghost Dance fault. Data from these studies will be compiled to produce review drafts of final reports for the Bow Ridge fault, Stagecoach Road fault, and the Paintbrush Canyon fault at Busted Butte.

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.

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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

The NRC accepted the study plan in a Phase I review letter to OCRWM dated October 4, 1991, with two comments. OCRWM responded to these comments in a letter dated September 17, 1993. The State of Nevada sent 16 comments to OCRWM on January 29, 1993, which were responded to in a letter from YMPO dated April 19, 1993.

Activity 8.3.1.17.4.10.1 - Relevel base-station network, Yucca Mountain and vicinity. The base-station network was releveled. A data records package on geodetic leveling was completed in July 1993, and submitted to the records center for the periods November 1990 to July 1991, and November 1992 to April 1993.

Activity 8.3.1.17.4.10.2 - Survey selected base stations, Yucca Mountain and vicinity, using global positioning satellite. A 50-km aperture trilateration network centered on Yucca Mountain was resurveyed in April. Previous surveys of the network were done in 1983 and 1984. Except at one station in the southeast corner of the network, no significant deformation was observed even though the precision of the surveys was such that the detection threshold (95 percent confidence) was $0.02 \mu\text{strain/year}$. The station near the southeast corner of the network was disturbed on June 29, 1992, by the Little Skull Mountain earthquake (surface wave magnitude=5.4), whose epicenter was only 3 km away. The measured displacement there is consistent with the reported 4.1×10^{17} N-m moment of the earthquake. An abstract entitled "Strain Accumulation near Yucca Mountain, Nevada, 1983-1993" (Sgoss et al.) was submitted to the Fall '93 American Geophysical Union Meeting.

Activity 8.3.1.17.4.10.3 - Analyze existing releveled data, Yucca Mountain and vicinity.

Forecast: A quadrilateral survey will be conducted during the first half of FY 1994. Observations will be made on four corners of a previously established quadrilateral at Yucca Mountain. Latitude, longitude and elevation will be calculated for each point and the data compared with previous results.

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.

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2.2.13.20 Study 8.3.1.17.4.12 - Tectonic Models and Synthesis

The study plan was returned from YMPO review and was in process of revision.

Activity 8.3.1.17.4.12.1 - Evaluate tectonic processes and tectonic stability at the site. Initial review of the geologic/tectonic map of the Death Valley region has been completed and it is undergoing final revision and drafting; the 1:100,000-scale map of the Beatty Quadrangle was submitted for initial review; segments of the TMM color-ratioed remote sensor image set (showing Yucca Mountain and terrain north) were received from the Jet Propulsion Laboratory; field excursions at and around the site were led by Principal Investigators to demonstrate field evidence pertaining to process and stability and to discuss problems of interpretation. Various data from published sources, instrumented surveys, and site characterization studies are presently being compared and evaluated.

Activity 8.3.1.17.4.12.2 - Evaluate tectonic models. The boundary element modeling scoping study was initiated and preliminary results were being evaluated; the methodology was being modified to match the geologic setting of Yucca Mountain. Geologic evidence for the existence and/or character of tectonic model components was being evaluated (e.g., bounding range-front faults, detachment faults, strike-slip faults) at Bare Mountain, Calico Hills, and Rock Valley, as well as in the Death Valley—Bullfrog Hills regions to the north and west. Evaluation of strike slip faulting and detachment faults was reported in an interim report, "Detachment Faulting and Tectonic Modeling in the Yucca Mountain Region" (Hamilton).

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: Results of the boundary element model scoping study will be integrated into the evaluation procedure along with results of radiometric age dating and tectonic field studies. Integration/evaluation of published data, compiled geophysical (including remote sensor) data, and site-specific field studies will continue. Preliminary reports on boundary element modeling results, and a preliminary tectonic model will be prepared. The Beatty map and the Death Valley region map will be released.

SECTION 2.3 REPOSITORY OVERVIEW

2.3.1 Geomechanical Analyses (SCP Section 8.3.2.1.4.1)

The objective of this work is to develop, evaluate, document, verify and validate material models, analysis methods, and computer codes for use in preclosure performance analyses of a repository. Rock mass properties for use in design activities are also developed under this work.

A series of laboratory tests was conducted over the reporting period that is designed to provide data for mechanical computer code validation efforts and to help develop laboratory testing techniques that could be used with jointed rock simulators and, in the future, jointed rock. In these tests, models of jointed rock structures were constructed and loaded mechanically. The models consisted of 1/4-in-thick, layered polycarbonate plates with a hole drilled in the center of the lay-up. The hole creates a nonuniform stress field in which local slip of the joints can occur. A Moiré technique was used to measure the slip and deformations in the model. A data reduction technique was developed, and several tests were conducted and analyzed. The tests consisted of: (1) a far-field view of loading normal to the plate, (2) a close-up view of loading normal to the plate, (3) a far-field view of loading at ten degrees to the plate, and (4) a close-up view of loading at ten degrees to the plate. For the first two experiments, the displacements around the hole were nearly symmetrical. The experiments detected joints that exhibited two to three μm of uniform slip. Although these experiments will be very helpful for the code validation efforts, the data reduction process for these tests is extremely time consuming. Sandia National Laboratories (SNL) will be exploring ways of either speeding up the data reduction or modifying the tests to obtain the information necessary for code validation. The report documenting the experiments is being drafted and will be ready for review near the end of September 1993.

A series of experiments designed to study the effects of a nonstandard loading condition on the mechanical properties of joints was conducted at the University of Colorado in 1992. During fiscal year (FY) 1993, the data were analyzed and reports were written to put the data in usable form. This work generated a wealth of information about joint behavior that can be used for model development and to help the design effort. Of particular interest were the data gathered on joint dilation. There appeared to be significant dilation in the tuffs tested. This behavior is not usually accounted for in the design analyses. If it were, it could result in higher safety factors (predict more stable rock masses) than previously calculated. This work will be documented in a number of reports that are in the final approval stages.

A study was conducted of the surface characteristics of natural fractures and how to relate these to the frictional data gathered on replicas on the surfaces. This study will place special emphasis on determining whether or not the fitting parameters in the 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. This work is essentially complete, with the report to be published early in FY 1994.

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A number of thermal-mechanical analyses were conducted to support experiments planned for the Exploratory Studies Facility (ESF). These experiments include the Heated Room Experiment, the Thermal Stress test, and the Canister Scale Heater test. These analyses were conducted and designed to determine the required separation between tests so that they do not interfere with other tests. This work is essentially complete and the report documenting the results will be issued in the next few months.

A report entitled "Rock Mass Mechanical Property Estimations for the Yucca Mountain Site Characterization Project" (Lin et al., 1993) that compiled and synthesized the available data on the mechanical properties of the rock mass in Yucca Mountain was completed and issued.

An important component of this work involved the development and application of constitutive models capable of analyzing the response of jointed rock masses. State-of-the-art analysis capabilities in which the composite behavior of the intact rock and joints are modeled are represented by SNL's current continuum jointed rock constitutive models. In this reporting period, there were ongoing efforts to improve both the capabilities and efficiency of the models. This work began with a critical review of the models to identify where improvements can be made. The possible improvements include adding more joint sets, the inclusion of joint dilation, and increased model robustness. Particular attention is being paid to develop techniques that are applicable in two dimensions but can be easily extended to three dimensions. Progress was made in developing a simple three-dimensional jointed rock model in the latter part of the year; however, the bulk of the actual testing and coding of this model will take place in FY 1994.

Work at the University of Colorado in developing joint constitutive models was completed. This work began by the University conducting a literature search to identify the "best" available joint constitutive model in the literature. Experimental data developed in related efforts were fitted to Plesha's joint constitutive model. The University and SNL are disappointed that, although the Plesha joint constitutive model originally appeared to have the features that were needed, working with the model showed a number of deficiencies that the original developers were apparently unaware of. Therefore, further work with this model will not be pursued.

In other work at the University of Colorado, modifications to the discrete element code, DDA, are being performed to implement an augmented Lagrangian approach for enforcing the contact constraints and a sub-block concept. A classical Lagrangian approach to explore the sub-blocking concept in a two-dimensional research code was implemented by SNL. The classical Lagrangian approach needed to be explored in order to have a basis to compare the augmented approach. The sub-blocking concept appears to be workable, although the particular numerical implementation of it needs some refinement. The objective of this work is to develop the needed refinements and include them into a discrete block code that can be used support the design and performance assessment efforts.

Notable progress was also made in developing methods which couple finite element and boundary element techniques. This capability will be particularly useful for repository

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scale analyses. By combining the nonlinear capabilities of finite elements with the efficiency of boundary elements for modeling large linear regions (far-field), repository scale analyses become technically and economically feasible. The main idea is for finite elements to represent the near-field solution and for boundary elements to capture the far-field effects. Not only has SNL been able to couple linear finite elements with linear boundary elements (Koteris, 1993), but in the last part of FY 1993, SNL was able to perform problems in which nonlinear finite elements were coupled to linear boundary elements. The test cases involved pressurizing a cavity in an infinite media.

Documentation for the JAC2D finite element code was essentially completed this year. JAC2D is the primary nonlinear finite element code used for the Yucca Mountain thermal-mechanical analyses.

Forecast: An objective of the work in FY 1994 is to evaluate the significance of rock mass creep on the stability of underground openings affiliated with the ESF and repository. The work in FY 1994 will analyze site-specific data and published information and interface with external experts to incorporate specific concerns into ESF/repository analyses and testing programs or to document that no further work is required.

Recent laboratory tests indicate that there are significant changes in the thermal expansion coefficients of rock samples that contain significant amounts of tridymite and cristobalite. This work is designed to evaluate the potential impacts of these silica phase transformations on the rock mass and repository drifts. Two- and three-dimensional thermal-mechanical analyses will be conducted to evaluate the effect of changes in the thermal expansion coefficients on the rock mass stability associated with the ESF/repository. The impacts may be reflected in the repository thermal goals or drift designs.

This activity will provide thermal and structural analysis support of planned ESF experiments. Field tests will be analyzed to develop and evaluate techniques for determining rock mass response to thermomechanical loading. The analysis methods developed here will be used in the pretest evaluation and analysis of the proposed underground experiments. The analysis results will help define the space requirements of each experiment so that the experiments do not interfere with each other.

Laboratory-scale experiments on rock joints and simulated rock masses will be performed for development, verification, and validation of ESF rock-mass design models. 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 such as joint geometries and roughness, and to obtain higher quality full-field data.

Mechanical properties data will be consolidated and placed into the Reference Information Base so that they are readily available to all Project Participants. These data may include, but not be limited to, intact mechanical and thermal properties and estimated rock mass properties.

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More general and robust continuum jointed rock models will be developed from existing models. This work will begin with two-dimensional models and extended as quickly as possible into three-dimensional models.

Coupled finite element-boundary element technology will be incorporated into production two-dimensional codes and three-dimensional work will be initiated.

2.3.2 Seismic Analyses (SCP Section 8.3.2.1.4.2)

Dynamic and quasi-static seismic loading analyses of the North Ramp were performed. Of the in situ, thermal, and seismic loading components on the upper portion of the North Ramp, the seismic loading components are clearly the dominate loading. For this work, quasi-static and dynamic analyses for a 0.4g ground acceleration were conducted using a variety of codes, including JAC2D, UDEC, and DYNA3D. These analyses were used to estimate if the planned ground support would be sufficient. Although there is a potential for significant damage of the Tiva Canyon welded unit at a collapse loading of 0.67g, the 4.88 m rock bolts and fibre-reinforced shotcrete planned for support appear to be sufficient to resist the fallout rock potentially loosened by the seismic event.

Forecast: It is anticipated that similar analyses will be conducted for Design Packages 1B (to the Bow Ridge fault) and 2C (the remainder of the North Ramp).

2.3.3 Ventilation Analyses (SCP Section 8.3.2.1.4.3)

An initial study was performed to develop and evaluate preliminary concepts and requirements for the repository underground ventilation system as a part of the repository Advanced Conceptual Design studies. The analysis used an ESF/repository design layout currently under consideration to evaluate the underground ventilation system. Emphasis was on the requirements of air-volume flow rates and concepts of ventilating air distribution.

Ventilation requirements for repository development were evaluated by considering the air flow requirements for underground personnel, dilution of diesel emission, air velocity, air cooling, and special mining operations and equipment. Preliminary results show that the air flow quantity requirement for the development of the repository is anticipated to be within the common range of the ventilation requirement for conventional underground mines.

Emplacement air quantities were investigated based on the air flow requirements for control of drift temperature during the emplacement activities, as well as other standard requirements for underground operations. Analysis of heat transfer between the waste packages and the surrounding air and rock was performed using the in-drift emplacement mode to represent the worst case scenario for control of drift temperature during the emplacement operations. It is anticipated that the forced convection in the drift will predominate the overall heat transfer process and remove most heat generated by the waste packages during the emplacement operations, if adequate ventilation is provided. Effects of

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ventilation on the air temperature in the drift were demonstrated through typical numerical calculations using the overall energy balance relation. The calculated results showed that the temperature of the operating emplacement drift can be controlled within an acceptable level for the range of thermal loadings evaluated.

Air flow requirements for retrieval of emplaced waste were also addressed. Heat transfer during the cooling period was analyzed using traditional methods for thermal fluids. The numerical results indicate that it is possible to regain access to an emplacement drift sealed for an extended time such as 50 years, by ventilating the drift with a fairly large air flow rate, for the range of thermal loadings evaluated. It is also possible to maintain the accessibility to an emplacement drift for an extended period of time by providing ventilation continuously.

Forecast: Engineering studies and evaluations will continue during FY 1994 to better define the subsurface ventilation system including fan, filter, and network requirements for various subsurface design options. Analytical solution of the heat transfer process from the waste packages to the rock mass will be performed for various thermal loadings and lengths and dimensions of drifts to support the repository/ESF interface design development.

2.3.4 Safety Analyses (SCP Section 8.3.2.1.4.4)

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

Forecast: No activity is planned for FY 1994.

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SECTION 2.4 REPOSITORY DESIGN

2.4.1 Configuration of Underground Facilities (Postclosure) (SCP Section 8.3.2.2)

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: No activity is planned for fiscal year (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

The waste package information needed for repository design has been tentatively identified as physical dimensions, mass, handling requirements, closure method, package heat and radiation output, throughput, environment requirements. While the information needed has been identified, the information is not yet available. Work continued in this area to support systems engineering studies that are aimed at defining waste package performance allocation for various waste package emplacement modes, thermal loads, and waste package designs so that the information needs can be met.

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Forecast: Work will continue throughout FY 1994.

2.4.1.6 Design Activity 1.11.3.1 - Area Needed Determination

Work continued in this area to understand the need for area required to accommodate different thermal loads.

Forecast: Work will continue throughout FY 1994.

2.4.1.7 Design Activity 1.11.3.2 - Useable Area and Flexibility Evaluation

Work in this area continued. Several areas beyond the repository block shown in the Site Characterization Plan-Conceptual Design Report (SCP-CDR) (SNL, 1987) that may be suitable for waste disposal have been preliminarily identified. The influence of faults, overburden thickness, and Exploratory Studies Facility (ESF) features is being considered.

Forecast: Work will continue throughout FY 1994.

2.4.1.8 Design Activity 1.11.3.3 - Vertical and Horizontal Emplacement Orientation Decision

This activity was previously expanded to include in-drift emplacement. Advanced Conceptual Design work continues toward determining the emplacement mode, which is intimately related to thermal load and waste package size and type. These have a strong influence on repository layout and waste package handling equipment. Preliminary layouts to accommodate the three emplacement modes and a variety of thermal loads were made. Some of the layouts involve a split-level repository and permit flatter gradients than in the SCP-CDR layout. The flatter gradients allow the use of rail transport as a viable option.

The emplacement mode selection will depend on a number of factors including: repository layout, thermal load, operational considerations, waste package size, worker safety, and cost. The following studies, performed during this reporting period, examined several of these factors.

A study was performed to investigate various types of equipment and shielding that may be used in the transportation of waste packages from the repository surface facilities to their final underground emplacement areas. The type and number of fuel assemblies in the canister and the type of overpack influences the ultimate size and weight of the waste package to be transported. These factors in turn affect the selection of the transport vehicle and emplacement mode that can physically be achieved using currently available technology. The waste package used in the study varied from 2-3 pressurized-water reactor assemblies and 66 cm diameter to 21 pressurized-water reactor assemblies and over 2 m diameter.

The study considered transportation equipment for use in horizontal and vertical borehole emplacement, as well as in-drift emplacement. The range of equipment investigated

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included rubber tired, crawler tractor drive and rail, powered by alternative sources involving diesel and electric schemes. Rail systems included both conventional ground mounted rails and overhead monorail configurations.

The size of the emplacement drift is a function of various factors including equipment characteristics and operating envelopes, emplacement mode, and waste package dimension. For example, smaller drift profiles can be used with rail and monorail systems, and larger profiles are necessary for the trackless haulage transporter.

Generally, diesel power provides a safe and reliable means of propulsion, but may be limited in both track and trackless application because of potential impacts to waste isolation. At this time, definitive results are not available on the effects of carbon-based residue on the transport of radionuclides through the rock medium. Alternately, electric power is available in either battery or trolley configurations, and mitigates the undesirable effects of diesel exhaust. The electric systems, however, tend to reduce flexibility of movement while providing a cleaner atmosphere.

The study concluded that transportation for all three emplacement modes can be accommodated by currently available technology.

A study was performed to initiate Advanced Conceptual Design of the subsurface repository related to operations and maintenance. Its scope was to advance the definitions of operating concepts and modes for repository systems and equipment. Included in these activities were engineering studies and evaluations of operating concepts for waste package emplacement, waste package retrieval, and backfill emplacement. Waste package dimensions and thermal outputs currently being considered impact features of the repository design and emplacement operations. The findings of the study are summarized below.

1. The large multibarrier and multipurpose canister waste package concepts impose changes to the Site Characterization Plan (SCP) (DOE, 1988c) conceptual designs. Major changes to the waste package conceptual designs that influence emplacement and retrieval modes include greatly increased waste package exterior dimensions and much higher thermal output. Vertical emplacement of these very large waste packages in boreholes may be shown to be impractical under the SCP-CDR concept. Horizontal long borehole emplacement of the large waste packages requires an opening with a cross sectional dimension approaching that of a drift. In-drift emplacement of large waste packages may have operating advantages over boreholes in accommodating the very large transport vehicles and the option of accommodating an in-drift rail system.
2. Waste package retrieval is conceptually the reverse of emplacement, however, this functional activity may follow emplacement by as much as 84 years. The ability to retrieve must be maintained in all waste package emplacement modes and operating systems. The effects of retrieval on total repository layout features, ventilation system design, backfill specifications and requirements, and the whole area of subsurface maintenance are being studied.

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3. Backfilling of the completed repository is an integral part of the total subsurface Advanced Conceptual Design effort. Design and management of the surface stockpile so that mined rock can be used as backfilling material without violation of specifications must be understood. Another concern is the fact that filled inverts of underground openings essentially become early backfilling operations. The quality of those invert fills should be in accordance with the end-product backfills at closure. Evaluation of these concerns has begun.

An Emplacement Mode System Study (CRWMS M&O, 1993f) provides an initial look at a range of potential emplacement modes associated with possible waste package designs and repository thermal loadings. This study evaluated several emplacement modes in terms of human health and safety, and repository cost. Preliminary recommendations, depending on the waste package configuration, were provided for various emplacement modes. Further work will include the effects of emplacement mode on thermal-loading-related ventilation requirements, handling requirements, costs, and postclosure performance. The Emplacement Mode System Study was submitted to the Yucca Mountain Site Characterization Project Office (YMPO) on September 30, 1993.

Forecast: Work will continue throughout FY 1994 and later years.

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.

2.4.1.11 Design Activity 1.11.4.1 - Chemical Changes Resulting From the Use of Construction Materials

Identification of materials to be left by ESF construction activities which could potentially impact the waste package were coordinated. This led to more detailed analyses of the amount of diesel exhaust which could be left on ESF drift walls, the amount of Tunnel Boring Machine fluids which could be left on the ESF drift floor, and the amount of conveyor belt covering which could be left in the ESF drift.

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The residual diesel exhaust was determined to be potentially significant. The residual Tunnel Boring Machine fluids were determined to be likely insignificant, while the residual conveyor belt covering was determined to be definitely insignificant.

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

A report entitled "Estimations of the Extent of Migration of Surficially-Applied Water for Various Surface Conditions Near the Potential Repository Perimeter" (Sobolik) (ESF Performance Assessment Analysis Number 12) was approved by YMPO and sent for publication.

A report entitled "Evaluation of the Effects of Underground Water Usage and Spillage in the Exploratory Studies Facility" (Dunn and Sobolik) (ESF Performance Assessment Analysis Number 13) completed technical review. This report addresses concerns regarding underground water usage for dust control during excavation and fire fighting in the ESF North Ramp, South Ramp, and Main Test Level tunnels. This analysis evaluated the effects of large quantities of water in the tunnel on spatial and temporal variations in situ moisture content, as well as the potential amount of water that may evaporate from the rock walls due to moving air required for ventilation in the tunnels. Recommendations for inclusion in Appendix I of the Exploratory Studies Facility Design Requirements completed Sandia National Laboratories (SNL) technical and management reviews and were transmitted to YMPO. Additional calculations assuming a higher fracture permeability have been performed to assess water imbibition in the densely welded devitrified lithophysal-poor tuff, Topopah Spring Member sections of the North Ramp and Main Test Level of the ESF. The results of all of these calculations are included in Analysis Number 13; a preliminary draft of this report completed SNL technical, management, and editorial reviews in September 1993. This work is also reported under SCP Section 8.3.2.5.7, Design Activity 1.2.1.6 (Mining ventilation).

Forecast: Activities in support of the M&O studies of test-to-test interference and waste isolation impacts for surface-based and ESF testing will be conducted. These activities include performing performance assessment analyses, and using performance assessment analyses to make recommendations for the appropriate design documents (e.g., Exploratory Studies Facility Design Requirements). The following activities have been identified as potential requirements for the M&O for FY 1994 in support of ESF construction and testing activities and surface-based activities. They are listed in expected order of priority. Other Project Participants, such as the M&O, Lawrence Livermore National Laboratory (LLNL), and Los Alamos National Laboratory may be involved in any or all of these activities.

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1. Determine the sensitivity of the results of previous performance assessment analyses on a variety of parameters. The purpose of these activities would be to evaluate the sensitivity of the expected changes in in situ saturation, and the resulting potential impact on waste isolation. Identify, test, and compare different models for rock drying due to ventilation, particularly as it relates to fracture flow of water and fracture/matrix interaction, and the potential effects of ventilation on in situ saturation, and thus on waste isolation and site characterization. This activity is related to the current activity (Analysis Number 13) evaluating the effects of water used underground for ESF construction and testing activities. Determine the sensitivity of the results of previous performance assessment analyses on the computational and conceptual models used for the analysis. Previous hydrologic performance assessment analyses have employed the equivalent continuum approach for matrix and fracture flow, and have usually modeled flow as single phase (liquid) and isothermal. Would the effect on saturation be different if a dual porosity or discrete fracture flow model were used? Can recent laboratory results on fracture/matrix interaction be integrated into performance assessment analyses? Would they differ if multi-phase water/air flow were considered? What about the effects of heat? Determine the sensitivity of the results of previous performance assessment analyses on the assumptions made regarding heterogeneity and isotropy of hydraulic parameters. This activity was initiated in FY 1993 by SNL (ESF Analysis Number 14) by beginning a study of the sensitivity of the results of previous performance assessment analyses on the material properties used for the Paintbrush Tuff nonwelded unit. How discretely must certain stratigraphic units be divided into homogeneous media? What are the effects on the calculations of heterogeneity within each unit? This activity would require integration with soil and rock properties, statistical simulation work.
2. Evaluate the effect of a given local or global change in saturation on aqueous or gaseous flux, and on chemical transport into/out of the emplacement area. This analysis would require the integration of total systems performance assessment, waste isolation performance assessment, and other gaseous flow work.

2.4.1.14 Design Activity 1.11.5.1 - Excavation Methods Criteria

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

Forecast: No activity is planned for 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.

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2.4.1.16 Design Activity 1.11.6.1 - Thermal Loading for Underground Facility

The M&O systems analysis group conducted systems studies and analyses in support of the Advanced Conceptual Design effort. Two related studies pertinent to this activity and conducted during this reporting period were: the Thermal Loading System Study and the Emplacement Mode System Study (CRWMS M&O, 1993f). The Emplacement Mode System Study progress is presented in Section 2.4.1.8 of this report.

Thermal Loading System Study

This study was performed with the intention of integrating the activities pertaining to the Mined Geologic Disposal System (MGDS) thermal loading decision, focusing the thermal loading activities and potentially determining what is "too hot," identifying a range of thermal loading options that are believed to meet licensing requirements, and identifying further analyses, code development, and/or testing required to reduce thermal loading issue uncertainties. A product of this study was the "Site Characterization Plan Thermal Goals Reevaluation" report (CRWMS M&O, 1993g) which was delivered to YMPO on September 22, 1993. The SCP (DOE, 1988a) developed a set of repository thermal goals which were used to estimate the "goodness" of design concepts on the basis of preliminary data and immature predictive models. These goals emphasized the SCP reference emplacement mode, a vertical borehole, and, for the most part, emphasized postclosure performance related to a thermal loading of 141 kW/ha (57 kW/acre). During the Advanced Conceptual Design phase, new emplacement modes and thermal loadings are being considered and improved performance prediction models have been developed, making it necessary to reevaluate the original SCP thermal goals. The results of this activity are reported in the SCP Thermal Goals Reevaluation report.

In support of this study, the conclusions of the Operations and Safety Team were compiled into a summary memorandum submitted to the U.S. Department of Energy (DOE) and the SCP Thermal Goals Reevaluation Working Group. In addition to researching the original intent behind established SCP thermal goals, preliminary work investigating the importance on structural predictions of recently measured changes in thermal expansion due to polymorph silica phase transformations was completed and incorporated into the reevaluation effort. The reevaluation report is currently being reviewed.

The SNL role in the development of the thermal loading systems study was to investigate a series of thermal loading scenarios with emphasis on preclosure performance. Numerous interactions with the M&O narrowed the FY 1993 focus of this effort to 17 combinations of two in-drift emplacement scenarios, three waste package designs, and five areal mass loadings. Three-dimensional, near-field calculations are currently being carried out to assess thermal environments that can be associated with these scenarios.

Extended Hot Evaluation

The SNL participation in the Project's evaluation of the "extended hot" concept was completed. Translations of the LLNL VTOUGH input decks used in the "extended hot"

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scenarios were provided to the Project by SNL. In addition, a preliminary assessment of addressing such issues as the importance of multiple material property designations (layering), functional property designations, and general repository layout on the prediction of host-rock thermal response was completed. Based on the work performed on this effort, SNL staff participated in a briefing to DOE on June 29, 1993, in Las Vegas, Nevada, and gave a presentation to the Nuclear Waste Technical Review Board on July 13, 1993, in Denver, Colorado.

Total System Performance Assessment 1993

As SNL input into the Total System Performance Assessment (TSPA) 1993, four thermal loading scenarios were investigated. Specifically, the induced thermal responses for two in-drift emplacement and two vertical borehole emplacement cases were modeled using a three-dimensional analytical and two- and three-dimensional finite element models. Areal power densities of 141 kW/ha (57 kW/acre) and 282 kW/ha (114 kW/acre) were investigated for a levelized waste stream. The results of the models were reduced to designations of the number of waste packages that would be "protected" at 5 m by a 96°C isotherm, estimates of dry-out volumes, and representative waste package temperature histories. The waste package temperature histories were also provided to LLNL and the M&O's waste package design team for use as boundary conditions in determining waste form temperature histories. This information is currently being used as input into the SNL TSPA calculations.

Non-Isothermal Flow Modeling and Experiments

Lab-scale experiments were performed to determine the effects of saturation variations on nonisothermal flow in sand enclosed within a square test cell with bottom heating. Totally saturated, half saturated, and residually saturated cases were examined for constant temperature boundary conditions at the top and bottom of the cell. Results showed that in all three cases, two counter-rotating convective cells developed in the saturated region of sand, but no bulk liquid movement was evident in the unsaturated regions. Preliminary numerical simulations using the TOUGH2 code provided consistent results with regard to flow patterns and temperature fields during simulations of the natural convection in a saturated, two-dimensional, porous media. Qualitative agreement of flow patterns between the numerical simulations and the experiment was achieved. Sensitivity analyses using TOUGH2 showed nonisothermal flow behavior to be very sensitive to boundary conditions. More rigorous experiments are planned so that boundary conditions can be monitored and stipulated in future numerical simulations. The results of the experimental and numerical modeling efforts for FY 1993 have been documented in a report entitled "Experimental and Numerical Investigations of Non-Isothermal Flow in Saturated and Partially Saturated Porous Media" (Ho et al., 1993).

Forecast: Further work on emplacement mode will include the effects on thermal-loading-related ventilation requirements, handling requirements, costs, and postclosure performance.

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The review process associated with the report documenting the review of current thermal design goals is expected to continue into FY 1994. Future changes to the final report and, hence, to the thermal goals is considered an evolutionary process to be made as new information becomes available. The Thermal Loading System Study report will be provided to YMPO in December 1993.

Work in the area of scenario evaluation is planned to continue in FY 1994. Evaluations will consist of thermal and thermal-mechanical simulations to establish predictions of the near-field response to various options of waste emplacement.

Documentation of the thermal loading scenarios investigated as part of TSPA 1993 will be completed early in FY 1994. In addition, sensitivity studies will be performed as necessary during FY 1994.

Experimental and numerical work in the nonisothermal area will continue in FY 1994. The primary emphasis in the FY 1994 work will be in evaluating the agreement between experimental and numerical results as well as establishing criteria for use in simplifying geostatistical simulations in a physically meaningful manner.

2.4.1.17 Design Activity 1.11.6.2 - Borehole Spacing Strategy

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

Forecast: No activity is planned for FY 1994.

2.4.1.18 Design Activity 1.11.6.3 - Sensitivity Studies

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

Forecast: No activity is planned for FY 1994.

2.4.1.19 Design Activity 1.11.6.4 - Strategy for Containment Enhancement

Due to the prioritization of analysis directly supporting the design of the ESF North Ramp, work in this area was discontinued in FY 1993.

Forecast: No activity is planned for FY 1994.

2.4.1.20 Design Activity 1.11.6.5 - Reference Calculations

No information generated in this reporting period.

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2.4.1.21 Design Activity 1.11.7.1 - Reference Postclosure Repository Design

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

Forecast: No activity is planned for FY 1994.

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.

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

In February 1993, SNL was requested to provide the M&O with design analyses required to support the 90% Design Review of the North Ramp. These analyses were originally defined to support the entire North Ramp connecting the surface with the potential repository horizon. In response to this request, SNL formulated and ran three-dimensional thermal calculations for use in determining the thermally induced boundary conditions (e.g., stress) for use in two-dimensional structural models of a series of North Ramp cross-sections.

Alterations in the alignment of the North Ramp and changes in schedule due to site-specific information from the North Ramp Geologic drilling program resulted in a change in the basic repository layout that made the original thermal studies of the North Ramp no longer applicable. Because of the changes in schedule, however, this did not have a major impact other than in the area of budget. Specifically, the only package that was due in FY 1993 was that for the first 200 ft of the Starter Tunnel (Package 1A). Due to the near-surface emphasis of this package, thermal and in situ loads are negligible. Seismic analyses were completed for this design package and were transmitted to the M&O design team. A memo report, "Static Analysis of a Representative North Ramp Cross-Section in Tiva Canyon" (Shephard to Dyer, September 7, 1993), was transmitted to YMPO for approval. It

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is noted that FY 1994 calculations will require a reformulation of thermal and seismic analyses for use in supporting Design Packages 1B (to the Bow Ridge fault) and 2C (the remainder of the North Ramp connecting to the repository horizon).

Forecast: It is anticipated that thermal/structural/seismic analyses will be conducted in FY 1994 for North Ramp Design Packages 1B (to the Bow Ridge fault) and 2C (the remainder of the North Ramp).

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

An initial version of the "Mined Geologic Disposal System Systems Engineering Decision List" (CRWMS M&O, 1993h) was delivered to YMPO. This list provided a first draft of MGDS-related design decisions required to support the Yucca Mountain site characterization activities. The list was compiled from a review of the SCP and baselined technical requirements and management documents.

Forecast: This decision list will be used as a tool to prioritize design and analysis efforts in support of Advanced Conceptual Design and site characterization.

2.4.4.2 Design Activity 4.4.3.2 - Operations Plan to Accompany the License Application Design

No information generated in this reporting period.

2.4.4.3 Design Activity 4.4.4.1 - Repository Design Requirements for License Application Design

No information generated in this reporting period.

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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 fiscal year (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

A report entitled "Initial Seal Test Definition of Subsurface Sealing and Backfilling Tests in Unsaturated Tuff" (Fernandez et al., 1993) was published. An extended abstract was also prepared for the upcoming rock mechanics symposium. The abstract entitled "An Overview of the Yucca Mountain Site Characterization Project, Field-Test Program for Evaluating Seal Performance" (Fernandez and Case, 1993) was approved by the Yucca Mountain Site Characterization Project Office (YMPO).

Forecast: Field-scale tests to validate borehole sealing concepts and strategy will be initiated. Activities include conducting limited field and laboratory testing and evaluations of borehole sealing concepts. Verification of these borehole sealing concepts is vital to the continued progress of the various drilling programs at Yucca Mountain. Simple tests to evaluate the performance of suggested cementitious sealing materials along with evaluations of the adequacy of standard emplacement techniques will be performed.

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. A report entitled "A Strategy to Seal Exploratory Boreholes in Unsaturated Tuff" (Fernandez et al.) was completed and submitted to YMPO for review. The report describes the proposed strategy for sealing boreholes and develops a strategy for sealing boreholes based on evaluations of the current and planned borehole system, the potential impacts on performance that the borehole system could have, and the available technologies to seal boreholes.

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Sandia National Laboratories provided extensive evaluation and information to YMPO regarding the potential impacts of testing in UE-25 UZ#16 on the ability to seal the boreholes. As a result, special grout mixes are being evaluated for use in UE-25 UZ#16 that would have minimal impact on eventual sealing.

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.

Forecast: "Proof-of-Concept" laboratory and in situ demonstration tests of cementitious exploratory borehole sealing systems will be defined and started. These tests will evaluate the exploratory borehole sealing design concepts defined in "A Strategy to Seal Exploratory Boreholes in Tuff" (Fernandez et al.) to be published in FY 1994.

A sealing design strategy for sealing the Exploratory Studies Facility (ESF)/repository openings will be developed for supporting the ESF design and construction process. This strategy will include design and performance analyses to address various sealing issues and requirements and will entail close cooperation with ESF design engineers using an iterative process. These ESF sealing strategies are necessary to ensure that portions of the ESF can be incorporated into the repository, if constructed.

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.

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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. Status of the waste package program is provided in this section.

2.6.1 Waste Package Design (SCP Section 8.3.4.2)

2.6.1.1 Design Activity 1.10.2.1 - Concept Development

During this reporting period, a report entitled "Waste Package Design Status Report, Fiscal Year 1993" (CRWMS M&O, 1993i) was issued. The report provides a detailed review of the analytical activities performed by the Waste Package Development staff. On October 1, 1992, Waste Package Development moved into the Advanced Conceptual Design phase of the three-phase design effort. The results presented in the status report are in support of the "Waste Package Implementation Plan," (DOE, 1992b). The evaluations and results support the goals of the waste package design process defined in the plan.

Advanced Conceptual Design is a four-year effort to provide the basis for License Application Design. During Advanced Conceptual Design a number of waste package/engineered barrier system design options are to be evaluated for applicability to the component design, performance and Mined Geologic Disposal System (MGDS) design requirements.

The "Waste Package Performance Allocation Study" (CRWMS M&O, 1993j) began the process of providing a technical basis for the design lifetime of the waste package. This study report described the regulatory background related to the issue of waste package performance allocation, provided initial estimates of the impact of waste package thickness on postdevelopment and evaluation repository costs, and related waste package thickness to preliminary estimates of corrosion time periods. The Waste Package Performance Allocation Study Report was delivered to the Yucca Mountain Site Characterization Project Office (YMPO) on September 30, 1993.

In September 1993, the "Multi-Purpose Canister (MPC) Implementation Program Conceptual Design Phase Report" (CRWMS M&O, 1993k) was completed. This report will assist the Department in making a decision on whether to proceed with further development of the multipurpose canister for the Civilian Radioactive Waste Management System.

During this period, the "Waste Package Engineering Interface Plan" (CRWMS M&O, 1993m) was also issued. The document first presents the purpose and requirements followed by a description of the waste package conceptual design and waste package performance requirements. The purpose of the plan is to outline the interface requirements between the Waste Package Design Section and other affected organizations.

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Interface Drawings and Specifications which will be derived from the Interface Plan will ensure the functional and physical compatibility of the waste package and other elements of the MGDS by documenting and controlling the design characteristics. As the waste package interfacing design features are developed and become more definitive, the Interface Drawings and Specifications will be modified to incorporate the latest interface design requirements.

Work during this reporting period, the early part of the Advanced Conceptual Design phase, was based on the ten years of data generated during preconceptual design. The scientific and engineering data gathered over the past years were the basis from which the Advanced Conceptual Design concepts were identified. The major goal for the first year of engineering evaluations was to develop a parametric data base from which specific design concepts could be evaluated in detail. The parametric evaluations performed included thermal response of the waste package and repository with respect to a number of variables including: age of spent nuclear fuel; stored energy (burnup); initial ^{235}U enrichment; repository thermal mass loading (areal mass loading and areal power density); drift spacing; waste package spacing; material properties of the waste package and repository; and spent nuclear fuel receipt rate. Included in the parametric evaluation was the understanding of long-term criticality behavior. The parametric evaluations explored many different initial enrichments and configurations. The results of the evaluation were a major contributor to the understanding of long-term disposal requirements.

Calculating the analytical evaluation of the multipurpose canister was the second major effort for the waste package design staff. Waste package concepts included a waste package (or disposal overpack) for the multipurpose canister. Much of the waste package design effort has been focused on the design of the waste package/multipurpose canister and the response of the repository to the multipurpose canister. For the multipurpose canister to be economical for the waste management system, its capacity should be as high as practical. Maximizing the capacity will cause the thermal output of the device to be relatively high. The thermal output will cause the multipurpose canister to be compatible with the "hot" or "extended hot" repository thermal load scenarios, but may not be compatible with the low thermal load scenario as it is presently defined. Various loading strategies are being considered which may allow a large package to be compatible with a low thermal loading. The thermal output of a single large multipurpose canister will be high enough to ensure above-boiling conditions into the near field. The large capacity multipurpose canister is suitable for in-drift emplacement only.

In addition to the parametric thermal and criticality evaluations, a number of engineering calculations and bases were developed (i.e., the design basis spent nuclear fuel for thermal and criticality evaluations was defined; shielding requirements were developed and evaluated; internal thermal variance due to different spent nuclear fuel was explored; initial cost estimates for a range of waste package sizes were developed; material selection criteria development was initiated; fuel rod cladding performance evaluation was initiated; evaluation of structural response over time was initiated; data and information for three system studies were provided; and performance assessment was supported). The analytical topics included in the report are summarized in the activity discussions below.

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Forecast: Total system performance analyses relating the waste package period of containment to the overall containment performance of the geologic setting will be conducted as part of the fiscal year (FY) 1994 emplacement mode/waste package performance allocation study.

Activity 1.10.2.1.1 - Advanced Conceptual Design concepts. This section provides a description of the waste package options being evaluated during Advanced Conceptual Design. During Advanced Conceptual Design a range of concepts are being investigated, from the thin-walled small capacity pre-Advanced Conceptual Design concepts to a variety of sizes and capacity multibarrier design concepts, including different levels of radiation shielding and spent fuel capacities. Included in the concepts are metallic and nonmetallic/ceramic barrier concepts. Depending on the repository environment and operational restrictions, the options will be combined as necessary to ensure a licensable waste package.

A matrix of waste package design options has been compiled, as shown in Table 2.6-1. The purpose of this section will be to define the seven basic spent nuclear fuel and defense high level waste Advanced Conceptual Design waste package design options that will receive further evaluation.

Activity 1.10.2.1.2 - Design basis fuel. This section describes the process by which a design basis fuel is systematically selected. The goal is to provide a source term for thermal and neutronic evaluations. The selection of the design basis fuel is the key to the design of the waste package. The design basis fuel will determine the capacity (thermal output of the waste package), criticality behavior, and shielding needs. It is also understood that not all of the spent nuclear fuel can be accommodated with just one waste package design. It is logical to provide at least two basic waste package designs: one design that can accept the majority of the spent nuclear fuel, and the other to accept off-normal or failed spent nuclear fuel assemblies. This method prevents over-designing the waste package for relatively few spent nuclear fuel assemblies.

Analysis Methodology

To determine the range of likely values for the 'enrichment' and 'burnup' parameters, statistics of the Energy Information Administration forecast data base have been tabulated: both for all 86,000 MTU expected to be discharged; and for only those discharges expected before 2003 (which will be the fuel available for pickup in the first ten years of waste acceptance). The latter is more relevant for design of the first phase multipurpose canister while the former is closer to what can be expected for the entire repository.

The statistics on criticality cannot be characterized by a single parameter, since criticality is a function of age, burnup, and initial enrichment. The situation is further complicated by the fact that burnup and initial enrichment are strongly correlated for most of the fuel. To determine parameters for criticality, a formula developed by Cerne et al. (1987) has been used. This formula gives k_{∞} as a function of age, burnup, and initial enrichment, based upon a curve fit to a set of 210 SCALE runs which actually computed k_{∞} for representative range of values for age, burnup, and initial enrichment. The formula developed by

Table 2.6-1. Advanced Conceptual Design Waste Package Design Concepts

Descriptions	Borehole Emplaced	Drift Emplaced	Metallic Barriers	Non-Metallic Barrier	Single Container	Multi-Barrier	Totally Shielded	Partially Shielded	Fillers	Backfill Credit	Storage/Transport/Disposal	Storage/Transport
Metallic Multibarrier		X	X			X		X	X	X		
Metallic Shielded		X	X			X	X		X	X		
Small, Metallic Multibarrier Borehole	X	X	X			X	X	X	X	X		
Nonmetallic Multibarrier	X	X	X	X		X	X	X	X	X		
Multipurpose Canister		X	X	X		X	X	X	X	X		X
Universal Cask (Multipurpose Unit)		X	X			X	X	X		X	X	
SCP-CDR (Single Container)	X		X		X				X			

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the Cerne et al. (1987) curve has a constant term, the three possible linear terms, the three squared terms, the three quadratic product terms, and an additional cubic term having the product of all three variables. Of course, it is recognized that any criticality analysis must consider the specific geometry of the fuel assembly and its environment, as represented by k_{eff} . However, it is assumed that the burnup-enrichment pairs which make up the lines of constant k_{∞} corresponding to a specified percentile of all k_{∞} values, will be the same burnup-enrichment pairs which would make up a constant k_{eff} line if the detailed, geometry-dependant values were calculated for all the batch points in the data base.

This formula was then applied to every batch in the Energy Information Administration data base and the resulting values of k_{∞} were statistically tabulated. To be conservative, an age of five years was assumed for all the fuel (although it is known that over half the fuel will be older than five years by the time it can be emplaced in a repository).

Design Basis Spent Nuclear Fuel Results

The results can best be presented as two sets of recommendations, one for the waste package, using all the fuel; and the other for the multipurpose canister in the first ten years of waste acceptance, using the fuel discharged before 2003.

By examining the statistical tabulation of all expected spent fuel, it is found that the 25 percent lines for burnup and k_{∞} intersect at the point burnup = 49 GWd/MTU, and enrichment = 5.05 percent. This means that 75 percent of the fuel will be less stressing from both a burnup (thermal and shielding) and a criticality standpoint. Similarly, from the pre-2003 discharges, there is an intersection of the 20 percent lines at the point 42.5 GWd/MTU, 4.35 percent enrichment. (Once again, the particular value of k_{∞} is unimportant. The only purpose of calculating it is to obtain statistics on forecast fuel according to a parameter which will be proportional to any ultimate criticality analysis.)

It is, therefore, recommended that the following design points, as illustrated in Table 2.6-2, be used.

Table 2.6-2. Design Basis Spent Nuclear Fuel

Application	Burnup	Enrichment	SNF Covered
Multipurpose Canister	42.5 GWd/MTU	4.35%	80%
Waste Package	49 GWd/MTU	5.05%	75%

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There are two problems with this single point definition of design basis fuel: (1) it might be desirable to have the primary waste package design capture/represent a larger fraction of the fuel than 75 or 80 percent; and (2) this design point would represent a very unlikely fuel assembly, having too low a burnup for this enrichment.

Design Basis Spent Nuclear Fuel for Shielding and Thermal Evaluations

It may be useful to abandon the concept that the design basis fuel should be expressed as a combination of parameters likely to be found in the same assembly, and use instead one set of parameters for shielding/thermal and another set for criticality. From a tabulation of all spent fuel, it can be shown that a more conservative design, covering 90 percent of all fuel, would have a burnup of 55.5 GWd/MTU. Similarly, from a pre-2003 tabulation, the 90 percentile for burnup for all discharges prior to 2003 would be 45 GWd/MTU. These results are summarized in Table 2.6-3. The design point enrichments are taken at the lower end of the range of initial enrichments corresponding to these burnups because neutron flux (and hence shielding requirements) increases with decreasing enrichment, for fixed burnup since the lower initial enrichment corresponds to a higher residual Pu.

Table 2.6-3. Design Basis Spent Nuclear Fuel for Shielding/Thermal

Application	Burnup	Enrichment	SNF Covered
Multipurpose Canister	45 GWd/MTU	3.25%	90%
Waste Package	55.5 GWd/MTU	3.85%	90%

Design Basis Spent Nuclear Fuel for Criticality Evaluations

The other half of the dual design basis fuel would be for criticality. For either waste package or multipurpose canister, one could pick any point on the 10 percent k_{∞} line, but it would be most meaningful to pick a value of burnup such that the constant burnup line intersects the constant k_{∞} line at the midpoint of the burnup line, so that the enrichment most represents the average enrichment for that burnup. The results are shown in Table 2.6-4.

Table 2.6-4. Design Basis Spent Nuclear Fuel for Criticality

Application	Burnup	Enrichment	SNF Covered
Multipurpose Canister	25 GWd/MTU	2.75%	90%
Waste Package	22 GWd/MTU	2.40%	90%

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The age of the spent fuel being emplaced will depend on the utility receipt rate. For any reasonable scenarios the average age will be upwards of 20 years, but as much as 50 percent could be as young as ten years. Accordingly, it would be more conservative to use a design basis fuel age of 10 years. The repository Mission Plan notes that five-year-old spent nuclear fuel will also be accepted at the repository. As part of the MGDS parametric evaluation, five-year-old spent nuclear fuel will be considered as a limit.

2.6.1.2 Design Activity 1.10.2.2 - Design Tools

No information generated in this reporting period.

2.6.1.3 Design Activity 1.10.2.3 - Design Evaluations

Activity 1.10.2.3.1 - Thermal. Many factors contribute to the thermal response of the waste package/engineered barrier system. Design-basis fuel characteristics and waste package capacity determine the heat produced; materials of construction, basket design (flux trap or burnup credit), emplacement mode, and tunnel diameter determine the waste package ability to expel its heat; and thermal loading of the repository determines the environment around the waste package.

The waste package/engineered barrier system thermal evaluation can be divided into two parts. The first is an analysis of the far-field repository thermal behavior, and the second is an analysis of the near-field waste package thermal behavior with boundary conditions from the repository analysis. Two finite element models were generated representing the repository and the waste package. Both systems exhibit highly time dependent behavior and must be modeled by a transient analysis unlike a spent fuel storage or transportation analysis where steady state conditions can be assumed.

Long-term thermal behavior of the repository rock is primarily a function of the areal mass loading in MTU/ha (or MTU/acre). The repository response is determined more by the integrated heat from the emplaced spent nuclear fuel and less by the initial heat of the individual waste packages. Thus, specifying an initial areal power density in kW/ha (or kW/acre) without specifying the fuel type will not determine the thermal response because the areal power density will change with time differently depending on the average fuel characteristics. For a given areal mass loading and assuming average fuel characteristics, the long-term repository thermal response is fixed and the average host rock temperatures can be determined and applied as the environment for a detailed thermal analysis of the waste package and near field.

The designs of the waste package must be sufficiently conservative to ensure that they will meet regulatory requirements when loaded. It is most efficient to design to the most stressing values of the parameters (age, burnup, and enrichment) which are likely to be encountered when loading the waste package. The most stressing parameter values are used to characterize the design basis fuel. The relevant regulatory requirements can be efficiently

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satisfied by designing shielding, package size, and neutron absorber material to accommodate the set of design basis fuel types. The relatively few assemblies having more stressing parameter values may be handled by de-rating the standard package and/or by designing and utilizing a more conservative (and, consequently more expensive) waste package. The design basis is currently expressed in terms of pressurized-water reactor fuel, since it is the more stressing with respect to age, burnup, and initial enrichment.

Several different waste package capacities have been evaluated, but recent interest has centered on the large multibarrier drift emplaced waste package with capacities up to 21 pressurized-water reactor assemblies or 40 boiling water reactor assemblies, (pressurized-water reactor assemblies are considered limiting because of their higher decay heat output compared to boiling water reactor assemblies). Higher capacity waste packages are more likely to exceed thermal goals than smaller ones in the same repository thermal environment. The choice of a design basis fuel is important because it will directly limit the number of assemblies that can be loaded and still meet thermal goals. The limiting thermal goal for large waste packages is 350°C at the spent nuclear fuel cladding. For the multipurpose canister conceptual design basis fuel characteristics of ten years aged with 40 GWd/MTU burnup, the 21 pressurized-water reactor capacity is considered at or above the maximum allowable temperature for a metallic multibarrier waste package such as the multipurpose canister with disposal container.

All these factors affect the timing of peak temperatures as well as the magnitude. Host rock temperatures will peak between 20 to 500 years depending on the thermal loading but peak rock temperature will be largely independent of the individual waste package design. The waste package will experience its peak temperature between initial emplacement and the repository peak depending on the design basis fuel and the basket/container design. For the large waste package, higher conductivity spent nuclear fuel baskets will lower and delay the peak temperatures experienced. The choice of the design basis fuel is of key importance to the timing of peak temperatures. Younger fuel types produce high peak temperatures within the first few years which then drop off quickly. Older fuel (at the same areal power density) produces lower temperatures and later peaks with more stable and higher long-term temperatures.

Although the parameters of a "cold repository" have not been defined, the large waste package most likely will preclude such a scenario because of the localized high temperatures immediately surrounding the 21 pressurized-water reactor capacity waste package. Preliminary analyses show that even at low thermal loads such as 87 kW/ha (35 kW/acre), near-field temperatures can exceed the boiling point. In any case, it would not be possible to emplace 63,000 MTU of spent nuclear fuel in Yucca Mountain without introducing significant thermal perturbations in the host rock.

Activity 1.10.2.3.2 - Structural. This section presents the structural evaluations that have been performed in the first year of Advanced Conceptual Design. Thermal and neutron concerns dominated the effort; only limited structural evaluations were performed. One of the concerns for drift emplacement is the size and weight of a rock that would breach the waste package. For a waste package with about a 12 cm wall thickness, a structural evaluation

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indicated that a 1.2-m-diameter rock weighing 2.26 metric tons falling from the ceiling would plastically deform the waste package but not fail it. Next fiscal year a plastic deformation evaluation will be performed to define the failure point. Additional evaluations will be performed for each waste package design concept—end load, slap down, lifting loads, and drop test—to note a few.

Activity 1.10.2.3.3 - Criticality. A number of important results were gathered during this reporting period. The criticality safety evaluations confirmed the viability of the high capacity burnup credit designs. In the area of long-term criticality safety for a waste package in the MGDS, two important points were found. The first point is that the criticality potential of spent nuclear fuel initially decreases (100 to 200 years) but then increases to a local maximum (10,000 to 20,000 years) before decreasing again. Waste packages must be designed for this increase in criticality potential.

The second important point investigated during the criticality safety evaluations is that neutron absorber materials will be partially depleted over the long time periods. To maintain criticality control in a disposal waste package, extra neutron absorber material must be included initially to control criticality in the out years. This may require the use of ^{10}B enriched boron, an expensive material, in the current waste package designs. Up to an additional 25 percent of ^{10}B is recommended for final disposal to compensate for the depletion process.

Two concepts were evaluated for radiation shielding in the MGDS, the 'shielding outer barrier' and the 'shielded waste package emplacement transporter.' The evaluation demonstrated that the reusable shielded waste package emplacement transporter is more efficient and cost effective than a shielding outer barrier for each waste package.

Other calculations and evaluations are needed, such as validation of criticality and shielding models against other codes. Evaluations needed include the amount of water in the waste package necessary for criticality, the effect of varying axial burnups, mixing of spent nuclear fuel assemblies with different spent nuclear fuel characteristics in a waste package, the depletion of the materials in the fuel over the long time period, and the total reevaluation of the new waste package design with the new criticality design-basis spent nuclear fuel characteristics.

Detailed two- or three-dimensional evaluations of each waste package design are required as well as evaluations of neutron activation of the waste package components and engineered barriers in the MGDS by the subcritical neutron flux over the time of operation. The neutron activation of Co impurities found in the stainless steel of the new baseline design is especially important due to the high strength gamma dose from the activated ^{60}Co . An evaluation of the new multipurpose canister waste package design (or disposal overpack) for the multipurpose canister is also needed.

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Activity 1.10.2.3.4 - Cost Estimation. This section describes an initial cost estimate of the multipurpose canister and large multibarrier waste package. The cost estimate takes into consideration the 1989 total life cycle cost estimate and expands to include additional cost and fabrication methods for larger containers.

Estimated costs for selected multipurpose disposal overpack and waste packages are presented in Table 2.6-5. The design cases which consider fuel burnup credit allowance are indicated by the footnotes. Taking a fuel burnup credit allowance results in a less bulky spent nuclear fuel basket design, reducing size and weight of the basket and concurrently reducing size and weight of the multipurpose canister overpack or waste package as well. On the basis of burnup credit, the 21 pressurized-water reactor cases in Table 2.6-5 are generally comparable, whereas the 12 pressurized-water reactor cases are less so. However, note that at present the multipurpose canister design and the waste package design do not have common spent nuclear fuel basket designs and sizes, which result in the multipurpose canister and waste package having slightly different inside diameters. Multipurpose canister disposal overpack and waste package costs are presently based on a single vendor budgetary estimate.

The baseline multipurpose canister material is 316L stainless steel, whereas Alloy 825 is considered an alternate material. Should the multipurpose canister be made of Alloy 825, the multipurpose canister would then qualify as the inner corrosion barrier, and the multipurpose canister overpack would be reduced to a single layer of carbon steel. The cost of materials places Alloy 825 at nearly three times the cost of 316L (\$9.37/kg versus \$3.20/kg, or \$4.25/lb versus \$1.45/lb). Whether made of stainless steel or Alloy 825, the multipurpose canister wall thickness would be essentially the same in either case because the thickness is driven by container stresses in the fully loaded condition.

2.6.1.4 Design Activity 1.10.2.4 - Material Selection Design Support

This section presents the method by which materials will be selected in support of the waste package/engineered barrier system. The selection process is a systematic approach based on component functions, performance and design requirements. The process is equally adapted to the multipurpose canister as well as the design concepts that include overpacks. multipurpose canisters, which are relatively thin-walled containers, may be a part of an onsite dry storage device, then loaded into a transportation overpack and shipped to the MGDS. While the engineering evaluations of this design concept will include structural, thermal, shielding and nuclear criticality studies, this section will be concerned with the selection of materials for different components of the multipurpose canister.

Activity 1.10.2.4.1 - Materials selection process. The materials selection process, illustrated in Figure 2.6-1, includes the following items.

1. Definition of component functions, performance/design requirements and environments.

Table 2.6-5. Multipurpose Canister Implementation Study Waste Package Cost Estimate Comparison

Costs based on 1993 material costs

Type	First Barrier (cm) = Second Barrier (cm) =		0.95 Alloy 825 10 Carbon Steel		Internal Support PWR (kg)	First Barrier (kg)	Second Barrier (kg)	Estimated Cost
	Number of PWRs	Number of BWRs	Inside Diameter (cm)					
Multi-Barrier Waste Package, SNF (note 1)	21	40	152.09		9540	2104	24537	\$367,835
Multi-Barrier Waste Package, SNF (note 1)	12	21	117.52		5900	1562	18849	\$247,098
Multi-Barrier Waste Package, DHLW (4)	—	—	156.04		790	1562	18582	\$111,009
MPC Overpack, Multi-Layer (note 1)	21	—	154.4/157.5		—	2260	26216	\$151,590
MPC Overpack, Single Layer (note 1)	21	—	154.4		—	0	25463	\$82,755
MPC Overpack, Multi-Layer (note 2)	12	—	127.3/130.4		—	1802	21429	\$122,578
MPC Overpack, Single Layer (note 2)	12	—	127.3		—	0	20729	\$67,369

Note 1: With burnup credit allowance

Note 2: No burnup credit allowance

MPCTABLE.130/12-20-93

WPSELECT.119/12-6-93

Figure 2.6-1. Waste Package Materials Selection Process

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2. Selection criteria and weighting factors.
3. Identification of candidate materials.
4. Collection of information/data.
5. Application of selection criteria and ranking.

The initial step in selecting a material for a waste package component is to define the functions required of that component. Specific functions will be assigned to each individual component of the waste package based on the need to satisfy federal as well as other regulatory requirements. For each identified component function, performance measures and quantitative performance requirements will be identified. Quantification will be achieved through use of models to be developed to predict each performance measure. Furthermore, the expected environmental conditions (including parameters and ranges) surrounding each component will be identified and defined as a function of service time.

Selection criteria are determined based on the performance and design requirements for each component. The selection criteria can typically be classified into two major categories: (1) those related to the performance of the candidate material in the anticipated repository environment; and (2) nonperformance-related aspects dealing with cost, engineering experience, and practical considerations of fabrication, closure, and material availability. Each selection criterion may consist of several topical areas such as mechanical and chemical performance, performance predictability, and compatibility with other materials, etc. Weighting factors will be assigned to the selection criteria so that eventually an overall score or figure of merit can be determined for each candidate material. Since there exists no universally accepted way of balancing the selection criteria against each other, the assignment of these weighting factors will be unique to each component and will require the application of engineering judgment.

The identification of candidate materials for a specific component will be based on a literature review of the anticipated degradation modes that may occur under the expected environmental conditions, information relevant to each selection criterion, and the results of preliminary tests. These preliminary tests will be focused on evaluating the selection criteria-related corrosion and mechanical properties of potential materials. Engineering judgment will be used to identify materials that have the desired properties and generally favorable attributes relative to the selection criteria.

Data and information will be developed to allow an assessment of how well the candidate materials will satisfy the selection criteria. Pertinent information related to the cost, engineering experience and fabricability of each identified material will be collected. Other information relevant to performance selection criteria will be generated, as appropriate. These collected data/information will eventually be applied in selecting material for each component.

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A quantitative rating will be given to each candidate material for each selection criterion. This rating will be based on the gathered information/data in both performance-related and nonperformance-related categories. The weighting factor for each criterion will be multiplied by these ratings and the results summed for each material to establish an overall material rating. These quantitative ratings will then be used to rank the candidate materials for each component. The information gathering and testing will be continued on fewer materials followed by reapplication of selection criteria and rating/ranking to provide sufficient basis for final materials selection near the beginning of the License Application Design.

Activity 1.10.2.4.2 - Container shell. The disposal waste package (or disposal overpack for the multipurpose canister) will contain a set of spent nuclear fuel assemblies inside a shell. These containers are to be designed to contain the radionuclides, and to provide contamination control from the possible reactor service crud build-up on some spent nuclear fuel assemblies. Furthermore, the shell will be designed to provide thermal coupling between the spent nuclear fuel basket and waste package overpack and will have to withstand a normal operating temperature of $<350^{\circ}\text{C}$ for a prolonged containment period.

Since the primary function of the shell is to contain the radionuclides, the metallic material to be used for the shell should be highly corrosion resistant. The fact that the potential repository will be located in an unsaturated zone suggests that the oxidation will probably be the dominant degradation mode of the shell. However, it seems prudent to allow for the possibility that the shell may be in contact with some bulk water for some period of time. Under this condition, the shell would be subjected to various modes of corrosion damage such as general corrosion, crevice corrosion, pitting attack, stress corrosion cracking, and other forms of environment-induced embrittlement. Thus, the selected material for the shell should possess sufficient resistance to these types of degradation modes.

From a design point of view, the shell material should be compatible with the spent nuclear fuel basket and disposal overpack. In addition, it should be capable of withstanding normal and off-normal handling loads. Deformation and failure of the shell may occur differently depending on the candidate material, and its processing and fabrication history. The fabrication process and the welding or other closure process may have a significant influence on the mechanical and microstructural properties that can influence the performance of the shell. The selected material should also possess high thermal conductivity so as to transmit heat away from the spent nuclear fuel.

In view of the above-mentioned functions, and the desired performance and design requirements of the shell, Alloy 825 has been recommended as the primary shell material. Alloy 825, which is a high-nickel austenitic alloy, is readily formable and weldable; reasonably priced for a sufficiently corrosion resistant material; and exhibits superior resistance to both general and localized corrosion compared to other ASME boiler and pressure vessel code materials. Titanium Grade 12 and Hastelloy C-4, which are also very corrosion resistant, have been recommended as back-up materials for the shell. However, the Titanium Grade 12 requires a greater degree of care in fabrication/welding, and the Hastelloy C-4 is more expensive than the Alloy 325.

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Activity 1.10.2.4.3 - Shield plug. The function of this component is to reduce the radiation dose so that the radiation workers can install the remote multipurpose canister lid closure device, namely the automatic welding apparatus. Thus, the plug material should be effective in shielding both the gamma and neutron radiations. From a design perspective, the plug material should be capable of withstanding normal and accident temperatures of up to 350°C for an extended time period, in hundreds of years. Furthermore, it has to be compatible with the spent nuclear fuel basket material and the outer shell.

Since the shield plug has no specific function relative to the waste package postclosure performance, degradation of this component during service is only a concern should retrieval of the spent fuel become necessary. Therefore, some degree of corrosion protection during the preclosure period may be desirable. This can be accomplished by using either stainless steel sheathing or a nickel plating. Since corrosion protection is unnecessary, either an unprotected iron based material or depleted uranium can be used as secondary materials for the multipurpose canister shield plug.

Activity 1.10.2.4.4 - Spent nuclear fuel basket (structural). The function of the basket is to provide structural separation of the spent nuclear fuel assemblies and to ensure that they remain in their original positions without interference as emplaced. The basket material is designed to withstand sufficient transportation loads (i.e., 9-m drop), and to withstand normal and accident temperatures of up to 350°C for a prolonged duration upon emplacement. Thus, the basket material should maintain structural integrity, and be capable of conducting heat away from the waste. In addition, it should be compatible with the basket criticality material and waste form.

In view of the above functional and design requirements, the basket material should possess sufficient strength and toughness, high thermal conductivity, superior fabricability/weldability, and excellent corrosion resistance. The fabrication process and the closure technique may exert a significant influence on the mechanical, microstructural and corrosion properties of this component. These requirements can most effectively be accomplished by using a corrosion resistant, American Society of Mechanical Engineers boiler and pressure vessel code material. The relatively corrosion resistant 316L stainless steel has been recommended as a primary choice due to its lower cost and satisfactory resistance to both general and localized corrosion.

Activity 1.10.2.4.5 - Spent nuclear fuel basket (criticality). The function of the criticality control component of the basket is to provide neutron absorption for a prolonged time period. Thus, the basket material should contain sufficient quantities of neutron absorbing element. This material should possess high strength, high toughness, and high thermal conductivity to enhance heat transfer from the spent fuel. In addition, the basket material should maintain its microstructural stability at temperatures of up to 350°C while in contact with the spent nuclear fuel assemblies.

It is necessary that the criticality control material remain intact for as long as possible, particularly after containment barriers breach. The addition of boron, a neutron absorber, to a relatively corrosion resistant material such as austenitic stainless steel can accomplish this

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goal. Therefore, the use of borated stainless steel has been recommended for the criticality control component of the spent nuclear fuel basket. The borated aluminum alloy has been identified as a secondary choice of material. However, aluminum alloys are susceptible to pitting corrosion and the possibility of galvanic corrosion due to its contact with the structural component material of the spent nuclear fuel basket.

Activity 1.10.2.4.6 - Filler material. A filler material may be required to provide enhanced heat transfer, criticality control, and chemical buffering for radionuclides. The material under consideration is a size graded iron shot. This material is designed to fill a substantial part of the space in and around the spent nuclear fuel assemblies to aid in transferring heat from the fuel rods. In addition, the use of filler material will eliminate the need for assuming complete water flooding in criticality calculations, and will provide chemical buffering of any water that may enter the waste package.

Activity 1.10.2.4.7 - Fill gas. The function of the fill gas is to provide an inert internal environment, thus minimizing the tendency for corrosion-related damage of internal components of the waste package prior to breach of the shell. Furthermore, it should act as a short-term thermal conductivity enhancer, and be compatible with construction materials for different components of the waste package. The primary choice of fill gas has been argon since it does not diffuse through the metallic containment barriers, is inert and inexpensive, and will not react in a moisture-containing gamma field to form deleterious radiolysis products. Helium has been identified as a secondary choice since it also exhibits the positive attributes of argon but does have the potential for diffusion through the shell wall over a period of time.

2.6.1.5 Design Activity 1.10.2.5 - Performance Evaluations

This section includes the progress made during the reporting period on performance of the container and the spent fuel waste form.

Activity 1.10.2.5.1 - Container oxidation and corrosion. Dry oxidation and aqueous corrosion of the outer corrosion-allowance containers were evaluated.

Dry oxidation data for iron-based materials in the 100° - 250°C range are almost nonexistent. Most of the data on dry oxidation are from atmospheric exposures over long periods in various environments including rural, semi-industrial, industrial, and marine. Data are available for many materials exposed for up to 20 years. The data, with the exception of those for marine environments, tend to fit an exponential equation with corrosion rates decreasing with time, suggesting the establishment of a protective film. (The chloride present in the mist in marine environments tends to inhibit the formation of protective films.) The time exponent usually falls between 0.3 and 0.6. Previously, this time effect was neglected in that a constant oxidation rate (20 µm/year) was provided. From the environmental data given in the American Society for Materials Handbook for carbon steels, an exponent of 0.57 was obtained. This would yield an expression for penetration, $P = 1.156 t^{0.57}$, where t is in days. Thus, the penetration for one year is 33 µm, for two years it is 50 µm, and for ten years it is

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124 μm , which agrees with the data. The average penetration rates are then 33, 25 and 12 $\mu\text{m}/\text{year}$, for one, two and ten years, respectively. The variation is on the order of ± 25 percent.

The American Society for Materials Handbook provides one set of data at elevated temperature, 454°C (850°F) and 538°C (1000°F), for air oxidation of carbon steels for about one year. (Similar data also are provided for a steam atmosphere.) The time exponent was about 0.3, suggesting that a more tenacious oxide film is developing at the higher temperatures than at the ambient temperatures discussed above. The penetration equations from the data provided are $P = 2.01 t^{0.33}$ for 454°C and $P = 5.35 t^{0.33}$ for 538°C. For one year, the penetrations would be 14 and 38 μm , respectively.

If the same process can be extrapolated to lower temperatures, then the penetration equation would follow the same form with the same exponent, but with a different coefficient. The coefficient can be estimated by using an Arrhenius approach (where the temperature effect is proportional to $e^{-Q/RT}$) by plotting the data vs $1/T$, where T is the absolute temperature, (Q is the activation energy, and R is the gas constant). The coefficients for 300°C and 200°C are 0.2 and 0.02, respectively. The activation energy for this process, which is presumably due to diffusion of oxygen through the oxide film, was calculated to be 57.1 kJ/mol. This compares favorably to data provided in a review by R. Freer, which gives the activation energy for the diffusion of oxygen in FeO as 83.6 kJ/mol and in Fe_3O_4 as 71 kJ/mol. The value of Q (57.1 kJ/mol), when divided by R , which is 8.3143 J/K-mol, yields a value of Q/R of 6870. Thus, the entire equation for penetration (in μm) can now be written as $P = 25,500 t^{0.33} e^{-6870/T}$. If an expression for penetration is needed in years, the equation becomes $P = 178,700 t(y)^{0.33} e^{-6870/T}$.

This approach provides much smaller penetration values for temperatures in the range of repository interest. For example, the penetration at 200°C would be 0.09, 0.19, 0.40, 0.86, and 1.84 μm , after 1, 10, 100, 1000, and 10,000 years, respectively. The error is likely to be larger because of the method of extrapolation. However, even at 100 percent error, these values are very low, which would make degradation by dry oxidation negligible.

The available data for corrosion of carbon steels in aqueous environments were also reviewed. Most of the data are for flowing river waters. These data follow a time dependency with an exponent ranging from 0.5 to 0.8. One set of data relate to static exposure in Gatun Lake for up to 16 years. This set of data was used by Westinghouse as their basis for design of waste packages in tuff. The time dependency was found to have an exponent of 0.47. From these data an equation was generated for penetration, $P = 200 t(y)^{0.47}$, with P in μm .

The Westinghouse (1982) report also estimates the effect of temperature using a very limited data set for corrosion rate of cast steel and iron in brine and seawater. A value was found of Q/R of 2850k. From a very sparse data set in a report by S. Pednekar (1987), a value of Q/R of 2300k was calculated. Thus the temperature effect from Westinghouse may represent conditions adequately for carbon steels in static waters. This report provides a combined penetration equation, $P = 2,525 t^{0.47} e^{-2850/T}$, where P is the penetration in mm, t is

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the time in years, and T is the temperature in degrees Kelvin. They estimated an error band of about +/- 25 percent. The penetration at 100°C would be 1.2, 3.6, 10.6, 31.2, and 92.0 mm for 1, 10, 100, 1000, and 10,000 years, respectively. The corrosion rate for these periods would then be 1.2, 0.36, 0.11, 0.03, and 0.01 mm/year (or 48, 14.4, 4.4, 1.2, and 0.37 mils/year). The calculated penetrations at 50°C would be 30 percent of those calculated at 100°C. The Westinghouse report also evaluates a pitting factor which is the ratio of pitting attack to general corrosion. The Gatun Lake data set yields a range from 2.6-3.4. (They then use a value of 4.0 for conservatism.) This is roughly consistent with values obtained for pitting factor by D. McCright of about 0.9-3.2. The pitting factor would be used as a multiple of the penetrations calculated using the above equation.

The recommended penetration equations can then be summarized as follows:

For high-temperature oxidation, $P = 178 t^{0.33} e^{-6870/T}$.

For general corrosion, $P = 2,525 t^{0.47} e^{-2850/T}$.

For general corrosion with a pitting factor, $P = 10,100 t^{0.47} e^{-2850/T}$.

Activity 1.10.2.5.2 - Waste package degradation by mechanical stress. Waste packages, especially degraded ones, may be damaged or breached by mechanical stresses. To guide future calculations, we have assessed possible sources of mechanical stress and their effects on waste packages.

Five sources of mechanical stress are considered:

1. A fault that intersects a waste package may slip and shear the package.
2. An earthquake or underground nuclear event may cause ground shaking, imposing acceleration loads on the package.
3. A large rock may fall on the package.
4. Lithostatic pressure may collapse the package.
5. Products of corrosion, which are larger than the original metal, may press against the backfill, imposing compressive forces on the package.

Analysis of these sources shows that the most important is forces due to products of corrosion. Fault shear and ground shaking are dismissed as being unlikely to cause failure because of their relatively small displacements and accelerations. Rock fall for a drift without backfill is being evaluated by the Waste Package Design group; it is thought to be unimportant for a backfilled drift because of the protection provided by the backfill. Lithostatic forces are smaller than those due to products of corrosion.

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It has been found that the robust containers currently under consideration must be seriously degraded before mechanical stress can cause failure. Buckling of the side of a container is predicted to occur at a wall thickness of 11.4 to 5.3 mm, depending on the effectiveness of the basket as a stiffener. The ends of the container will not buckle but must sustain tensile stresses of up to 153 to 710 MPa. If the container thins uniformly as a result of general corrosion, the ends of the container will probably fail before the side unless additional thickness is provided there.

Current designs for a metallic multibarrier waste package call for at least 9.5 mm of corrosion resistant material. This material alone has roughly enough thickness to sustain the expected mechanical stresses. Since this layer is expected to fail by localized and not general corrosion, failure as a direct result of mechanical stress will not significantly reduce the life of a waste package.

Fault Shear

Fault shear could severely damage a waste package. In a report entitled "Preliminary Near-Field Environment Report, Volume I: Technical Bases for EBS Design" (Wilder, 1993a), Wilder suggests such damage can be avoided by not placing waste packages in a fault zone. Damage by fault shear will thus occur only if waste packages are placed on an unrecognized fault. Even if this should happen, the waste packages are not in immediate danger. According to Wilder, the design basis underground nuclear explosion or earthquake allows for displacements of up to 50 mm horizontally and 20 mm vertically. These displacements are small enough that even borehole-emplaced packages would not be sheared by a single event. Drift emplacement provides large clearances around a waste package and thus allow large displacements. The most important fault in the vicinity of Yucca Mountain (as defined by Wilder), the Bare Mountain fault, has a slip rate of only 0.15 mm/year, so shearing of a drift emplaced waste package would take a long time.

Ground Shaking

Ground shaking is not expected to be intense enough to damage an undegraded waste package. The design basis earthquake has a vertical acceleration of 0.2g and an acceleration of 0.1g in each horizontal direction. These accelerations are smaller than those expected from handling incidents such as tipping. Shaking of a badly degraded package may produce damage, but dynamic calculations are necessary.

Rock Fall

The importance of falling rocks depends on whether the emplacement drift has been backfilled. Backfill will protect the waste packages by only allowing rocks to fall a short distance, distributing force, and absorbing energy. These effects greatly reduce the effects of falling rocks. Rock falls onto unprotected waste packages are under study by the Waste Package Design group. However, little degradation is expected before the drifts are backfilled, and the robust waste packages under consideration should be able to survive large rock falls without damage.

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Lithostatic Force

Lithostatic forces will be present only after the drift is backfilled. Tuff shows no tendency to creep under expected repository conditions (Wilder, 1993a), so the lithostatic pressure will be due only to the backfill and any fallen rock. However, the lithostatic pressure will be smaller than the pressure from products of corrosion, so we may consider only the latter.

Forces Due to Products of Corrosion

Several of the proposed designs for waste packages include a thick disposal container of carbon steel or cast iron. These materials expand significantly upon oxidation; oxidizing iron to Fe_2O_3 produces a 114 percent increase in volume. Some volume increase can be accommodated if the products of corrosion move into the interstices in the backfill. Especially for fine or densely packed backfill, however, the available volume is small and the backfill must be displaced.

The stress state in the backfill at the surface of the container may be approximated by a hydrostatic stress from the backfill plus a uniaxial compressive stress from the products of corrosion: $\sigma_{xx} = \sigma_{yy} = p_3$, $\sigma_{zz} = p_1$, $p_1 > p_3$, where the x and y directions are parallel to the surface of the waste package and the z direction is normal to the surface. All off-diagonal components are zero. The stress state is equivalent to that used in standard triaxial tests of the strength of soil, in which p_3 is the confining or all-around pressure and p_1 is the vertical pressure. In dry sand or gravel, shear failure occurs when

$$\frac{p_1}{p_3} = \frac{1 + \sin \phi}{1 - \sin \phi} \quad (2.6.1.5-1)$$

A value of $\phi = 35^\circ$, which is appropriate for a sandy gravel (Peck, 1974) was used. The confining pressure will be the lithostatic pressure, which is approximately $h\rho fg$, where h is the height of the overlying layer, ρ is the density of pore-free backfill material, f is the packing fraction, and g is the acceleration due to gravity. For waste packages 1.5 m in diameter, a 7.5 m drift, 1.5 m of invert, and 0.5 m of unfilled space at the top of the drift, there is 4.0 m of backfill on top of the packages. This is taken to be crushed tuff with a packing fraction of 0.74. (This is the packing fraction for close packing of spheres.) There may also be loads from fallen rock. Rocks of up to half the drift diameter may fall, so the load from a 3.75-m high block of solid rock is added. With $\rho = 2300 \text{ kg/m}^3$ (Wilder, 1993b) and $g = 9.806 \text{ m/s}^2$ (Weast, 1980), $p_3 = 150 \text{ kPa}$ and $p_1 = 560 \text{ kPa}$. To provide a safety factor, p_1 was doubled. The waste package must thus withstand pressures up to $q = 1.12 \text{ MPa}$.

As general corrosion thins the container, pressure from the products of corrosion may cause buckling of the cylindrical wall. The container was approximated as a thin-walled elastic cylinder. Such a cylinder will buckle (Roark and Young, 1975) at a pressure q , where

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$$q = \frac{Et/r}{1 + (\pi r/nl)^2/2} \left[\frac{1}{n^2 [1 + (nl/\pi r)^2]^2} + \frac{n^2 t^2 [1 + (\pi r/nl)^2]^2}{12 r^2 (1 - \nu^2)} \right] \quad (2.6.1.5-2)$$

Here E is Young's modulus, ν is Poisson's ratio, t is the wall thickness, r is the radius, l is the length, and n is the number of lobes for collapse. The equation applies only for $n \geq 2$. The actual buckling mode is expected to be that with the smallest q . It is assumed that $r = 0.75$ m, $l = 4$ m, $E = 210$ GPa, and $\nu = 0.3$ and found that, for $q = 1.12$ MPa, buckling occurs at $t = 11.4$ mm. The corresponding hoop stress is $-qr/t = -73$ MPa.

No credit is taken in Equation 2.6.1.5-2 for the basket, which will support the cylindrical shell along lines of contact. The area between supports may be approximated as a long, curved panel with hinged straight edges and free curved edges. The pressure for buckling is (Roark and Young, 1975)

$$q = \frac{Et^3 (\pi^2/\alpha^2 - 1)}{12 r^3 (1 - \nu^3)} \quad (2.6.1.5-3)$$

where 2α is the central angle of the panel. For a 21 pressurized-water reactor package, the widest span between contacts has $2\alpha = \text{Arctan}(5/3) - \text{Arctan}(3/5)$. The panel buckles at $t = 5.3$ mm and a hoop stress of -158 MPa. However, if there is a clearance between the basket and the container, buckling should be described by Equation 2.6.1.5-2. The extent of buckling will be limited by contact of the container with the basket, but the effective values of r and α may be changed so that Equation 2.6.1.5-3 is no longer conservative.

Force on the supports for the waste package may affect the thickness for buckling, but the change is expected to be small for three reasons. First, the total force on the panel discussed in the previous paragraph is 1.6 MN, but the weight of the waste, basket, and 9.5 mm inner barrier is only 0.27 MN for a 21 pressurized-water reactor package. Second, products of corrosion will tend to fill any available space under the package, thus transferring load from the supports. Third, the thickness required to prevent buckling is not linear as pressure varies only with its cube root.

The ends of the waste package will not buckle, but the stresses there are still of interest. The end is a continuous member, supported by the walls of the basket as well as the cylindrical outer wall, so the square part covering one opening in the basket was approximated by a plate with fixed edges. The maximum stress is

$$\sigma = Cqa^2/t^2 \quad (2.6.1.5-.4)$$

where $C = 0.3078$ and a is the spacing between basket walls. It has been assumed that $a = 240$ mm and that the thickness of the ends is the same as that of the side. For $t = 11.4$ mm, $\sigma = 153$ MPa; and for $t = 5.3$ mm, $\sigma = 710$ MPa. Membrane effects will reduce these stresses somewhat. The lower of these stresses is comparable to the yield strength of the materials under consideration.

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Activity 1.10.2.5.3 - Thermal degradation of fuel cladding. It is generally desirable to take credit for all available containment barriers because additional barriers tend to delay release and to distribute it over a longer time. For spent fuel, potential containment barriers include the fuel cladding. But if cladding credit is to be taken, the thermal exposure must not destroy the integrity of the cladding. To predict the effects of thermal exposure we modeled the durability of the cladding.

Disposal of spent fuel is much like dry storage, so a search was made of the literature on fuel storage for information on cladding degradation. The authors of a report entitled "Control of Degradation of Spent LWR Fuel During Dry Storage in an Inert Atmosphere" (Cunningham et al., 1987) assessed numerous mechanisms for cladding failure during storage and concluded that creep rupture by diffusion-controlled cavity growth is the most important. The U.S. Nuclear Regulatory Commission (NRC) reached similar conclusions (NRC, 1985). In diffusion-controlled cavity growth, tensile stresses cause lenticular cavities to form along the grain boundaries and grow by grain boundary diffusion of vacancies. Analysis of constitutive equations and conditions indicates that diffusion-controlled cavity growth also dominates during disposal. Past applications of this model have predicted unrealistically short lifetimes. Part of the goal in this effort was to apply the model without excessive conservatism. To do so, a model of diffusion-controlled cavity growth that includes the effects of microstructure was developed.

Analysis of the model gives a temperature-dependent damage accumulation rate. The rule of thumb that maximum cladding temperatures should be kept below 350°C was examined. For one calculation, the rule was surprisingly accurate. But for fuels that cool slowly or that have been damaged by long dry storage at high temperatures, the rule may not be conservative, so the use of damage accumulation integrals is recommended.

Cladding Failure by Diffusion-Controlled Cavity Growth

The method of damage accumulation was used: the amount of damage accumulated at time t , $D(t)$, is given by

$$D(t) = \int_0^t \frac{d\tau}{L(\tau)} \quad (2.6.1.5-5)$$

where L is the lifetime of the material under the conditions at time τ . When $D(t) = 1$, the material fails. The lower limit of integration is the time of fuel discharge, so the integral includes exposure during storage. In standard models of diffusion-controlled cavity growth (Raj and Ashby, 1975), failure occurs when cavities cover a certain area fraction of the grain boundaries. The lifetime L is

$$L = \frac{n\lambda^3 kT}{\delta D_{gb} \Omega \sigma m} \quad (2.6.1.5-6)$$

where n is a constant that depends on cavity shape and diffusion geometry, λ is the cavity spacing, k is Boltzmann's constant, T is temperature, δ is the effective thickness of the grain boundary, D_{gb} is the grain boundary diffusivity, Ω is the atomic volume, σ is the hoop stress

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in the cladding, and m is a constant that depends on microstructure. The values of each of these factors are discussed below.

Several factors are straightforward. The atomic volume Ω is the volume of the crystallographic unit cell divided by the number of atoms per cell: $\Omega = 2.327 \times 10^{-29} \text{ m}^3$. If the gas inside the fuel rod is ideal and thermal expansion of solids is negligible, T/σ is a constant. The value of σ depends on the geometry of the fuel rod, the burnup of the fuel, and the amount of fission gas release. Einziger and Kohli (1984) state that $\sigma = 90 \text{ MPa}$ at $T = 623 \text{ K}$ (350°C) is conservative for most fuel, so these values were used. The cavity spacing $\lambda = 10 \text{ }\mu\text{m}$ from Schwartz and Witte (1987) and NRC (1985) was taken.

Grain-boundary diffusivity is normally reported as δD_{gb} , but literature on diffusion-controlled cavity growth often separates the factors. Following Schwartz and Witte (1987) and NRC (1985), $\delta = 9.69 \times 10^{-10}$ was used. For diffusivity, $D_{gb} = 5.9 \times 10^{-6} \exp[(-131 \text{ kJ/mol})/RT] \text{ m}^2/\text{s}$, where R is the gas constant was used. At temperatures of interest, this is the largest of the reviewed values.

From analysis of the diffusion geometry, the geometric constant n , for a lenticular cavity, is

$$n = \frac{3\sqrt{\pi}}{32} \frac{F_v(\theta)}{F_b(\theta)^{3/2}} \int_{A_i}^{A_f} \frac{dA}{f(A)} \quad (2.6.1.5-7)$$

where

$$F_v(\theta) = (2\pi/3) (2 - 3\cos\theta + \cos^3\theta) \quad , \quad (2.6.1.5-8)$$

$$F_b(\theta) = \pi \sin^2\theta \quad , \quad (2.6.1.5-9)$$

and

$$f(A) = \frac{(1 - \sqrt{A_c/A})(1 - A)}{\sqrt{A} [A(1 - A/4) - 3/4 - (\ln A)/2]} \quad . \quad (2.6.1.5-10)$$

Here F_v and F_b are defined so that $F_v \rho^3$ is the volume of the cavity and $F_b \rho^2$ is the area of the grain boundary that is cut out by the cavity. The function f takes account for the geometric effects of radial diffusion to the cavity. (NOTE: Raj and Ashby (1975) and NRC (1985) give slightly different equations for $f(A)$. Raj and Ashby's equation is clearly in error, since it is inconsistent with other equations in the paper. The form of the equation used by NRC (1985) suggests the derivation may be in error, but since some variables are not defined, that cannot be determined with certainty. Schwartz and Witte (1987) gives an equation with this form but it fails to mention, let alone treat, the singularity discussed below. Constants A_i and A_f are the initial and final values of the fractional areas that are decohered, that is, the values upon fuel discharge and at failure. Similar to NRC (1985) it was assumed that failure occurs at $A_f = 0.15$. This value is fairly conservative; some authors have used values as large as 0.5. Some authors have suggested that A_i should be A_c , the fractional area that is decohered by cavities of the critical size, where

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$$A_c = \left(\frac{4\gamma_s \sin \theta}{\sigma \lambda} \right)^2 . \quad (2.6.1.5-11)$$

But such cavities have zero driving force for growth, so n is infinite. To avoid this singularity in n , A_i was taken to be equal to $2A_c$. For reasonable choices of A_i , the exact value has only a small effect on n . For surface energies, Pescatore, et al. (1990) were followed by taking $\gamma_s = 2\gamma_{gb} = 2 \text{ J/m}^2$.

The constant m describes the effect of microstructure. Standard models of diffusion-controlled cavity growth assume a uniaxial tensile stress and grain boundaries that are normal to the stress axis. But this geometry is inappropriate for cold-formed cladding, so the model was modified. The cavity growth rate is proportional to the normal traction on the grain boundary. The principal stresses used are those for a pressurized, thin-walled tube: σ in the circumferential direction, $\sigma/2$ in the axial direction, and 0 in the radial direction. The average normal traction over the surface of an ellipsoidal grain with semi-axis lengths of a , b , and c in the circumferential, axial, and radial directions was then calculated. The constant m is the ratio of the average normal traction to the hoop stress σ ; m depends on a/c and b/c .

For cold forming, it can be assumed that the grains have a constant volume (the product abc is a constant) and that no grain-boundary sliding occurs. Under these conditions, $b/c = (a/c)^2$. From photomicrographs of cladding, it was estimated that $a/c = 5$. For conservatism, $a/c = 3$ was used and resulted in $m = 0.164521$. The dependence of m on a/c is shown in Figure 2.6-2.

Using the data above, the lifetime L was calculated as a function of temperature; the results are plotted in Figure 2.6-3. Cladding in a repository was also simulated. The repository contained 21 pressurized-water reactor packages in 7.62-m (25-ft) drifts with a thermal loading of 282 kW/ha (114 kW/acre); equivalently, the mass loading was 247 MTU/ha (100 MTU/acre). The characteristics were 42.21 GWd/MTU burnup, 3.92 percent ^{235}U initial enrichment, and emplacement 22.48 years after discharge. The temperature and damage function D are plotted in Figure 2.6-4. The damage occurs mostly during the first 100 years; as the temperature drops, damage accumulates slowly because grain boundary diffusion is slow.

For convenience, repository designs have often been evaluated by the rule that the cladding temperature must not exceed 350°C. The previous calculation was modified to test that rule, increasing the temperature by fixed increments until failure occurred at 10,000 years. This criterion was satisfied for a peak temperature of 354.9°C, which is in surprising agreement with the temperature-limit rule. For other fuels and repository designs the methods may not agree so well. The discrepancy may be especially large for fuel that has been damaged by dry storage at high temperatures.

Figure 2.6-2. Microstructure constant m as a function of ratio a/c
 (where a and c are the grain semiaxis lengths in the circumferential and radial directions)

Figure 2.6-3. Predicted cladding life as a function of temperature for isothermal exposure

Figure 2.6-4. Temperature and fraction of cladding life consumed as functions of time for one repository design

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2.6.2 Postemplacement Near-Field Environment (SCP Section 8.3.4.2)

2.6.2.1 Design Activity 1.10.1.1 - Consideration of 10 CFR Part 60.135 (a) Factor

A meeting was held in Las Vegas, Nevada, on April 16, 1993, to discuss possible revision of the Yucca Mountain Site Characterization Project (YMP) thermal goals originally detailed in the Site Characterization Plan (SCP). Some of the goals need to be changed to reflect the greater diversity of repository and waste package designs being considered in the Advanced Conceptual Design phase.

A Thermal Goals Workshop was held on May 12, 1993, in Las Vegas, Nevada. The goals were established in the SCP in 1988, but since then new considerations in the repository design, and improved knowledge of the site, necessitate review of the goals to determine: the original rationale for the goal; whether the individual goals are still relevant; and if the goals need to be changed and what the changes should be. The recommendations were incorporated into a report prepared for YMPO.

In support of the thermal loading systems study, Lawrence Livermore National Laboratory (LLNL) staff developed a new suite of repository-unsaturated zone-saturated zone-scale models for repository areas of 230, 301, 460, 709, and 1050 ha (570, 744, 1139, 1755, and 2598 acres). For 63,000 MTU of spent nuclear fuel, these repository areas correspond to areal mass loadings of 273, 206, 136.6, 88.7, and 60.3 MTU/ha (110.5, 83.4, 55.3, 35.9, and 24.4 MTU/acre). The models employ a relatively fine gridblock spacing at the outer perimeter of the repository in order to more accurately account for the effect of edge-cooling. A "youngest fuel first" receipt scenario with a ten year cut-off for the youngest fuel [referred to as YFF(10)] is being assumed. The calculations also account for the emplaced inventory of boiling water reactor waste packages containing 40 assemblies and pressurized-water reactor waste packages containing 21 assemblies.

Also, in support of the thermal loading systems study, LLNL staff developed a preprocessor "PBHEAT" that calculates the heat generation tables for the V-TOUGH code. This preprocessor incorporates the GETHT6 subroutine developed by the M&O which calculates kilowatts per metric ton uranium for a given fuel type (pressurized-water reactor or boiling water reactor), age, burnup, and enrichment. PBHEAT is capable of producing a blended heat generation curve (averaged over the entire repository area), based on the yearly increments of pressurized-water reactor and boiling water reactor waste packages and the yearly averaged spent nuclear fuel ages, burnups, and enrichments for each of these increments. Rather than assuming that all of the heat generation instantaneously begins at $t = 0$ year, the heat generation curve produced by PBHEAT accounts for the "ramping up" of the heat output that occurs over the emplacement period. PBHEAT can also be used to calculate the heat generation curve for specific increments of the emplaced waste packages, thereby accounting for the spatial variability of heat generation within the repository. For 30-year-old pressurized-water reactors with a burnup of 33 GWd/MTU and an enrichment of 3.2 percent, PBHEAT produced nearly the identical heat generation curve produced by the pressurized-water reactor heat generation preprocessor, HEATCAL, which was developed several years ago at LLNL.

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A YMP Colloid Workshop was held May 3-5, 1993, in Santa Fe, New Mexico, where results of the analysis of inorganic colloids in Nevada Test Site ground waters were provided. A strategy for addressing issues related to colloid transport of radionuclides was developed. An initial draft of a strategy document is currently being edited.

2.6.2.2 Study 1.10.4.1 - Characterize Chemical and Mineralogical Changes in the Postemplacement Environment

The revised Study Plan 8.3.4.2.4.1, "Characterization of the Chemical and Mineralogical Changes in the Post-Emplacement Environment," was returned by the LLNL editor, with several editorial suggestions. The comments were being addressed.

The April and June Geochemistry Integration Task meetings were participated in. They focused on the colloid workshop at Los Alamos National Laboratory (Los Alamos) and developing a Project strategy for addressing the issue of colloidal mediated transport of radionuclides.

Activity 1.10.4.1.1 - Rock-water interactions at elevated temperatures. The contract for the work on the New Zealand natural analog site was initiated. A visit by two LLNL scientists to evaluate several potential sites for conducting validation activities using EQ3/6 was completed. A prioritized list of site studies has been developed, and a draft memorandum describing the site work has been written. The screening process to select specific sites for study has been started, with initial work focusing on Champagne Pool, where fluid mixing is occurring. The first sampling of waters and solids has been done by the Crown Research Institute collaborators and analysis of the materials is under way. When the results are available, modeling of the mixing process and associated precipitation of metal phases will begin. Simultaneously, evaluation of the GEMBOCHS data base is being done at LLNL to determine what additional solid phases may be required to adequately simulate the mixing/precipitation process. Particular consideration is being placed on the sulfides, oxides, and hydroxides of antimony, iron, and other metals that may participate in the precipitation process. Staff again visited New Zealand in August 1993. The purpose of this visit was to finalize methods for transferring data from one organization to the other, and for establishing arrangements for collaborative activities with the companies involved with the day-to-day operation of the geothermal fields and drilling activities. Data are also being collected and processed to develop a three-dimensional model of the geothermal field. This model will form the basis for understanding the areal distribution of properties and for selecting additional sites for subsurface studies. Discussions are under way with the principal corporations controlling proprietary data to schedule a meeting to discuss how best to handle requests for such information. Discussions were also held concerning the first phase modeling activities. Samples collected are being analyzed and used in initial modeling exercises with the use of the EQ3/6 data base. Activity diagrams were compared with previous studies to ensure that consistency was maintained.

Models of mineral evolution in the vicinity of waste packages were further developed. A reference set of computations that will be used as a comparison for calculations involving

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flow and transport has been initiated, using UE-25 J#13 water chemistry and rock systems idealized from the known stratigraphy. The current calculations do not consider the role of moving water. Computations have also been initiated in which the dissolution and precipitation kinetics of various silicates are used to bound estimates of the rates at which mineralogical and chemical equilibrium may be achieved in the vicinity of waste packages, and also in the areas surrounding the repository in the altered zone. Initial calculations indicate that local equilibrium will be achieved in periods from a few months to a few years at the nominal SCP areal power density, and at higher thermal loads, for most regions. The exceptions are those areas nearest emplacement drifts where fluid velocities may be high, and those areas that never exceed approximately 60°C.

The samples obtained of the fracture system at the Large Block facility in late June were sectioned and have been submitted for analysis. These are being evaluated for mineralogical and petrological properties.

Activity 1.10.4.1.2 - Effect of grout, concrete, and other repository materials on water composition. This activity is now reported under 1.10.4.5.1 as a result of the Rev. 9 revision of the Site Characterization Program Baseline.

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

Activity 1.10.4.1.6 - Effects of container and borehole liner corrosion products on water chemistry. No progress during the reporting period; this was an unfunded activity.

Activity 1.10.4.1.7 - Numerical analysis and modeling of rock-water interaction. No progress during the reporting period; this was an unfunded activity. This activity is also reported under 1.10.4.5.1, because the activity was divided between geochemistry and man-made material activities (in Site Characterization Program Baseline, Rev. 8).

Forecast: The study plan is scheduled to be sent to YMPO. Work will continue on modeling the evolution of mineralogical properties and water chemistry. Emphasis is being placed on the effects of geochemical processes on hydrological properties. Testing modeling capabilities on field work will continue. Emphasis will be placed on developing guidelines for selecting modeling strategies where thermodynamic data or field information are not complete. Experimental studies of water-rock interaction will be conducted using vitric material in environment of low relative humidity. This information will allow completion of characterization of reaction processes likely to occur in the vicinity of the repository. Evaluation and development of codes capable of coupling hydrology and chemistry will continue, with the goal of designing experiments against which codes can be tested.

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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. Study Plan 8.3.4.2.4.2, "Hydrological Properties of Waste Package Environment," is being prepared and will be submitted for approval in FY 1994.

Activity 1.10.4.2.2 - Two-phase fluid system properties. Work continues to measure electrical resistivity as a function of moisture content of Topopah Spring Tuff samples from USW GU-4 and USW GU-3 holes at room temperature, using UE-25 J#13 water as pore fluid. The purpose of following this experimental procedure is to determine the effect of the electrical conductivity of pore fluid on the relationship between the bulk electrical conductivity of a rock sample and the degree of saturation in it. The samples from USW GU-3 are being used for the high temperature measurements. For the USW GU-3 samples, the wetting phase measurements at 40°C have been completed, and the drying phase measurements at 40°C were started. The preparation of samples machined parallel to the core axis was also started. It was decided to use a humidity chamber to hold the moisture content in a sample when it is at high temperature. The measured bulk resistivity using UE-25 J#13 water as pore fluid at water saturation levels less than 80 percent is very similar to that when distilled water is used as pore fluid. When the saturation level is greater than 80 percent, the bulk electrical conductivity using UE-25 J#13 water as pore fluid did not decrease with respect to increase of water saturation, as was observed when distilled water was used as pore fluid. The electrical conductivity of UE-25 J#13 water at high temperatures has been determined to be near 100°C.

The determination of electrical resistivity as a function of water saturation using disc samples from USW G-4 core at room temperature was completed and the measurement at 40°C was started. These measurements included wetting and drying cycles, using UE-25 J#13 water and distilled water, on samples machined parallel and perpendicular to the axis of the original core section. Very little anisotropy in the measured electrical conductivity with respect to the core axis was found. The measurement of electrical conductivity as a function of frequency within the range of water saturation from 0 to 50 percent was completed for the USW G-4 sample. The data are being analyzed.

Work continued on the experiment to determine the moisture retention curve and one-dimensional imbibition using USW G-4 core. The data from this experiment will be used for calculating relative permeability as a function of water saturation. In the one-dimensional imbibition experiment, UE-25 J#13 water was introduced to the bottom of a sample that is 2.54 cm in diameter, and 10 cm long. The water was imbibed into the sample against gravity. Eight pairs of electrodes were mounted along the axis of the sample to determine the distribution of moisture content as a function of time. The imbibition rate of water was determined from the water level in a burette. The samples are at 90 percent relative humidity at 25°C. The wetting phase of the moisture retention curve at 25°C was completed. The sample was saturated with water, some of which will be extracted for chemical analysis. The Si concentration in the water is about five times that of virgin UE-25 J#13 water, indicating rock-water interaction during the six-week experiment at room temperature. To improve the accuracy of determining water saturation using electrical resistivity measurements during

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imbibition, a rectangular plate sample from USW G-4 core was prepared. A four electrode method will be used to determine electrical resistivity. The samples are in the drying phase. Data analysis is continuing.

Work continued on an experiment to determine the effect of fracture surface coatings on the imbibition of water into the matrix. Eight Topopah Spring Tuff samples machined from outcrops from Busted Butte, Nevada, were prepared for this purpose. Work progresses to determine the mineralogy of the coating material, the pore size distribution in the coating layers, and the porosity of the samples.

An intact Topopah Spring Tuff sample from the USW G-4 hole to be used to determine saturated water permeability has been put into a pressure vessel under a confining pressure of about 5 MPa. The sample is being resaturated with UE-25 J#13 water in the pressure vessel. The pore water pressure will be brought to equilibrium before measuring the water permeability.

Work continued on the analysis of thermohydrological behavior for a wide range of thermal loading conditions and hydrological properties. This analysis has been conducted at a variety of scales, including the mountain scale, subrepository scale, and drift-scale. Analyses have demonstrated that the only significant source of liquid water is from nonequilibrium fracture flow from three potential origins: meteoric sources, condensate generated under boiling conditions, and condensate generated under sub-boiling conditions.

The first source of liquid water arises from the ambient system; the second and third sources are generated by repository heat. Buoyant vapor flow, occurring either on a subrepository scale or on a mountain scale, may play an important role in the generation of the second and third sources of liquid water. Zones of sharply contrasting bulk permeability, k_b , are also found to influence condensate generation and drainage, both under boiling and subboiling conditions. Of particular concern are conditions that promote the focusing of vapor flow and condensate drainage, which could cause persistent two-phase conditions (often referred to as the heat-pipe effect) in the vicinity of waste packages. Repository heat can generate a mobile liquid phase in fractures even if temperatures are below the boiling point.

In addition to generating condensate flow, repository heat can redistribute the liquid saturation in the unsaturated zone, causing regions of net dryout below the repository and saturation buildup above the repository. These changes in the saturation distribution can impact ambient fracture flow, possibly amplifying the effects of natural infiltration in regions of saturation buildup and attenuating those effects in regions of net dryout. For high areal mass loadings, expressed in MTU/ha (or MTU/acre) that result in significant dryout, mountain-scale, buoyant, vapor flow can also increase the rate at which the dryout zone is rewetted. Repository-scale analyses have indicated that repository-heat-driven changes in the saturation distribution can persist for more than 100,000 years, even for low areal mass loadings that never drive temperatures close to the boiling point.

It is important to note that repository-scale analyses assume the repository thermal load to be uniformly distributed over a disk-shaped area with areally uniform thermohydrological

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properties. The vertical distribution of thermohydrological properties was included, assuming the major hydrostratigraphic units are horizontal. Effectively, the results of those calculations are representative of averaged, mountain-scale, thermohydrological behavior. How the spatial variability of heating conditions and hydrological properties may cause local thermohydrological behavior to deviate from averaged, mountain-scale behavior have been examined. The conditions under which buoyant, vapor flow begin to dominate hydrological and thermal behavior for both sub-boiling and above-boiling thermal loads have been examined.

Thermal Loading Approach

The extent to which the three major sources of fracture flow may impact waste package performance and radionuclide migration depends on ambient site conditions as well as on the thermal-loading strategy that will eventually be adopted for the MGDS at Yucca Mountain. With respect to repository-heat-driven thermohydrological performance, there are three primary thermal loading approaches. These three approaches are best framed as three fundamental questions:

1. Can the thermal load be limited and distributed so that it has a negligible impact on hydrological performance of the MGDS?
2. For intermediate thermal loads, will the impact of thermohydrological processes and our understanding of those processes allow us to demonstrate that the MGDS meets regulatory compliance?
3. For higher thermal loads, that have the potential of generating extended-dry conditions, will the impact of thermohydrological processes and our understanding of those processes allow us to demonstrate that the MGDS meets regulatory compliance?

The first thermal loading strategy is to minimize the hydrological impact of repository heat so that the primary concern in assessing hydrological performance is the ambient hydrological system. The motivation for this approach is to avoid any potentially adverse effects of repository heat. The second approach is the baseline case that has been under consideration. The third approach would be to demonstrate that, for some period of time, repository heat is capable of dominating the ambient system with above-boiling conditions surrounding the repository. The primary motivations for this approach are to reduce the sensitivity of repository performance to hydrological variability; extend the period of radionuclide containment in the engineered barrier system; and reduce the probability of water contacting waste packages and the flow rates associated with transport.

Important uncertainties related to evaluating these options are the influence of buoyant, gas-phase convection and hydrogeological heterogeneity that may focus vapor flow and condensate drainage. The influence of these processes will largely determine what thermal loads are sufficiently "hot" (or whether any such thermal loads exist) to allow demonstration of that extended-dry condition that will prevail for some time in the vicinity of waste packages.

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Use of Hypothesis Testing in Model Validation

A broad range of parameters and conditions are important in predicting thermohydrological performance. These include:

- (1) whether heat conduction dominates heat flow,
- (2) whether a region of above-boiling temperatures surrounding the repository corresponds to the absence of mobile liquid water at the waste package environment,
- (3) whether fracture density and connectivity are sufficient to promote rock dryout due to boiling and condensate shedding,
- (4) whether rewetting of the dryout zone back to ambient saturation lags significantly behind the end of the boiling period,
- (5) whether mountain-scale, buoyant, gas-phase convection may eventually dominate moisture movement in the unsaturated zone,
- (6) whether sub-repository-scale, buoyant, gas-phase convection dominates moisture movement at the repository, and
- (7) whether heterogeneity results in focusing enough vapor flow and condensate drainage to cause persistent local liquid flow at the waste package environment.

The first three hypotheses provide the basis for reliably predicting the spatial extent of the dryout zone surrounding the repository. The fourth hypothesis provides the basis for predicting how long the dryout zone persists. Demonstrating that hypotheses (5) through (7) are false is favorable for both above-boiling and sub-boiling performance. By showing that hypotheses (5) and (6) are false, a major potential source of fracture flow, particularly for sub-boiling conditions, as well as a potential mechanism for building up the saturation above the repository and re-wetting the dryout zone will be eliminated. By showing that hypothesis (7) is false, a major potential source of fracture flow for both sub-boiling and above-boiling conditions will be eliminated.

Resolution of hypotheses (1), (5), (6), and (7) is important even if temperatures never exceed the boiling point. Mountain-scale, buoyant, gas-phase convection will dominate heat flow only for a very large vapor flux that results in a large saturation buildup above the repository and/or a large condensate drainage flux in fractures. Therefore, hypotheses (1) and (5) are important for all areal mass loadings. Hypothesis (6) is particularly important for a thermal loading strategy that relies on a sub-boiling thermal load having a negligible impact on hydrological performance. Hypothesis (7) is important for all areal mass loadings, because focused vapor flow and condensate drainage can cause persistent liquid flow at the waste package environment for both sub-boiling and boiling conditions.

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Mountain-Scale and Sub-Repository-Scale, Buoyant, Gas-Phase Flow

The repository-scale, unsaturated zone-saturated zone model has been used to study the thermohydrological impact of mountain-scale, buoyant, gas-phase flow over a wide range of k_b and areal mass loading, including 67, 121.5, and 382 MTU/ha (27.1, 49.2 [the reference SCP-CDR thermal load], and 154.7 MTU/acre). For a broad suite of cases, a homogeneous and isotropic k_b distribution was considered in the unsaturated zone and saturated zone. The impact of a layered, heterogeneous k_b distribution has also been considered. With the cross-sectional, drift-scale model, the thermohydrological impact of sub-repository-scale, buoyant, gas-phase flow over a wide range of k_b and areal mass loading, including 33.3, 67, 121.5, and 382 MTU/ha (13.5, 27.1, 49.2, and 154.7 MTU/acre) was investigated.

Mountain-scale, buoyant, gas-phase convection appears to occur within fracture networks having a connectivity with length-scale comparable to the unsaturated zone thickness and repository width. Sub-repository-scale, buoyant, gas-phase convection is predicted within fracture networks having a connectivity with length-scale comparable to the distance between the hot and cold regions of the repository. Buoyant, gas-phase, convection cells are predicted as the warmer, less dense column of gas within the footprint of the heated region is displaced by the cooler, denser column of gas outside of this region. As the initially cooler gas is heated, its relative humidity is lowered, causing it to evaporate water below the repository. The model results show that warm moist air is convected upward to where it cools above the repository, generating condensate that drains down fractures back toward the repository and/or is imbibed by the matrix, causing a saturation buildup above the repository. Because water removed below the repository may be replenished by water imbibed from the saturated zone, mountain-scale, buoyant, the modeling results suggest that vapor flow can result in a net saturation buildup in the unsaturated zone. Results support that mountain-scale, buoyant, vapor flow can dominate moisture movement on the order of 100,000 years.

Model results show that sub-repository-scale, buoyant gas-phase convection will continue as long as significant temperature differences persist within the repository, dominating moisture movement for up to 1000 years for a center-to-center drift spacing of 38.4 m. These effects will persist longer for larger drift spacing. Sub-repository-scale, buoyant, vapor flow can move significant quantities of moisture, resulting in persistent dripping onto waste packages for temperatures that are well below the boiling point. For an areal mass loading of 33.3 MTU/ha (13.5 MTU/acre), which yields an areal power density of 24.7 kW/ha (10 kW/acre), for 30-year-old spent nuclear fuel, modeling results show that sub-repository-scale, buoyant vapor flow can drive significant moisture movement even though the peak drift wall temperature is only 42°C.

By considering a wide range in bulk permeability k_b , the threshold k_b (called k_b^{hyd}) was identified at which buoyant, vapor convection begins to dominate hydrological behavior, and the threshold k_b (called k_b^{th}) at which this convection begins to dominate thermal behavior. It was found that k_b^{hyd} is roughly the same for mountain-scale and sub-repository-scale, buoyant, gas-phase flow. It was also found that k_b^{th} is generally an order of magnitude larger than k_b^{hyd} . The development of a large above-boiling zone is found to suppress the effects of buoyant vapor flow, both on the mountain scale and sub-repository scale.

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Focused Vapor Flow and Condensate Drainage Due to Heterogeneity

Two models were used to model focused vapor flow and condensate drainage which arise due to hydrogeological heterogeneity. These include the drift-scale model that accounts for the actual cross-sectional geometry of heat producing waste packages and the emplacement drifts, and the cross-sectional, uniform, heat flow model that smears the repository heat load, but is useful in investigating the effects of heterogeneity with a length-scale larger than the drift spacing. With the drift-scale model, it was assumed that a vertically oriented, high permeability zone intersects the emplacement drift directly over a waste package. With the cross-sectional, uniform, heat flow model, the sensitivity of focused vapor and condensate flow to the spacing between the highly permeable zones was investigated.

Zones of sharply contrasting k_b are found to influence vapor flow and the resulting condensate generation and drainage. It was found that if the contrast in k_b between the high- k_b zone and the rest of the rock surrounding the drift (called the nominal- k_b zone) is sufficiently large, then the p_g differential between these zones will drive water vapor back toward the drift and into the high- k_b zone. In effect, the emplacement drift functions as a manifold that enhances the gas-phase communication between the high- k_b and nominal- k_b zones. If enough water vapor is focused into the high- k_b zone, then the resulting condensate generation and drainage back down that zone may result in persistent two-phase conditions at the edge of the drift and water dripping onto the waste packages. These effects can occur under both sub-boiling and boiling conditions. Because the cross-sectional, uniform, heat flow model under represents the local h in the vicinity of waste packages, it tends to overpredict the duration of two-phase conditions near the emplacement drifts.

The degree of vapor flow focusing into the high- k_b zone, and the resulting duration of two-phase conditions at the repository horizon depend on three factors. First, k_b in the nominally fractured zone must be large enough not to significantly throttle the rate of vapor generation due to boiling (or due to evaporation under sub-boiling conditions). Second, a large contrast in k_b between the high- and nominal- k_b zones results in a gas-phase pressure (p_g), differential between these zones that preferentially drives vapor flow into the high- k_b zone. If enough vapor enters and condenses in the high- k_b zone, the return condensate flux will be large enough to maintain two-phase conditions at the repository horizon, possibly resulting in dripping onto waste packages. Third, there must be sufficient spacing between the high- k_b zones to delay, or minimize, the interference between the high- k_b zones with respect to the p_g distribution. Larger spacing between high- k_b zones allows a greater p_g buildup within the nominal- k_b zone, and increases the duration of this buildup. Moreover, larger spacing allows a greater volume of vapor generation to be focused into the high- k_b zone.

Of course, the examples considered thus far are highly idealized relative to the complex geometry of real fracture networks, but they illustrates the principle that large contrasts in k_b between neighboring zones can result in focusing of vapor flow and condensate drainage, and, hence, persistent dripping onto waste packages. They also illustrate the principle that for a given contrast in k_b , the duration of two-phase conditions increases with spacing between the high- k_b zones. Effectively, the high- k_b zones are competing for a finite quantity of vapor

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flow and condensate generation. Consequently, there is a trade-off between the duration of two-phase conditions and the number of locations where such conditions can occur in the repository. If there are too many such zones, there will be insufficient condensate focusing to cause persistent two-phase conditions at the repository horizon. The degree of focusing necessary to cause persistent two-phase conditions limits the number of locations where such conditions can occur.

In general, regardless of how it is generated, repository-heat-driven, condensate flow can drain away from the boiling zone, can drain back toward the boiling zone, can be imbibed by the matrix. Because the small matrix permeability, k_m , limits the rate of matrix imbibition, modeling results suggest that condensate drainage down fractures persists for considerable distances before being imbibed by the matrix. Note that the Equivalent Continuum Model used in these calculations does not explicitly represent this nonequilibrium drainage in fractures. Below the boiling zone, condensate drainage is away from the boiling zone, enhancing the dryout rate. Above the boiling zone, condensate tends to drain back toward the boiling zone, where it reboils, thereby retarding the net rate of dryout. Until boiling reduces the liquid saturation to zero, temperatures will be determined by two-phase thermodynamic equilibrium. The effect of vapor pressure lowering (which results from surface forces between the water and the matrix) can make it difficult to reduce the liquid saturation in the matrix to zero even though temperatures may be well above the nominal boiling point. Under such conditions, the fractures are likely to be completely free of mobile liquid water. Immobile water, tightly held by surface forces, may be present in the rock at temperatures above the boiling point.

It should be noted that very extreme examples of heterogeneity may have been considered. However, the same degree of heterogeneity was considered for a wide range of thermal loads, yielding very different outcomes. The two-phase effects of focused vapor flow and condensate drainage are seen to be more persistent in the vicinity of waste packages for marginal boiling cases, and continue long after temperatures have dropped below the boiling point. For increasing areal mass loading, the effects of focused vapor flow and condensate drainage were decreasingly persistent. For several extreme examples of heterogeneity, an areal mass loading of 121.5 MTU/ha (49.2 MTU/acre) (the reference SCP-CDR thermal load), resulted in two-phase conditions (with a mobile liquid phase in the fractures) for more than 1500 years at the emplacement drift, long after temperatures had dropped below boiling. For exactly the same degree of heterogeneity and an areal mass loading of 382 MTU/ha (154.7 MTU/acre), two-phase conditions at the emplacement drift ceased within nine years, and the effects of focused vapor and condensate drainage virtually vanished in the far-field long before temperatures dropped below the boiling point. Work continues to address condensate focusing that arises from preferential, gas-phase focusing. In future work, condensate focusing that arises from preferential, liquid-phase focusing of condensate, as well as from combinations of gas-phase and liquid-phase focusing that include the impact of climatological change will be addressed. The potential impact that climatological change may have on liquid-phase flow focusing will increase with time as the decaying heat load from the repository causes the mean condensate flux to decrease.

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Forecast: Modeling activities will continue. Study Plan 8.3.4.2.4.2 will be submitted to YMPO for approval.

Activity 1.10.4.2.3 - Numerical analysis of flow and transport in laboratory systems.
At the Performance Assessment Model Validation Meeting held in Las Vegas, Nevada, on June 29, 1993, presentations were made on the following subjects: Repository-Heat-Driven Hydrothermal Flow: Modeling and Analysis (Buscheck); Analytical Expressions Quantifying the Influence of Convection on Fluid and Heat Flow (Nitao); and Modeling Statistical Variability in Condensate Drainage (Nitao).

Forecast: The work of building up a data base of electrical resistivity as a function of water saturation will continue. Laboratory model validation experiments will be started.

2.6.2.4 Study 1.10.4.3 - Characterization of the Geomechanical Attributes of the Waste Package Environment

Study Plan 8.3.4.2.4.3 was approved by YMPO on December 11, 1992, and sent to NRC on December 31, 1992. The NRC accepted the study plan in a letter to the Office of Civilian Radioactive Waste Management (OCRWM) dated April 21, 1993, and posed four questions. The OCRWM responded to the NRC questions in a letter dated September 2, 1993. A response to NRC comments was prepared and forwarded to YMPO. This response included a description of proposed revisions to the study plan scheduled for FY 1995. In addition, a draft Activity Plan for Geomechanical Investigations has been prepared.

Set-up of laboratory facilities for geomechanics testing of rock samples has been started. Emphasis is on apparatus to support the Large Block Test to determine the effect of the cristobalite behavior at temperatures of 200° - 250°C on the mechanical properties of the rock.

Thin sections of several samples of Topopah Spring Tuff were prepared from core ends of samples to be tested on the geochemical and hydrologic tasks and a set of approximately 100 images of the microstructure of Topopah Spring Tuff were produced at a variety of magnifications in the range 50x to 1000x. The images are of samples taken from holes USW GU-3 and USW G-4. The purpose of this imaging of the microstructure is to gain quantitative information on the pore structure of the rock. The images were digitized and stored on computer disks, and two-point spatial correlation functions were computed for many of them. This function is a statistical way to measure the geometry of the pore space and provides the basis for estimating several parameters of interest such as local distribution of specific surface area and local estimates of pore size and connectivity. In addition, standard morphological measurements were made on several of the images. These results will aid in understanding the fundamental properties of the pore structure and in identifying any changes in pore structure that may occur during laboratory testing.

Activity 1.10.4.3.1 - Block stability analysis. No progress during the reporting period; this was an unfunded activity.

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

Forecast: A major portion of the effort on this task for FY 1994 will be directed to geomechanics measurement and analysis of the Large Block Test. This includes development and testing of instrumentation for geomechanics measurements, laboratory characterization of geomechanical behavior of smaller blocks quarried from the site of the Large Block Test and modeling of the geomechanical behavior of the Large Block Test.

Work will continue on the interface of thermogeomechanics models with thermo-hydrologic models. This work will focus on developing the capability to use the temperature fields computed by the hydrologic models such as V-TOUGH and NUFT, as input to geomechanical models. In particular, temperature fields estimated for the Large Block Test will be interfaced to the FLAC geomechanics code. This will enable the geomechanics code to be used to develop estimates of stress field for various thermal-loading regimes, based on a temperature field that is consistent with that used by the hydrologists.

Work will start to obtain/develop a capability for discrete element analysis. The discrete element method is a technique for modeling rock behavior based on the movement along fractures of independent rock blocks. This method is well suited to analysis of the Large Block Test and the Exploratory Studies Facility (ESF). During FY 1994 the LDDA discrete element code will be evaluated for analysis of the Large Block Test.

2.6.2.5 Study 1.10.4.4 - Engineered Barrier System Field Tests

Study Plan 8.3.4.2.4.4 was submitted to YMPO for approval on July 9, 1993.

Activity 1.10.4.4.1 - Repository horizon near-field hydrologic properties. Comment resolution for the draft Scientific Investigation Plan for the Large Block Test has been completed and the plan is awaiting approval signatures by YMPO. Linkage of the Scientific Investigation Plan to (draft) Study Plan 8.3.4.2.4.4 also continues. The drafting of the Activity Plan was started.

The design of the loading frame has been finalized. The Mechanical Engineering Department (LLNL) personnel have prepared fabrication drawings of the frame. Preparation work for laboratory tests on smaller blocks and quarry of the large block has been started. Preliminary scoping model calculations indicate that it is possible to generate both a dryout zone and a condensate zone in the block. The procurement package for the load-retaining frame has been sent to potential vendors. Environmental management approval was received on May 25, 1993, to clear the potential test area. The LLNL staff assisted by Los Alamos, Sandia National Laboratories (SNL), Raytheon Services Nevada and Reynolds Electrical & Engineering Co., Inc. (REECo) personnel visited the Nevada Test Site June 1-2, 1993, to map

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fractures and select a test area. The REECO personnel then completed the clearing and rock surface cleaning activity. The LLNL staff continued mapping the fractures and sampled the fracture system. Emphasis was on identifying mineralogy of fractures, number of fracture generations, and characteristics of fracture alteration haloes and fracture surfaces.

A geomechanical numerical simulation of the Large Block Test was initiated. The purpose of this work is to aid in the experimental design of the test and to provide a point of reference for evaluation of various thermal and material models for predicting the block response. The initial focus is on evaluation of options for the placement of heaters and the rate and duration of heating/cooling cycles, and to assist in the design of the type and location of diagnostic instrumentation, especially for the geomechanical measurements. The numerical model used for this simulation is called FLAC which is a time-dependent, finite difference model capable of treating both mechanical and thermally induced stresses and deformations. It is a two-dimensional code in which materials are represented by arbitrarily shaped quadrilateral zones. FLAC is based on a Lagrangian scheme which is well suited for large material deformations, is capable of using several built-in material models including the ubiquitous joint model, and is installed on a Sun Sparc work station. Preliminary results for temperature, stress and displacement fields as a function of time from start of heating were prepared and compared to results from the V-TOUGH model.

The samples obtained of the fracture system at the Large Block Test facility in late June were examined by petrographic microscopy and x-ray diffraction. Preliminary examination of the thin sections indicates that dark alteration zones along the fracture margins are the result of fluid-rock interaction during vein formation in which oxidized iron phases are reduced, possibly from hematite to magnetite. Carbonate has invaded the rock along the vein margins, partially replacing the feldspar/cristobalite phases. The veins themselves consist of quartz margins, bladed calcite vein filling, and calcite-quartz polygonal mosaics in the vein center. Further work to more thoroughly characterize these materials will be undertaken in October.

Review of specifications was initiated for several geomechanical diagnostic systems for the Large Block Test. These include multiple point displacement extensometer systems, stress meters, acoustic velocity systems and a borehole scanner. This review led to the discovery that there may be two multiple point displacement extensometer systems on site and efforts to locate them were initiated.

The LLNL staff continued the hydrothermal modeling analysis of the Large Block Test. The 3 m x 3 m x 4.5-m-high block has an upper boundary with a constant temperature, pressure, and relative humidity (that allows gas to escape the block). Heat and fluid flow is represented between the block and the underlying rock. The model effectively extends infinitely downward below the ground surface. The block is being modeled with the use of a two-dimensional model, which represents the cross-section that is orthogonal to five parallel, uniformly-spaced, 300 W heaters. The two-dimensional, cross-sectional model assumes adiabatic boundaries on the sides of the block (i.e., perfect insulator) and is very useful in showing how long it takes for thermal interference between the heaters to occur.

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The block was modeled with an R-Z axisymmetric model which averages the heating from the individual heaters with a disk-shaped heat source. The 3 x 3 m cross-sectional area of the block is represented by a circular cross section with a 3.385-m diameter (giving it the same cross-sectional area).

The heater horizon is located 3 m below the top of the block. The R-Z axisymmetric model can represent the heat loss out of the sides of the block. The sides are modeled as having a layer of insulation with a specified thickness and thermal conductivity, k_{th} . Because of its large heat capacity and k_{th} , the loading frame (that confines the block) is assumed to be at a constant temperature. For the insulation layer, a k_{th} of 0.110 W/m°C was assumed which is a typical value for wood (Douglas Fir). A suite of calculations assuming the block to have adiabatic sides (which could be achieved through the use of guard heaters) was also run. Gas-phase and liquid-phase flow can occur across the upper boundary of the block. The upper boundary is either a constant temperature boundary or an adiabatic boundary which is capable of becoming a constant temperature boundary.

The model extends vertically downward to the water table (assumed to be at a depth of 568.1 m) and out to a radial distance of 205 m. For the time-scale of the Large Block Test, the model effectively extends infinitely in the radial and vertical (downward) direction. It was found that heat from the Large Block Test drives hydrothermal flow effects in the rock underlying the Large Block Test. These effects occur primarily within the first 10 m of rock underlying the Large Block Test. The initial vertical temperature, saturation, and pressure profiles correspond to the geothermal and pneumatostatic pressure gradients, and to a net recharge flux of 0 mm/year. Note that this yields an initial liquid saturation of 58 percent in the large block. In order to adequately represent gas-phase flow, it is necessary to start with a pneumatostatic pressure distribution.

In the parameter sensitivity study, three variables were considered: the insulation thickness (or whether adiabatic boundaries are maintained), the manner in which temperature is controlled at the upper boundary of the block, and bulk permeability, k_b .

The lateral insulation thicknesses of .3 and .6 m were considered. Even for a .6-m-thick insulation, the heat loss out of the sides of the block is substantial, causing sub-boiling conditions and condensate drainage to persist at the outer edges of the block. Condensate shedding around the perimeter of the block diminishes the magnitude of saturation buildup in the condensate zone overlying the boiling zone. Because of the intent to maximize the potential for refluxing, possibly resulting in the heat-pipe effect occurring above the heaters, condensate shedding along the cooler sides of the block is not desired. When the upper boundary is maintained at a constant (ambient) temperature, it takes about 0.5 year for a steady-state temperature profile to develop. The heat loss out of the top and sides of the block limits the spatial extent of dryout and condensate buildup.

When an adiabatic lateral boundary and constant temperature upper boundary are maintained, the boiling zone extends out to the lateral boundaries within 90 days, substantially limiting condensate drainage around the perimeter of the block. Consequently, the saturation buildup in the upper condensation zone is very pronounced, maximizing the potential for

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refluxing above the heater horizon. A steady-state temperature profile is established within 0.5 year. Adiabatic sides also enable the development of a larger dryout zone; however, it was found that maintaining a constant (ambient) temperature upper boundary substantially limits the vertical extent of refluxing above the heater horizon. Consequently, sub-boiling conditions persist for much of the block overlying the heater horizon.

In order to maximize the vertical extent of refluxing (i.e., two-phase conditions) above the heater horizon, it is necessary to maintain an adiabatic upper boundary until the top of the block approaches the nominal boiling point. In a further suite of calculations, an adiabatic upper boundary was maintained until the temperature at the top of the block reached 83°C, and thereafter the upper boundary was maintained at 83°C. Controlling the upper boundary in this manner resulted in the upper two-phase zone being more than 1 m in vertical extent. The saturation buildup in this zone was substantially greater than the case where the upper boundary temperature was fixed at ambient temperature.

Also considered were the values of bulk permeability, k_b , of 10 and 100 microdarcy, 1, 10, and 280 millidarcy, and 5 and 40 darcy. For k_b of 1, 10, and 280 millidarcy, the vertical extent of the dryout zone is almost identical, and the effect of buoyant, gas-phase convection is negligible (i.e., does not cause the dryout zone to deviate from being vertically symmetrical about the heater horizon). For a k_b of 5 darcy, the effects of buoyant gas-phase convection begin to become noticeable, with more than 50 percent of the total steam flow being upward. For a k_b of 40 darcy, buoyant vapor flow dominates gas-phase flow, with all of the steam flowing upward, resulting in a much greater buildup of condensate above the heater horizon. The threshold k_b (where the effects of buoyant vapor convection begin to dominate gas-phase flow) is essentially the same in the Large Block Test as in the in situ heater tests and repository-heat-driven hydrothermal flow. For k_b values of 10 and 100 microdarcy, dryout due to boiling is effectively throttled, thereby reducing the volume of the dryout zone relative to the cases where $k_b > 1$ millidarcy.

Activity 1.10.4.4.2 - Repository horizon rock-water interaction. No progress during the reporting period; this was an unfunded activity.

Activity 1.10.4.4.3 - Numerical analysis of fluid flow and transport in repository horizon near-field environment. No progress during the reporting period; this was an unfunded activity.

Forecast: The Activity Plan for the Engineered Barrier System Field Tests will be drafted. Work will continue on the preparations, procurement, etc. for the Large Block Test.

2.6.2.6 Study 1.10.4.5 - Characterize the Effects of Man-Made Materials on Water Chemistry in the Postemplacement Environment

Revision of Study Plan 8.3.4.2.4.5, "Characterization of the Effects of Man-Made Materials on the Chemical & Mineral Changes in the Post-Emplacement Environment" is currently being reviewed.

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Activity 1.10.4.5.1 - Effect of grout, concrete, and other repository materials on water composition. The revised Study Plan 8.3.4.2.4.1, "Characterization of the Chemical and Mineralogical Changes in the Post-Emplacement Environment," was completed in draft form.

As a result of contacts made at meetings, activities continued with emphasis on procurement of information on introduced materials. Emphasis has been placed on diesel fuel and other organic compounds, colloids, biodegradation of tracer fluids, and water. The sources and potential amounts of water under investigation are those that may result from human intrusion and construction of the repository.

Staff have initiated the first series of diesel fuel stability experiments. The preliminary results demonstrate that diesel fuel comprises a vast array of constituents of varying stabilities. There is good evidence of chemical reactions taking place at 200°C. Some of the products are carboxylic acids which may prove to be aggressive to waste canister materials.

Staff from LLNL met with M&O personnel to discuss concerns regarding organic materials in general. They also reviewed the present diesel fuel experiments and visited the organic materials experimental facilities. Interest was expressed in obtaining information regarding the stability of hydraulic fluids and the M&O agreed to supply information regarding the range of hydraulic fluids that may be used during the construction of the ESF.

An LLNL representative of the Man-Made Materials Task attended a meeting on Waste Isolation Analyses and Test Interference Evaluations, held July 2, 1993, in Las Vegas, Nevada. This interaction improves the coordination of results from the Man-Made Materials study with Waste Isolation Evaluations.

Geothermal power companies in Taupo, New Zealand, were visited in August 1993 by LLNL and YMPO staff. The purpose of these meetings was to discuss the development of a collaborative relationship that will provide long-term chemical information of interest to YMPO and to obtain access to chemical data, samples of degraded materials, boreholes for experimentation and sampling, and geothermal areas not accessible to the public. This study will benefit both the Geochemistry and the Man-made Materials Tasks at LLNL and will be conducted by both tasks. A contract is presently in place between the Institute of Geological and Nuclear Sciences, a Crown Research Institute of New Zealand, and the Geochemistry task at LLNL for the initiation of geochemical studies. Of particular interest to the power companies are many of the long-term materials degradation issues of the man-made materials task.

The potential for conducting studies on degradation of man-made materials in collaboration with New Zealand geothermal interests is being pursued as part of a geochemical analog project for the YMP. One area of mutual interest that will be addressed immediately is cement biodegradation. The rare opportunity to acquire cement samples from an usually inaccessible area that has been exposed to elevated temperatures over a period of five years and is showing extensive signs of biodegradation will present itself in mid-October 1993. A complete plant shutdown at this site, which only occurs once every two years for a period of two days, will take place at that time. During that window of opportunity, if

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foreign travel arrangements can be made in time, plans are to collect samples for culture and identification, as well as future experimentation. Another site, which contains some of the oldest (up to 40 years) synthesized materials, will be shut down for a similar period of time in February 1993. This shutdown will offer the opportunity to obtain other samples, primarily inorganic materials for analysis.

A paper entitled "Chemical and Mineralogical Concerns for the Use of Man-Made Materials in the Post-Emplacement Environment" (Meike) was submitted to YMPO for approval on August 9, 1993. This paper was originally prepared for M&O personnel and submitted in January 1993.

A paper entitled "Formation of Colloids from Introduced Materials in the Post-Emplacement Environment: A Report on the State of Understanding" (Meike and Wittwer, 1993) was presented at Focus '93. This literature review will provide the basis for determining the necessity of future experimental and analog studies.

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.

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

Forecast: Work will continue on the diesel fuel stability experiments and the studies on degradation of man-made materials in collaboration with New Zealand geothermal interests.

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. The responses to the review comments for the Preliminary Waste Form Characterization Report were completed and returned to YMPO.

Subactivity 1.5.1.1.2 - Integrate glass waste form information. No progress during the reporting period; this was an unfunded activity.

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: Integration of waste form data into the Waste Form Characterization Report will continue.

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2.6.3.2 Activity 1.5.2.1 - Characterization of the Spent Fuel Waste Form

Subactivity 1.5.2.1.1 - Dissolution and leaching of spent fuel. The dissolution response of spent fuel is a part of the characterization and data input for performing waste package design activities and repository performance assessments. The dissolution response testing addresses spent fuel types, reactor burnups, oxidation phases, heterogeneous effects of radionuclides on and in pellet fragments, potential water temperatures, and water chemistries. Only the flow-through dissolution activities are currently supported. The activity plans for these tests contain test matrices that prescribe conditions and types of flow-through runs to be completed for dissolution model development.

The eight UO_2 dissolution experiments begun in April 1993, as a part of the LLNL test matrix, were completed. These eight experiments are at temperatures of 50° and 75°C, and at subatmospheric oxygen levels of 0.2 and 2 percent. This group included three identical runs at midvalues of the variables to test for reproducibility of the runs. This completes the initial test matrix of nineteen experiments at alkaline conditions. These tests were continued at room temperature using the same buffers to obtain additional test replications and data. These results will provide additional data to test intrinsic UO_2 dissolution models that are developed. These continuations, plus the original test matrix runs, gives 35 experimental runs under a wide variety of conditions to develop dissolution response models. Detailed analysis of the final results of the full test matrix is required before formal conclusions can be made.

Analysis has begun of the final results of the original test matrices at Pacific Northwest Laboratory (PNL) for spent fuel dissolution and at LLNL for UO_2 dissolution. The trends in dissolution rates are similar in both matrices. There are a few experimental points in both matrices that do not seem consistent with the other data. These are being re-examined or repeated. Two experiments at LLNL are under way that are repeats of individual runs in the original test matrix. The two earlier runs had dissolution rates that varied considerably during the course of the experiments and were not consistent with other runs in the matrix.

Work is continuing at LLNL on the two long-term, room-temperature dissolution experiments ongoing since fall of 1992. These experiments use UO_2 powder from a batch provided by PNL that had been used in similar experiments. Our Canadian colleagues at Pinawa, Manitoba, are performing similar experiments. The first buffer composition is 0.02 M sodium bicarbonate at a pH of 8. The second composition is a 'standard' saline solution with 0.01 M sodium bicarbonate and 0.1 M sodium chloride saturated with air; the pH is not controlled. Since February 1993, the uranium dissolution rate for the first nonsaline solution slowly increased to about 2 $\text{mg/m}^2\cdot\text{d}$ in mid-April 1993. The experiments were stopped for about one month during a move of the equipment to another building. Upon resuming the experiment in mid-May 1993, the dissolution rate has increased to 2.5-4.0 $\text{mg/m}^2\cdot\text{d}$. The UO_2 dissolution rate in the saline solution did not change during the one month stoppage. Its dissolution rate has also slowly increased over time, but is less variable at about 4-5 $\text{mg/m}^2\cdot\text{d}$.

Analysis and documentation are being completed for all the experimental data of the previous dissolution tests performed on UO_2 and spent fuel. Following this report work, a

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sequence of experiments will be performed to examine the effects of oxidation state on uranium oxide dissolution. Two experiments with schoepite have begun at room temperature and 20 percent oxygen. One experiment includes hydrated schoepite ($\text{UO}_3 \cdot 2\text{H}_2\text{O}$) as a sample; the other experimental sample is dehydrated schoepite ($\text{UO}_3 \cdot \text{H}_2\text{O}$). The results of these two experiments will be compared with similar experiments previously conducted at very low oxygen concentrations. These prototypes will provide data to plan a test matrix of dissolution tests on the higher UO_2 oxidation states. These experiments are similar to those experiments begun at PNL on spent fuel.

A test matrix for flow-through dissolution tests at PNL with three different spent fuels (Approved Testing Material [ATM]-104, ATM-105, and ATM-106), three oxidation states (UO_2 , O_4O_{9+x} and O_3O_8), two temperatures (25° and 75°C), and three carbonate/bi-carbonate concentrations (0.2, 2, and 20 mmol) was completed and included in an addendum to the test plan. This addendum was included in the Activity Plan, "Flow-Through Dissolution Studies on Spent Fuel."

The flow-through dissolution tests at PNL on ATM-106 fuel (pressurized-water reactor fuel with a 50 GWd/MTIHM burnup and 18 percent fission gas release) in both oxidized (O/M ~2.4) and unoxidized forms are in progress. Preliminary results from the oxidized specimens do not indicate a high initial release of Tc such as was found in a previous test with oxidized ATM-105 fuel (boiling water reactor fuel with 31 GWd/MTIHM burnup and 0.6 percent fission gas release).

Another specimen of ATM-106 fuel was oxidized to U_3O_8 by heating in air overnight at 425°C . The surface area (measured by Brunauer-Emmett-Teller surface area measurements) increased by a factor of about 40 compared with unoxidized particles of about 1 mm in size. The large increase in surface area is the result of substantial intra- and inter-granular cracking during oxidation. Flow-through tests on the U_3O_8 material have been completed. Preliminary analytical results indicate that 15 percent of the total Cs inventory in the fuel was dissolved in the first 29 hours compared with only 4 percent of the total uranium. Thereafter, the U and Cs dissolution rates were equal. A possible explanation for the 11 percent excess of Cs over U dissolution is that some of the Cs may be associated with gas bubbles in the spent fuel matrix. Cracks caused by the oxidation probably intercepted many of these bubbles thereby exposing the associated Cs for immediate dissolution. It was anticipated that oxidizing the fuel to U_3O_8 might also give rise to an increase in the initial dissolution of Tc; however, this was not observed.

Subactivity 1.5.2.1.2 - Oxidation of spent fuel. The oxidation drybath testing (D-20-45) activity on spent fuel at low temperatures ($<200^\circ\text{C}$) continued at PNL. The drybath apparatus was initially designed to run two to three years; testing has continued for about eight years. The temperature control system in one drybath has failed; samples were transferred from the failed drybath to another and testing restarted. At the existing temperatures ($<200^\circ\text{C}$), the spent fuel oxidation changes crystalline phase from a UO_2 lattice to a U_4O_9 lattice structure; however, the oxygen content is that of a $\text{UO}_{2.4}$. The excess oxygen atoms means that the U_4O_9 phase is nonstoichiometric. Also, the U_4O_9 with an O to U of (<2.4) is metastable, because the U_3O_7 ($\text{UO}_{2.33}$) lattice structure is also stoichiometrically accessible. Some

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previous spent fuel oxidation experiments indicate that the metastable U_4O_9 phase ($UO_{2.4}$ oxygen excess) transitions upon further oxidation directly to a U_3O_8 phase. However, little was known of the phase transition kinetics nor the rate of oxidation and its associated mechanism.

Because of this spent fuel degradation by oxidation and the potential for higher dissolution rates of the higher oxidation phases, the oven drybath test plan and activity plan were updated to run a drybath at a higher temperature ($\sim 250^\circ\text{C}$). In this temperature range, the transition testing of some existing U_4O_9 (at $UO_{2.4}$) and some "fresh" UO_2 spent fuel multifragment samples were initiated. The phase transition kinetics of the two types of samples will be quantified through weight gain measurements and by selecting fragments at various time intervals of the weight gain measurements in order to systematically perform microscopic observations on them.

The first interim examination of the 255°C drybath test was completed at 195 hours of test time. Those samples that were initially unoxidized had oxidized to an O/M between 2.35 and 2.42 (i.e., essentially all the way to the 2.4 weight gain plateau). Those samples that had been oxidized to O/M ~ 2.4 at 175°C had very little change in O/M which would be expected for samples already on the plateau. In the next interim examination of the drybath samples, the weight gain was as expected in the 110° , 130° , 175° , or 195°C drybath tests. However, the 255°C drybath test continued to provide new information:

1. The Turkey Point fuel samples oxidized to a higher plateau than the other fuels (in the lower temperature tests, it was the lowest O/M plateau).
2. A weight gain plateau appeared to be occurring, the samples continued to gain weight and O/M ratios of 2.5 have been reached by some samples.
3. While sample preparation for microscopic analysis indicated the spent fuel was friable, x-ray diffraction analysis detected only U_4O_9 and no U_3O_8 .

A third interim examination was conducted at 1667 hours. The samples continued to gain weight, but at a significantly reduced rate. No samples were removed for additional microscopic analysis. It appears that after the initial transient weight gain, the samples are all now gaining weight at the same reduced rate; this includes the samples with a higher initial O/M that were taken from earlier tests at 175°C . Future sample examinations as oxidation progresses will continue to be performed to obtain a time history of the phase change kinetics and the oxidation rate response.

In addition to the oven drybath testing at higher temperatures, thermogravimetric apparatus testing for phase change kinetics are being initiated. Thermogravimetric apparatuses were brought out of storage and one is now fully operational. The thermocouples in the other thermogravimetric apparatus is being calibrated, and should also be operational shortly. An $^{18}\text{O}_2$ run indicated that the equipment was leak tight. During some calibration testing, fluctuations in the thermogravimetric apparatus balance were observed but were well within tolerable limits. These fluctuations are apparently caused by thermal convections and

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were also present in previous thermogravimetric apparatus runs. To restart the thermogravimetric apparatus testing activity, an update of the existing test and activity plans are required. Therefore, some preliminary tests are being performed in support of a thermogravimetric apparatus oxidation test plan, to calibrate the equipment, and to obtain baseline information to be used to determine a suitable test matrix.

For one of the preliminary thermogravimetric apparatus tests, a piece of unirradiated UO_2 doped with eight percent Gd_2O_3 was held at 283°C for 454 hours. This sample exhibited behavior similar to that of drybath tested spent fuel (an oxygen-to-metal ratio of 2.35 plateau was reached). This sample broke into powder while being removed. Subsamples for x-ray diffraction and scanning electron microscopy analysis were taken. An adequate subsample for transmission electron microscopy analysis was not obtained due to sample friability. Both x-ray diffraction and scanning electron microscopy confirmed the presence of U_4O_9 and approximately three percent U_3O_8 . The initial results from scanning electron microscopy analysis indicate the U_3O_8 is dispersed throughout and not located on the grain boundaries.

In another preliminary thermogravimetric apparatus test, a fragment of BWR-ATM 105 fuel has run for over 300 hr at 283°C . An O/M ratio of 2.647 has been reached. The sample rapidly gained weight to an O/M of 2.35. However, a true plateau around an O/M of 2.4 was never attained since the sample continuously gained weight. But the weight gain rate, $[d(\text{O/M})/dt]$, decreased significantly after obtaining a 2.35 O/M at around 125 hours. It now appears that the rate of weight gain is slowing down and possibly may be approaching a second "plateau." The test is continuing.

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

Subactivity 1.5.2.1.6 - Other experiments on the spent fuel waste form. No progress during the reporting period; this was an unfunded activity.

Forecast: A new sequence of experiments will be performed this coming year to examine the effects of oxidation state on uranium dissolution. Studies of spent fuel with matrix oxidation states of U_4O_9 and U_3O_8 will continue at PNL, with some variation in burnup, according to the ATM fuels available. The higher uranium oxide forms, U_3O_8 and UO_3 , will be studied at LLNL. These results will provide data to evaluate the effect of burnup on the spent fuel dissolution rates. In addition to the ongoing flow through dissolution testing activities at PNL and LLNL, dissolution testing on spent fuel under unsaturated conditions will be initiated at Argonne National Laboratory. The unsaturated

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testing conditions use relatively small amounts of water and will provide release rate data for dripping water flow (thin film flow) and partial surface wetting conditions.

The higher temperature oven dry bath oxidation testing will be continued to obtain phase change kinetics data for the transformations of UO_2 to U_4O_9 to U_3O_8 to UO_3 . In addition, the test plan and activity plan to restart the thermogravimetric analysis oxidation testing will be completed and thermogravimetric testing at the Quality Affecting level will be initiated. The two oxidation testing methods provide flexibility and breadth in atmospheric and temperature controls to provide the spent fuel oxidation rate and oxidation phase change data in the temperature range of 200° to 300°C that is required to assess spent fuel repository response issues.

2.6.3.3 Activity 1.5.2.2 - Characterization of the Glass Waste Form

Subactivity 1.5.2.2.1 - Leach testing of glass. The N2 tests (SRL actinide-doped glass) have been in progress for 92 months. The N3 tests (ATM-10, a West Valley actinide-doped glass) continue and have been in progress for 73 months.

Subactivity 1.5.2.2.2 - Materials interactions affecting glass leaching. No progress during the reporting period; this was an unfunded activity.

Subactivity 1.5.2.2.3 - Cooperative testing with waste producers. No progress during the reporting period; this was an unfunded activity.

Forecast: The N2 and N3 unsaturated tests will continue. A low level of geochemical modeling work will continue using input from experimental work not performed as part of the YMP.

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. The Yucca Mountain Integrating Model submodels are being incorporated into the Total System Performance Assessment (TSPA) 1993 source term.

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. Near-field environment/engineered barrier system model parameters were elicited and abstracted for use in TSPA 1993 source term. No scenario analysis was funded.

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: Work will continue to incorporate the Yucca Mountain Integrating Model submodels into the TSPA 1993 source term.

2.6.3.5 Activity 1.5.3.2 - Develop Geochemical Speciation and Reaction Model

Subactivity 1.5.3.2.1 - Develop data base for geochemical modeling. GEMBOCHS Change Requests 2-5 and 7-15 using the CNGBOCHS system were resolved and submitted during this reporting period.

Programs FACET and JEWEL (formerly DBAPP and D0OUT) were used to generate five revised suites of thermodynamic data files (DATA0 suites R19-R23) that support the EQ3/6 geochemical modeling package. These new data files reflect various revisions associated with resolution of the change requests submitted this reporting period. These DATA0 suites together with their DATA1 analogs, were transferred to a dedicated directory on s60 where they can be accessed by local EQ3/6 users.

The development of a WINDOWS/4GL Graphical User Interface version of JEWEL was completed and beta testing of this new software has begun. This user-friendly, mouse-driven code facilitates point-and-click generation of thermodynamic data files for use with EQ3/6, GT, and other geochemical modeling packages. The development of a WINDOWS/4GL version of FACET has begun. This code will permit point-and-click review of GEMBOCHS data by onsite and offsite GEMBOCHS users; password-restricted to GEMBOCHS staff members.

GEMBOCHS was updated to include equilibrium-constant and reaction-enthalpy data from the CHEMVAL-II data base. A modified version of JEWEL which facilitates generation of CHEMVAL-II data files for use with EQ3/6 was created. Work has started on establishing a GEMBOCHS "patron" account. This login account will provide offsite GEMBOCHS users with direct access to GEMBOCHS software (which facilitates review and application of GEMBOCHS data) and the current DATA0 suite (for use with EQ3/6). These online services will provide convenient and timely access to GEMBOCHS for offsite YMP Participants.

Subactivity 1.5.3.2.2 - Develop geochemical modeling code. This activity maintains and develops the EQ3/6 software package for use in near-field environment characterization and site characterization. Version 7 is being maintained. Version 8, which involves a significant rewrite to support new capabilities, is being developed.

Testing and final preparation of Version 7.2 was completed in the reporting period. Update packages were distributed to YMP Participants and other YMP-related recipients. This new version is available in a 486 personal computer form, in addition to a UNIX work station form. It is the first version of EQ3/6 produced by LLNL for the personal computer. It contains special personal computer interface software to complement the existing UNIX interface software. It also contains two new input file reformatters, XCON3 and XCON6. These allow input files for the EQ3NR and EQ6, respectively, to be changed from a compact

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format to a menu-style format and vice versa, and from one supported version level to another. The input file formats for Version 7.2 are slightly different from those employed in Versions 7.0 and 7.1. These reformatter codes can be used by current users to update their old input files to Version level 7.2;

A new suite of data files (R22) is included in Version 7.2. It contains corrections to the thermodynamic data for two magnesium hydroxysulfate minerals. It also reflects a reorganization of the reactions involving aqueous organic species. The EQ3/6 test library was rebaselined using these new data files

Internal use of this version has uncovered a few minor bugs, which are being addressed for a Version 7.2a update. Version 5.11 of the Lahey FORTRAN compiler has been received and is being tested to see if it will eliminate a memory manager fault when running the personal computer version other than in a DOS window under Microsoft Windows 3.1. The Version 7.2a update will be distributed in late-October 1993.

Work is continuing on Version 8.0. As specified in the Software Design Description, this version is a major rewrite incorporating major changes in the data structure in order to accommodate improvements in numerical methods and the addition of new functional capabilities. The new capabilities planned for Version 8.0 include:

1. Allowing for redox disequilibrium in reaction-path calculations (important to treating the metastable persistence of dissolved components such as sulfate, nitrate, and organics;
2. A generic ion-exchange model; and
3. Correction of supporting data, mostly thermodynamic, to pressures off the 1.013 bar steam saturation curve.

The data restructuring has been completed. The new structure, which is common to both EQ3NR and EQ6, is significantly different from that previously employed in either code. Both codes formerly had different data structures, which was why EQ3NR had a redox disequilibrium capability, but EQ6 did not. The new structure is more like the old one in EQ3NR, although it incorporates some important new features. All chemical species are now defined by a common set of arrays. The set of basis species is defined by a point array, instead of being equated to a particular subset of aqueous species. Thus, basis switching no longer requires switching species indices. The new structure allows a species of any type (e.g., aqueous, gas, mineral, solid solution component, exchange species) to be defined as a basis species. This is important to maximizing numerical stability.

The new structure also incorporates a dual basis concept. All mass balances are defined in terms of a convenient, familiar set of basis species (e.g., Na^+ , Ca^{2+} , Cl^-) as defined in the supporting data file. A second set of basis species is used to define the reduced set of unknowns used to solve the set of governing equations. Defining mass balances in terms of a familiar set of species is important because it helps prevent misinterpretations of mass balance

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quantities in code input and output. Mass balances computed using a basis set selected to maximize code numerics may appear to have physical significance (e.g., correspondence with chemical analyses), when instead they may have only mathematical significance.

Version 7 was heavily dependent on COMMON blocks to define the data structure. It was also heavily dependent on INCLUDE files (mostly to contain these COMMON blocks). Among EQLIB, EQ3NR, and EQ6, there were about 134 COMMON blocks, 147 INCLUDE files, and 2052 references to INCLUDE files. This has been reduced to 16 COMMON blocks, 11 INCLUDE files, and 52 references to INCLUDE files. This was accomplished by making greater use of calling sequences to handle data flow. The resulting code is much more modular and hence much easier to maintain and develop.

The general rewrite has been largely completed. The redox disequilibrium capability in EQ6 is now in the code. The software (EQ3NR as well as EQ6, as this code has been extensively changed even though no new capabilities have yet been added) is now in a testing phase. The test case library from Version 7 is being converted to Version level 8 format, using extended versions of the XCON3 and XCON6 input file reformatter codes that were created for Version 7.2. New problems are being added to test the redox disequilibrium capability in EQ6.

Software validation activities leading to the certification of Version 7 of EQ3/6 for use in quality affecting work continued through the reporting period, and have now covered all of the software with the exception of EQ6.

At the request of the Quality Assurance Manager, Quality Procedure 3.2 and associated Technical Implementing Procedures (TIP-YM-10 through TIP-YM-20) are being reviewed.

Forecast: The current testing phase for Version 8 of EQ6 will be completed in early FY 1994. The new capabilities for handling the generic ion exchange model and thermodynamic pressure corrections will then be added. After final testing and preparation, including preparation of the relevant code documentation, Version 8.0 will be released. This is currently planned to take place at the end of July 1994. Activities will then begin for Version 9.0, focusing on the addition of sorption models.

Software validation activities for Version 7 will continue through the first few months of FY 1994, focusing on the EQ6 code. This version should then be ready for certification for use in quality affecting work. Software validation activities for Version 8 will commence when Version 8.0 completes the final testing phase.

The beta testing of the WINDOWS/4GL JEWEL and a user's manual for this software will be completed.

The prototype development of a WINDOWS/4GL FACET will be completed.

Work will continue to establish a GEMBOCHS "patron" account.

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As dictated by availability and/or user requirements, additional or revised thermodynamic data will be incorporated into GEMBOCHS and new or improved extrapolation algorithms will be incorporated into JEWEL. As required by GEMBOCHS and/or EQ3/6 modifications, FACET and JEWEL will be used to generate revised suites of thermodynamic data files (DATA0 suites) that support EQ3/6.

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: Activity plan for glass release models will be developed in 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. This activity has focused on development of an engineered barrier system/near-field environment source term model for use in TSPA 1993 which has improved mechanistic submodels and incorporates thermal effects. This source term will allow TSPA 1993 to examine alternative designs and thermal loading strategies.

Work continues on the scoping study of cladding temperature history for various drift emplacement heat loadings, and of cladding creep endurance. Drift backfill 75 years after waste emplacement is assumed. Based on recent literature, the temperatures are somewhat higher than in the earlier parameterization of thermal results, but feasible repository loadings can meet both dryout and cladding goals. The cladding creep model was extended to incorporate reduced pressure load due to the progress of creep. This effect had been included in some previous papers, but just examined and not included in others; noninclusion is somewhat conservative.

The main contributors to elevated temperatures in the fuel cladding are the heating of the rock mass (dependent on the areal power density) and the temperature difference across the backfill (dependent on the heat generation rate of the package at any given time and on the thermal conductivity of the backfill). The container wall-to-center difference contributes only on the order of 10 percent of the total heat rise, assuming a 21-pressurized-water reactor-assembly container. The current analysis based on recent papers gives somewhat higher

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temperatures than reported previously. There are still some feasible loading plans that will provide an areal power density of 223-247 kW/ha (90-100 kW/acre) using 30-year-old spent fuel (areal mass loading of 301 to 336 MTU/ha [122 to 136 MTU/acre]) and still meet the cladding strain limit as calculated by a conservative approach. These loadings have 10 to 12 pressurized-water reactor assemblies per waste package, rather than 21 assemblies as in the preliminary analysis. Increasing the loading per package would require some other design choices affecting the heat transfer.

The cladding creep rate is dependent on temperature and stress. Creep reduces the stress. In the initial analysis used above, this source of reduction was not included. Further analysis showed that including it makes an appreciable difference, with improved performance. The stress is generated by internal gas pressure in the fuel rod. The internal gas is a fill gas plus a small amount of fission gas released to the fuel rod's void space. During reactor operation, the fuel pellets swell, reducing the void volume by 30 to 50 percent. Gas pressure depends on temperature and volume. The cladding creep increases the volume progressively. The creep model was extended to include the strain-dependent effects and it was found that it makes an appreciable difference in extending creep lifetime and a modest difference in increasing the allowable temperature. Analysis is continuing. Note that creep of cladding can occur mainly in two time periods: the first decade of temporary dry storage, if utilized, and the first few decades after backfill is emplaced in repository disposal. It is urged that there be coordination of creep allowables in these two design periods before changing any allowables to take the benefit of the finite-strain effect on creep.

The LLNL staff is developing a summary model of the near-field environment of the waste package. This will consider the thermal transient and dryout based on papers by LLNL personnel and others in the field. The product will be time histories, in table or algorithm form, of temperature, fractional saturation, fraction of waste packages wetted, and liquid water flux. A calculational procedure was implemented to evaluate the distance of fracture flow penetration due to refluxing of condensate water above the repository. This procedure includes a spatial variability in water flux and in fracture sizes, and hence a spatial variability in distance of refluxing.

Information on the source term was presented to SNL for use in TSPA 1993. As part of this effort, Near Field and Performance Assessment staff modeled an important near-field hydrological process, localized water penetration beyond a boiling front, through a dried-out zone, down to the level of a repository. At random locations, this flux could wet some waste packages. In order for penetration to happen at some location, it is necessary that the localized water flux be greater than the amount of water that can be evaporated by the heat flux from the repository. This heat flux is assumed to be essentially uniform, whereas water fluxes are known to exhibit spatial heterogeneity. Using a lognormal distribution to characterize this heterogeneity (as is suggested in the literature), numerical results have been derived for the fraction of waste packages that get wet under the assumptions of 141 and 282 kW/ha (57 and 114 kW/acre) initial areal power density, both at the center and edge of the repository. For representative assumed input values, the fraction of waste packages in the repository center zone that get wet is on the order of a few per thousand for the first 50 to 100 years. The fraction then drops by about an order of magnitude in the 141 kW/ha

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(57 kW/acre) case. The fraction drops by about three orders of magnitude in the 282 kW/ha (114 kW/acre) case, to an expected value well below one waste package in the whole repository center zone after a few hundred years.

Staff continued providing both SNL and the M&O with detailed temperature, saturation, and liquid flux histories throughout the repository and unsaturated zone for repository-unsaturated zone-saturated zone-scale model calculations using V-TOUGH. This is being done in support of TSPA 1993. We applied a blended repository thermal loading history provided by the M&O that is based on the oldest fuel first waste receipt scenario, yielding an average spent fuel age of 26 years. Calculations for areal power densities of 70.5, 141, and 282 kW/ha (28.5, 57, and 114 kW/acre) (yielding areal mass loadings of 71.7, 143.5, and 287 MTU/ha [29, 58, and 116 MTU/acre]) were conducted. The 141 kW/ha (57 kW/acre) case (which falls within the thermal loadings described in the SCP-CDR) has a boiling period duration, t_{bp} , of 2600 years at the repository center.

At the request of the M&O, the liquid-phase velocity field at various times and the liquid-phase velocity history at various points from the repository horizon down to the water table have been provided based on the repository-unsaturated zone-saturated zone-scale hydrothermal calculations using V-TOUGH. These results can be used to calculate radionuclide transport in the unsaturated zone on the basis of averaged liquid-phase fluxes. Because of the spatial variability of liquid-phase flux, basing transport calculations on average fluxes may not accurately reflect the flow field calculated by V-TOUGH. In order to more accurately reflect the V-TOUGH-calculated flow field, it is preferred to track packets of particles released from waste package locations, as they are driven by the flow field in the underlying natural barrier system. Staff developed a family of "particle tracking" post-processors for V-TOUGH, called P-TRACK, PT-PLOT, and PT-MOVIE. P-TRACK calculates the x-y location versus time for each of the particles. PT-PLOT calculates the pressure, temperature, and saturation history for each of the particles. PT-MOVIE is a graphics program that produces a video animation of the moving particles. Colors can be used in PT-MOVIE to "tag" when or where the particles were released, or can be used to indicate the value of either pressure, temperature, or saturation of the moving particles. P-TRACK and PT-PLOT can be the basis for conducting radionuclide transport calculations where retardation may be treated as a function of pressure, temperature, and saturation. PT-MOVIE is an extremely valuable aid to visualize the spatial and time dependence of transport, as well as the relationship between transport and temperature and saturation.

Staff began work on documenting the stochastic model for condensate drainage. This model is being used for performance assessment modeling and predicts the spatial variability of condensate drainage onto waste packages. The condensate flux is modeled as a lognormal random field in space. The waste packages can become wet in those regions where fluxes are sufficiently focused that they overcome the vaporizing effect of the above-boiling thermal field. The mean condensate flux is the conditional expectation of the flux given that the flux exceeds a critical flux proportional to the mean condensate flux calculated by the V-TOUGH calculations. The proportionality factor is a function of the thickness of the dryout zone. In general, the thicker the dryout zone, the higher the threshold flux required for breakthrough to the waste packages.

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The following two workshops were hosted at LLNL to develop models and data for TSPA 1993. LLNL is responsible for a near-field environment/engineered barrier system source term which incorporates thermal processes:

1. June 11, Thermal History Workshop (participants from LLNL, U.S. Department of Energy, SNL and M&O).
2. June 23, Hydrothermal Water Flux Workshop (participants from LLNL, SNL and M&O).

A paper entitled "Post-Closure Performance Assessment of Waste Packages for the Yucca Mountain Project" (O'Connell et al., 1993) was approved by YMPO on August 25, 1993, and was published.

The PANDORA-1.1 user's manual is in technical editing for reviewers' stylistic comments and for ease of use.

The performance assessment function is continuing its development of a new-generation waste package/engineered barrier system performance assessment code. This work is being carried out on behalf of the M&O by the staff of PNL. Two working documents were written that describe progress in this effort. The first is "Mathematical Document for the AREST Code Development" and the second is "Software Requirements Specification for the AREST code Development." These documents are currently in M&O technical review. The focus of the AREST code upgrade effort is to ensure that the detailed waste package model accounts for the principal processes affecting container degradation, waste form alteration, and radionuclide release to the host rock.

The M&O performance assessment staff developed a model to perform thermal calculations in the vicinity of waste packages placed horizontally in drifts. The main features of this finite difference model include radiative heat transfer from the waste package to the drift wall and conduction heat transfer in the host rock. The effects of heat convection and moisture content in the host rock are neglected in this model. This model is presently being used to perform bounding calculations to determine the ranges of drift diameters and waste package spacings for various emplacement configurations, such that the allowable temperature limits of waste package and the host rock are not exceeded.

The M&O and University of California, Berkeley, staff completed documents entitled "Mass Transfer Induced by Thermal Effects in Unsaturated Porous Media" and "Evaporation of Water on a Heated Surface in a Cavity in Unsaturated Porous Media." The first report is an analysis of the evaporation of water from a liquid film on a heated surface into a surrounding unsaturated porous medium. The second report is a study of the steady-state heat and mass transfer near a heat source in an unsaturated porous medium to evaluate potential heat pipe effects. These reports are undergoing internal review.

A Performance Assessment Thermal Modeling Meeting was held in Las Vegas, Nevada, on June 29, 1993. The meeting presented a range of modeling results, from coupled

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multiphase thermal flow analyses through thermal-conductance-only evaluations. The M&O performance assessment staff presented talks discussing results of hydrothermal calculations performed with VTOUGH entitled "Subrepository Scale Hydrothermal Analysis in Support of TSPA," results of near field calculations for in-drift emplacement of robust canisters entitled "Bounding Thermal Calculations for Individual Waste Package Placement," and a summary of thermomechanical calculations for predicting spall from the drift walls entitled "Very Near Field Thermomechanical Analysis Using Discontinuous Deformation Method."

Subactivity 1.5.3.5.2 - Development of uncertainty methodology. A paper entitled "The Role of Multiple Barriers in Assuring Waste Package Reliability" (Bradford) has been submitted to YMPO for approval.

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: Work will continue to complete LLNL contributions to TSPA 1993 including the temperature dependent processes in the engineered barrier system and near-field environment.

Work will begin on the engineered barrier system sensitivity studies based on TSPA 1993.

Work will continue on trade studies for waste package-Advanced Conceptual Design.

2.6.3.9 Activity 1.5.4.1 - Deterministic Calculation of Releases From the Waste Package

While not funded in FY 1993, improved waste package models were developed and release calculations were performed in support of the TSPA 1993 source term as described above.

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

This activity is currently in the prototype and planning stage. The revised Scientific Investigation Plan for waste package performance assessment has been approved for interim use and has been submitted to the Project. Improved waste package models were developed and release calculations were performed in support of TSPA 1993 as described above.

Forecast: No activity is planned for FY 1994.

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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 due to reduced funding levels in FY 1993.

Subactivity 1.5.5.1.2 - Radionuclide distribution in tuff cores. Samples of single crystals of clinoptilolite to be used for diffusion experiments were added to #1N, Na, K and Ca chloride salts, heated to 85°C, and are currently maintained at that temperature. These crystals were removed from the reaction flasks and embedded in epoxy in preparation for analysis by scanning electron microscopy and electron and ion probes. The single crystals were oriented so that (010), (100), and (001) crystal planes would be exposed for subsequent diffusion experiments. Additional single crystals were added to #1N Na, K, and Ca chloride salts at 85°C for future analysis. The preparation of a status report on diffusion in clinoptilolite was initiated.

Flow testing of the saw-cut fracture at ambient temperature showed that the automatic flow monitoring system is working. Small oscillations in the differential pressure and consequent flow are readily detected using this system. Flow-rate stability was difficult to maintain, apparently due to microbial fouling of the saw-cut fracture. At low differential pressures, the bacterial growth effectively shut down fracture flow. A sample injection loop was added to the flow-through apparatus and will be used for testing the behavior of a conservative tracer (Br^-). Preparation of a report on the test phase for the flow-through apparatus was initiated. Transmission electron microscopy analysis of effluent showed the presence of iron (hematite) and silicon oxides (quartz) that may be related to the sawing process.

A sample of Well UE-25 J#13 water was analyzed for colloids using light scattering. Samples of this water were prepared for transmission electron microscopy analysis.

Forecast: Work will continue on the flow testing experiment and the diffusion experiments using samples of single crystals of clinoptilolite.

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)

During the reporting period, a report entitled "Waste Package Engineering Development Task Plan" (CRWMS M&O, 1993n) was issued. This plan satisfies the requirement specified

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in the Waste Package Implementation Plan for a description of planned activities associated with Work Breakdown Structure 1.2.2.4.2.

The Waste Package Engineering Development Task Plan is to cover the entire engineering development period. Thus, the waste package engineering development tasks will be subject to periodic review by the M&O Waste Package Development Department, to verify that they still meet the waste package development needs. The plan will be revised as necessary to accommodate changes in the Waste Package Development Program; it is a controlled document and changes to it shall be controlled in accordance with applicable procedures.

The principal goal of the Advanced Conceptual Design phase of the Waste Package Program is to evaluate and develop a set of waste package design concepts that will satisfy NRC requirements. As part of this development process, evaluation of each waste package concept will be based on both technical feasibility and cost effectiveness of the manufacturing processes (for containment barrier fabrication, closure, and inspection). Designs that will be evaluated for fabrication will include spent nuclear fuel and defense high-level waste. Spent nuclear fuel waste package concepts will also include the multipurpose canister disposal container.

The specific engineering development tasks described herein involve test and evaluation of full or reduced-scale sections of various waste package design concepts during the Advanced Conceptual Design phase. 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 generated for each of the selected Advanced Conceptual Design and License Application Design design concepts.

Early in the License Application Design phase of the program, the evaluation of concepts developed during Advanced Conceptual Design will be completed and the final two (primary and alternative) waste package designs for spent nuclear fuel and defense high-level waste will be selected. The required manufacturing processes will influence the selection of the designs selected for further evaluation and refinement. Manufacturing studies during License Application Design will include full-scale prototypes that will be subjected to realistic system-imposed conditions.

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 interrelated tasks of fabrication, closure, and inspection is to identify and demonstrate the optimum manufacturing process for container manufacturing consistent with the functional and performance requirements of the application. The solution is complex because the manufacturing method affects the characteristics and properties of the product being produced. The effects must be understood and integrated into the overall

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program to achieve a selection of both materials and manufacturing methods that meet the design requirements, and perform satisfactorily for 1000 years and more. Processes selected should be technically conservative to ensure safety and long-term performance. In this regard, manufacturing costs should not impose sacrifices in construction methodology (i.e., cost is a concern, but not a top priority).

The objective of this development task is to select and develop fabrication techniques for several waste package container design configurations, with the exception of the lid closures (that subject is addressed separately in the next section), that are technically and economically acceptable and also may be conditioned during fabrication to minimize stresses. The multibarrier container configuration is a right cylinder made of two layers of material, probably configured with some integral lifting feature. The two layers may be a cylinder within a cylinder, or a single cylinder made of two-layer clad material. The waste material, whether multipurpose canister, spent nuclear fuel, or defense high-level waste, is then placed into the container at the repository site and the lids are installed. The development concerns are the fabricability of the design configurations and their relative cost, plus the need to minimize tensile stresses within the fabricated container.

2.6.5.2 Design Activity 4.3.1.2 - Waste Package Closure Process Development

The objective of this development task is to select and develop waste package remote closure welding processes that are technically and economically acceptable, and will also minimize stresses. Viable methods of repairing defective closure welds must also be developed. This remote closure task, as well as the waste package remote nondestructive examination task that follows, must be performed in concert with the waste package container fabrication task, because of the strong technical interrelationships between these tasks.

Installation of the waste package closure lids will take place at the MGDS repository surface facility, following placement of the waste within the waste package container. Each of the two closure lids must be separately remotely welded into place and remotely inspected to complete the envelope for each corrosion barrier. The primary development concerns are the combined choice of weld joint configurations and welding techniques to result in lowest possible post-weld tensile stress conditions, and of joint configurations that can be inspected. Various standard industrial remote closure welding processes will be investigated for each of the selected waste package container design configurations (evolved from the previous task). Other areas that must be considered include: quality of the closure welds (weld integrity, and good mechanical properties of the welds and heat affected zones), economy and time involved in making the closure welds (high deposition rate and minimizing amount of weld filler material), fully automatic remote closure welding equipment, the ability to use the same equipment for both the thin inner weld and thick outer weld, the capability of hardening the welding equipment to the anticipated levels of radiation exposure, and viable methods for repair of defective welds or for container replacement if weld repair should be unfeasible.

The fabrication industry is making continual advances in development of fully automatic remote welding equipment and process control to meet the combined challenges of:

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stricter quality standards, consistent quality and reduced rejection rate; adaptation to computer numerical control; computer monitoring of weld process parameters for quality assurance; cost control and labor cost reduction; improved health and safety standards; increased productivity through improved operating factors; and the expansion of worldwide competition.

This Program shares most of the aforementioned challenges. This development task is expected to benefit greatly from recent and near-future automatic remote welding advances, with the expectation that the needed level of technology already exists, or will be available. The implementation and adaptation of that technology to the circumstances of the waste package closure welds is what remains, which is the major endeavor of this development task. The waste package closure circumstances that require complete isolation of the welding activity within a hot cell, plus effects of the radioactive environment upon the welding equipment, are circumstances which tend to be outside those of the more stringent industrial welding conditions.

2.6.5.3 Design Activity 4.3.1.3 - Waste Package Closure Inspection Development

The objective of this development task is to select and develop nondestructive examination technique(s) that are technically and economically acceptable, and can accommodate the selected waste package materials, thicknesses, and geometries. As previously indicated, certain closure configurations may be incompatible with available nondestructive examination techniques, thus this task must be performed in concert with waste package closure configuration design activities. The nondestructive examination technique(s) finally chosen will have to prove the quality of both inner and outer closure welds for the chosen configuration for each waste package closure joint, both for the License Application Design prototype welds and for each and every closure weld made during production.

The types and sizes of flaws that might be encountered in the remotely welded joints must be well understood. Ongoing evaluations of weld test samples produced by the recommended weld methods will provide the data base necessary to characterize the weld defects and for subsequent nondestructive examination tests. Weld inspection methods must be selected which are capable of detecting the types of defects or flaws potentially produced by the weld method.

The condition of the completed weld (contour, surface finish) must be compatible with the inspection techniques. Post weld cleaning and metal removal may be necessary to provide a surface free of undercutting, splatter, ripple, etc.

Joint geometry will be a major concern in the development of the closure weld nondestructive examination. The ideal case would be one in which there are 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 is a clear straight line access to the weld in two orthogonal directions.

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2.6.5.4 Design Activity 4.3.1.4 - Remote In-Service-Inspection Development

The performance of the waste package, as specified by 10 CFR 60, requires a performance confirmation period. The objective of this development task is to select and develop remote in-service-inspection equipment and techniques that are technically and economically acceptable, and which can withstand the radiation dose and temperatures of the waste package environment. The needed equipment will consist of sensors, transmitters, and cabling to be installed in a selected area within the repository for the purpose of monitoring conditions therein. The sensors may be mounted on or around waste packages and/or sample material coupons, mounted on and within the drift rock walls both near and far from emplaced waste packages, and would also be located within any environmental monitoring stations as might be placed in the drifts. Parameters which may be expected to be of interest in order to monitor conditions within the repository will include: temperature, pressure, humidity, pH level, air velocity, strain gages, radioactivity level, and seismic accelerometers.

2.6.5.5 Design Activity 4.3.1.5 - Internal Filler Material Process Development

The use of waste package internal filler material versus filling the void space with an inert gas is an issue to be resolved. The choice will be determined by the benefits or penalties related to use of filler materials, as derived from future engineering studies and performance assessment analyses. Filler materials may be solids placed while in a liquid state such as low melting temperature metals, graded coarse granular solids such as iron shot, or fine materials such as dry cementitious mixes (e.g., sand and cement). Cementitious materials would be placed in the dry unreacted state. The material would remain unreacted until such time as the barriers might breach and water would enter the waste package interior, causing the material to react with the water and to solidify.

The purpose of this development task is to perform engineering development activities as may be defined by, and in support of, future engineering trade studies in regard to use of filler material within the waste package. The engineering study must first compare use of filler materials versus an inert gas in the void spaces within the waste package, followed by the comparison of various candidate filler materials. Specific activities will include the following areas: material placement including infiltration and uniformity of distribution in the presence of the internal basket and spent nuclear fuel assemblies, effective thermal conductivity measurements, and additional material properties at elevated temperatures as may be required.

This development task will support both the waste package and multipurpose canister engineering development activities. Filler material, if used, would be added remotely to a spent nuclear fuel container/canister following placement of the spent nuclear fuel assemblies into the basket, prior to closure of the container/canister. A manner of measuring the quantity of filler material would be required to establish that placement of the proper total quantity was accomplished, to confirm absence of voids within the space. In the case of the multipurpose canister, addition of filler material would take place at the MGDS.

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Use of waste package filler materials would assist in achieving several technical objectives. Among these are:

- Minimization of waste package internal void space to minimize the amount of water that could enter the waste package in the event of repository flooding and a breach of the waste package containment barriers
- Aid in transferring heat from the fuel rods
- Criticality control
- Chemical buffering for radionuclides

The use of fillers would increase waste package or multipurpose canister weight and cost.

Forecast: The Waste Package Engineering Development Task is scheduled to begin in FY 1994 and will continue through conclusion of the License Application Design phase.

2.6.6 Waste Package Performance (SCP Section 8.3.5.9)

2.6.6.1 Activity 1.4.1.1 - Integrate Design and Materials Information (Metal Container)

Revision of the Scientific Investigation Plan for the Metal Barrier Task (SIP-CM-01) has begun.

Staff from LLNL met with M&O staff on August 17, 1993, to discuss interfaces between the work scopes for the two organizations. The discussions principally involved evaluations and selections of waste package materials for the different configurations being considered in the Advanced Conceptual Design phase. A follow-up meeting on this subject was scheduled for September 2, 1993.

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.

Subactivity 1.4.1.1.5 - Characterization and inspection of weld integrity. No progress during the reporting period; this was an unfunded activity.

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Subactivity 1.4.1.1.6 - Characterization of the container surface. No progress during the reporting period; this was an unfunded activity.

Forecast: Work will continue on the assessment of degradation modes affecting bimetallic metal systems in preparation for the Advanced Conceptual Design of robust packages. Work will continue on the crack growth studies at Argonne National Laboratory.

2.6.6.2 Activity 1.4.1.2 - Integrate Design and Materials Information (Alternate Barriers Investigation)

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

Forecast: No activity is planned for FY 1994.

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.

Forecast: No activity is planned for FY 1994.

2.6.6.5 Activity 1.4.2.3 - Degradation Modes Affecting Candidate Austenitic Materials

Subactivity 1.4.2.3.1 - Assessment of degradation modes in austenitic container. The statement of work from Principal Investigators at Argonne National Laboratory was received and the interlaboratory agreement for continuation of the slow crack growth rate studies on Alloy 825 and other austenitic alloys was finalized. The studies involve application of a tensile load to precracked compact tension specimens exposed to laboratory-simulated J-13 well water at 95°C. The studies measure crack propagation by the very small changes in electrical resistance manifested as the crack grows, and the technique is sensitive to crack rates less than 10-12 m/s. The crack growth studies have been maintained since 1991.

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During that period, the crack propagation on Alloy 825 has been imperceptible. A progress report will be drafted at the end of FY 1993 on results to date.

The mechanical components of the crack growth measurement system have been completed for the new corrosion testing laboratory at LLNL. The initial system operation was checked out for the pump, heater assemblies, system leak check, and the efficiency of the heat exchangers. The heaters and heat exchanger operated as designed, and the pump appears to operate at a maximum of 26.5 L/h (7 gal/hr), a flow rate better than expected. A missing switch that controls the interlocks for pump and heater shutdown was ordered. The G.E. data acquisition and reversing DC system was turned on. A Project work plan was prepared for the crack growth testing and other experimental work. This work at LLNL will complement the work being performed at Argonne National Laboratory.

Subactivities 1.4.2.3.2 through 1.4.2.3.9. No progress during the reporting period; these were unfunded activities.

Forecast: Subactivity 1.4.2.3.1 - Work is proceeding on running shake-down tests to evaluate the software performance. Work is planned for conducting slow crack growth studies on carbon steels and other ferrous materials under repository-relevant environment conditions. Degradation mode studies of candidate austenitic materials will continue.

Subactivities 1.4.2.3.2 through 1.4.2.3.9 - No activity is planned for FY 1994.

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 metal systems. A high sensitivity thermogravimetric analysis unit will be procured. This unit will be used in an experimental study to discern at what point there is a transition between "dry" oxidation and "wet" corrosion. It is expected that the study will be conducted on a corrosion allowance material (such as carbon steel) with temperature, humidity, and surface condition as the principal variables. The transition between dry and wet conditions is very important with respect to performance of the container material and the design strategy for keeping the waste package in a "dry" condition for an extended period of time.

An experimental arrangement is being designed for use in conjunction with the thermal gravimetric analysis system for monitoring the low corrosion and oxidation rates in low and high humidity environments. Experiments are planned over a temperature range from

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ambient to above the normal boiling point of water and humidities ranging from very dry to saturation. Staff has been in contact with Cahn Microbalances, Inc. on the status of the thermogravimetric analysis unit.

Following discussions with U.S. Geological Survey (USGS) Principal Investigators, staff visited the REEC Co Subdock in Area 25 on May 11, 1993, to examine a carbon steel tubing string that had been removed from Well USW H-5 on the north side of Yucca Mountain. The string had been used as a conduit for an instrument package placed in the well and had been exposed in the well for more than ten years. The string was about 1100 m in length and traversed both the unsaturated and saturated zones. The water level was 705 m from the surface, the well was cased to a depth of around 750 m. It was very evident which part of the string was immersed in water and which part was exposed to the atmosphere. There was little corrosion of the part that was exposed to the atmosphere. In fact, most of the original stenciling on the tubing was still intact. The part immersed in the water showed abundant corrosion products, apparently ferric oxide.

Samples from different parts of the string were shipped to LLNL for characterization. The steel used for the string is American Petroleum Institute Grade J-55, a common carbon-manganese steel used in petroleum wells. Samples of a string recently pulled from the WT-2 well were received at LLNL for evaluation. Samples exposed in the saturated zone from this well appear to be much less corroded than those obtained from the H-5 well, even though the time of exposure was the same (ten years). Information received from USGS Principal Investigators involved in these wells, and others, suggests that the depth of the well, the particular tuff layer, the fracture pattern in the rock, and the flow rate are important in determining the corrosion rate, since these factors govern the transport of oxygen that can reach the corroding steel surface. A report on the observations of steel exposed in these wells is being prepared. This information will be incorporated in the evaluation of steel as an overpack material in different waste package designs being considered by the Project.

Work continues on compiling information on the corrosion and oxidation behavior of carbon steels, cast irons, and low-to-intermediate-alloy steels. An experimental plan for studying the degradation (oxidation and corrosion) of materials in humid environments is also being prepared. The emphasis of this work will be on carbon steel and other iron-base materials and will focus on the effect of humidity and temperature in the transition from oxidation under "dry" conditions to corrosion under "wet" conditions. A system was designed for generating different humidity levels. This system will be used in conjunction with the thermal gravimetric analysis unit that was recently ordered as part of the YMP capital acquisition and will be used for the degradation mode survey on this family of materials.

Staff has completed a draft of the degradation mode survey on carbon steels, cast irons, and low-alloy steels. These materials are corrosion allowance materials that could be used in multiple-barrier waste package designs. The survey is undergoing internal technical review.

Subactivity 1.4.2.4.4 - Laboratory test plan for bimetallic/single metal material systems.
No progress during the reporting period; this was an unfunded activity.

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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 expected delivery date of the thermogravimetric analysis unit is October 15, 1993. Assessment of degradation mode studies affecting bimetallic metal systems will continue in FY 1994.

Subactivities 1.4.2.4.1, 1.4.2.4.2, 1.4.2.4.4 through 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. Staff met with personnel from the Performance Assessment Technical Area to discuss previous work with pitting survivability models and how this work might be applicable to the performance of a corrosion resistant material under repository environmental conditions.

Subactivities 1.4.3.2.7 and 1.4.3.2.8. No progress during the reporting period; this was an unfunded activity.

Forecast: The studies in Subactivity 1.4.3.2.6 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 unfunded activity.

Forecast: Work on this activity will begin during FY 1994.

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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

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

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.

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SECTION 2.7 PERFORMANCE ASSESSMENT

The Performance Assessment Program was assigned two high-level priorities for fiscal year (FY) 1993: (1) to support Exploratory Studies Facility (ESF) construction and surface-based testing support through Waste Isolation Evaluations, and (2) to carry out the Total System Performance Assessment (TSPA) 1993 exercise. In addition, the performance assessment function is providing input to one of the top Regulatory & Licensing Department's initiatives, which is the evaluation of possible alternative regulatory requirements.

Waste Isolation Evaluations

In terms of the first initiative, the M&O Performance Assessment Department provided the following 46 ESF construction and surface-based testing support Waste Isolation Evaluations:

- Waste Isolation Evaluation for YMP Temporary 69-kV Power Distribution System
- Waste Isolation Evaluation, Road Oyl and EMC², Dust Suppression and Soil Stabilization Products
- Waste Isolation Evaluation, Need for Separate Rock Storage Areas for Topopah Spring and Calico Hills Muck
- Waste Isolation Evaluation, TFM (Tracers, Fluids, and Materials) for C-Well Pump Tests
- Waste Isolation Evaluation, TFM for UE-25 NRG#4, Electrical Grounding Grid
- Waste Isolation Evaluation, Drilling of USW SRG-5
- Waste Isolation Evaluation, Drilling of UE-25 NRG#2 and UE-25 NRG#2A, Supplement #1
- Waste Isolation Evaluation, Drilling of UE-25 NRG#5, Supplement #1
- Waste Isolation Evaluation, Package 1A Water Supply System for the Exploratory Studies Facility
- Waste Isolation Evaluation, Package 1B Surface Buildings, Parking, and Compressed Air Facility
- Waste Isolation Evaluation, Fran Ridge Large Block Experiment
- Waste Isolation Evaluation, Concrete Batch Plant
- Waste Isolation Evaluation, Drilling of UE-25 NRG#2B

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- Waste Isolation Evaluation, Package 1A Water Distribution System for the Exploratory Studies Facility
- Performance Assessment Concerns Regarding a Diesel Transportation System to Service Tunnel Boring Machine (TBM) Operations
- Waste Isolation Evaluation, Package 2A Extension of the North Ramp Starter Tunnel
- Waste Isolation Evaluation, Tracers, Fluids, and Materials for North Ramp Starter Tunnel Testing and Construction, Supplement #1
- Waste Isolation Evaluation - Different ESF Ramp/Drift Sizes - Thermo-Mechanical and Flow and Transport
- Waste Isolation Evaluation TFM for North Portal Pad Substation & 69-kV Power and Feeder System
- Waste Isolation Evaluation, ESF Subsurface Wastewater Pond, Pkg 1B
- Waste Isolation Evaluation, Shop, Pkg 1B (Package 1B Surface Buildings Supplement #1)
- Waste Isolation Evaluation, H-Road Widening and Paving, Pkg 1B (Pkg 1A Water Supply System Supplement #1)
- Waste Isolation Evaluation, Package 1B Sewer System
- Waste Isolation Evaluation, ESF Explosives Storage Area, Pkg 1B
- Waste Isolation Evaluation, Excavation Trenches along Solitario Canyon Fault
- Waste Isolation Evaluation, Drilling and Testing of USW SD-12
- Waste Isolation Evaluation, ESF Package 1A North Ramp Alcove #1
- Waste Isolation Evaluation, TFMs for North Ramp Starter Tunnel Testing and Construction, Supplement #2
- Waste Isolation Evaluation, ESF Package 1A North Ramp Alcove #1: Rev. 01
- Waste Isolation Evaluation, TFMs for FY-1993 ESF Phase 1A Construction, Rev. 02
- Waste Isolation Evaluation, Package 1A Water Supply System for the ESF, Rev. 01

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- Waste Isolation Evaluation, USW UZ-14 Perched Water Grouting Plan
- Waste Isolation Evaluation, USW NRG-7 Drill Pad and Access Road
- Waste Isolation Evaluation, Midway Valley Alice Ridge Trenching
- Waste Isolation Evaluation, Package 1A Water Distribution System for the ESF, Rev. 01
- Waste Isolation Evaluation, TFMs for North Ramp Starter Tunnel Testing and Construction, Supplement #2, Rev. 01
- Waste Isolation Evaluation, Seismic Reflection Line, ESF Support
- Waste Isolation Evaluation, TFMs for the UE-25 C-Well Complex, Rev. 01
- Waste Isolation Evaluation, ESF Package 1B Explosives Storage Area, Rev. 01
- Waste Isolation Evaluation, ESF Package 1B Surface Buildings, Parking, and Compressed Air Facility, Supplement #1, Rev. 01
- Waste Isolation Evaluation, TFM, for the ESF North Portal Pad 69-12.47 kV Electrical Power, Site Grounding and Lightning Systems, Rev. 01
- Waste Isolation Evaluation, H-Road Widening and Paving, Rev. 01
- Waste Isolation Evaluation, ESF Package 1A North Ramp Alcove #1, Rev. 02
- Waste Isolation Evaluation, TFMs for North Ramp Starter Tunnel Testing and Construction, Supplement #2, Rev. 02
- Waste Isolation Evaluation, Additional Grouting of Perched Water Zones in USW UZ-14
- Waste Isolation Evaluation, Drilling of USW NRG-7

Preparing Waste Isolation Evaluations involves the inspection of design analyses, drawings, and specifications from a performance assessment viewpoint to ensure that the facilities will not impact waste isolation and to recommend design changes if necessary. In support of surface-based testing, this includes the review of designs of facilities such as access roads, drill pads, and water lines. For the ESF, it includes reviews of the ESF design packages being prepared during FY 1993: the North Ramp Starter Tunnel redesign, the North Portal surface facilities, the North Ramp, the South Portal, and the Topopah Spring Level main drift.

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The M&O performance assessment staff conducted the following three generic evaluations in support of ESF design and surface-based testing (all currently undergoing internal review): (1) an evaluation of ESF and surface-based testing tracers, fluids and materials, to determine their potential impacts on waste isolation and to recommend any constraints on their use; (2) an evaluation of ranges of ESF ramp and drift sizes being considered, to determine differences in impacts, if any, on potential repository preclosure radiological safety and postclosure waste isolation; and (3) a comparison of drill-and-blast ESF excavation with mechanical excavation techniques (including tunnel boring machines) with respect to potential repository preclosure radiological safety and postclosure waste isolation impacts.

In addition, Sandia National Laboratories (SNL) completed two performance assessments in support of establishing water use controls and requirements for the ESF.

Total System Performance Assessment

The second performance assessment initiative was the effort called TSPA 1993, which included work in many areas of data analysis and model development supporting the top-level analyses. This is discussed in more detail in Section 2.7.6. A brief summary of these activities follows.

TSPA Calculations

- SNL completed and published sensitivity studies on TSPA 1991 (April 15, 1993).
- The M&O and SNL constructed the TSPA 1993 problem set and developed source-term and site system data with Los Alamos National Laboratory (Los Alamos), Lawrence Livermore National Laboratory (LLNL), M&O, and U.S. Geological Survey (USGS) participation.
- The M&O and SNL completed the bulk of the TSPA 1993 calculations, and are drafting reports to be completed by end of calendar year 1993.
- The M&O, through Golder Associates Inc., issued three documents describing the Repository Integration Program total system code, one giving the structure, another providing user guidance, and the third describing the Yucca Mountain data set (February 22, 1993, April 20, 1993, and September 30, 1993).

Source-Term Modeling and Model Development

- The M&O, through Pacific Northwest Laboratory (PNL), prepared two documents providing the mathematical description and software requirements for the next generation source-term model currently being developed (June 15, 1993, and September 30, 1993).

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- The LLNL staff prepared the source term for the TSPA 1993 exercise participants, and provided a preliminary version of the Yucca Mountain Integrating Model to SNL (August 1993).

Development of Scenarios for use in TSPAs

- The SNL staff continued to make progress in describing volcanism scenarios, and is ready to publish the first report on this topic entitled "Scenarios Constructed for Basaltic Igneous Activity at Yucca Mountain and Vicinity."
- The SNL staff continued work to define nominal flow scenarios.

Unsaturated and Saturated Zone Flow Modeling and Model Development

- The M&O submitted a draft report on the Review and Selection of Unsaturated Flow Models (September 30, 1993).
- The SNL staff completed development of a transient gas flow model for use in TSPA 1993 (September 30, 1993).
- The SNL staff developed an updated three-dimensional saturated zone flow model for their use in TSPA 1993.
- Work on understanding unsaturated flow was described by Lawrence Berkeley Laboratory (LBL) in a number of presentations to various audiences, and two documents were produced describing a TOUGH-2 code enhancement and application.

Calculations and Experimental Work Supporting TSPA

- The M&O, through the University of California at Berkeley, produced two draft papers on thermal effects in the near field environment (September 15, 1993).
- The USGS staff reported progress in experimental and modeling work addressing infiltration rates and the potential for lateral flow in Yucca Mountain was reported in four conference papers and two draft reports.
- Joint experimental work on validating radionuclide transport modeling and on understanding fracture flow continued between SNL and Los Alamos.

Alternative Regulatory Requirements

The M&O performed calculations in support of U.S. Department of Energy (DOE) positions on potential new environmental standards for Yucca Mountain. The calculations were begun using the model UCBNE-41, which was the basis for the National Academy of Sciences Waste Isolation System Panel report (Pigford et al., 1983). Initial results were

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compared to results, and sensitivity analyses were conducted over ranges of parameters that include values similar to those at Yucca Mountain. More detailed assessments were conducted using the Repository Integration Program. This model is the basis for the M&O contribution to TSPA 1993. In addition, the effects of natural uranium ore bodies are being compared to the effects of a potential repository. These calculations consist of a series of simple performance assessments of a repository at Yucca Mountain, and have been used to begin to formulate DOE positions on issues related to environmental standards for Yucca Mountain. The DOE positions as well as the calculations that support them will be ready for presentation to the National Academy of Sciences' Committee on Technical Bases for Yucca Mountain Standards when that body requests DOE input. The preliminary results of the calculations were presented to the Nuclear Waste Technical Review Board in July 1993, and the detailed results will be presented to that technical oversight group early in 1994.

Detailed descriptions of performance assessment accomplishments for the second half of FY 1993 are presented in the appropriate subsections of Sections 2.6 (2.6.3.8) and 2.7 (all).

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)

A report entitled "Preclosure Radiological Safety Evaluation" (Schelling and Smith, 1993) closed out SNL participation in this activity. This report describes the use of standard probabilistic risk assessment methods to evaluate the impact of ESF design changes (from the original vertical shaft configuration to the current dual ramp configuration) on previous public radiological risk evaluations and to estimate the level of uncertainty in the assessment results. This activity has now been transitioned to the M&O.

Forecast: No direct activity in FY 1994; see Section 2.7.3 for related work.

2.7.3 Worker Radiological Safety - Normal Conditions (SCP Section 8.3.5.4)

The M&O conducted an initial preclosure probabilistic risk assessment on items important to safety for the ESF components that could be incorporated into the Mined Geologic Disposal System (MGDS). This initial study was conducted using proprietary spreadsheet software to provide a timely response. Individual areas of work included collection and analysis of mining rock-fall data and transportation accident data; quantifying radioactive waste container releases arising from energetic events; radionuclide transport in the MGDS ventilation system; atmospheric dispersion; and potential exposure levels to the

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general public outside the restricted area. Statistical methods were used to incorporate, in the overall assessment, the uncertainties present in the accident and rock-fall data.

The preliminary findings of the probabilistic risk assessment showed that if the MGDS is to have a high reliability two-stage high-efficiency particulate air filter then the ESF components to be incorporated into the MGDS do not have to be on the Q-List. If only a single stage high-efficiency particulate air were to be deployed in the MGDS and a thin (10 cm) walled container is used, then ESF (and the waste transporter) are marginal in meeting the statutory requirement and thus would have to be included on the Q-List. An analysis of the ESF/MGDS system indicated that the greatest uncertainty in the predictions arise from the simple (1½ dimension) model used to predict the response of, and subsequent release from, the nuclear waste container following a rock-fall or transporter accident.

Rock-fall likelihoods and consequences were estimated from an analysis of mining rock-fall data and underground transportation accident data. Using the Bureau of Mines Accident Data Analysis program, such data was obtained from the collection of mining accidents managed by the Health and Safety Analysis center of the Mine Safety and Health Administration. The analysis was performed using mining accident statistics over the period of the last ten years and the configuration of the ESF main drift shown in ESF Title II Design.

The M&O performed numerical calculations using the Discontinuous Deformation Analysis method to assess tunnel stability under the expected range of thermal loads. Specifically, the model enables the representation of a discontinuous system of rock blocks separated by joints, allowing relative movement of individual rock blocks that may be undergoing block deformation, rigid rotation, and translation. Friction/cohesive discontinuous joint surfaces are considered. Elastic blocks and elastic contact between blocks were addressed; however, energy dissipation occurs during sliding. Quasi-static mechanical effects of the tunnel excavation, thermal effects of a ten-year temperature field (added instantaneously to the rock mass around the tunnel), and thermal effects of instantaneous removal of the temperature field around the tunnel were modelled to provide qualitative descriptions of thermal loading effects on the stability of a repository drift.

Forecast: This work will be documented for review by the M&O and subsequently by DOE. The report will contain recommendations for future work. At present two areas can be identified for improvement: (1) container modeling, and (2) incorporation of actual Yucca Mountain meteorological conditions into the atmospheric dispersion calculations.

2.7.4 Accidental Radiological Release (SCP Section 8.3.5.5)

Potential effects of accidental rock falls were addressed in Section 2.7.3.

Forecast: See Section 2.7.3.

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2.7.5 Ground-Water Travel Time (SCP Section 8.3.5.12)

The Ground-Water Travel Time Issue Resolution Working Group met in Las Vegas in September 1993, and is currently examining the technical aspects of ground-water flow at Yucca Mountain. The primary objective is to develop a methodology for demonstrating compliance with regulations related to natural barrier performance that is technically prudent and acceptable to the NRC.

2.7.5.1 Activity 1.6.2.1 - Model Development

The M&O performance assessment staff finished its previously reported review of unsaturated flow models in use in the Yucca Mountain Site Characterization Project (YMP), and recommended a limited subset of those in use for continued development. Review results were summarized in a paper entitled "Review and Selection of Unsaturated Flow Models" (Reeves et al., 1993) presented at the 1993 High-Level Waste Conference. A draft report was submitted to YMPO for review.

Forecast: The completed report will be published after YMPO review. Its recommendations are already being implemented, and are reflected in the discussions of cooperative code development work in Section 2.7.5.3.

Subactivity 1.6.2.1.1 - Development of a theoretical framework for calculational models. M. Harr from Purdue University visited SNL August 9-11, 1993. While at SNL, he reviewed the methods for generated random, auto-correlated fields (covered in the memo discussed above) that were developed at Purdue as a software package in support of YMP.

The performance assessment staff from DOE and the M&O were briefed by SNL in Las Vegas, Nevada, on August 23, 1993, on advanced geostatistical simulation and economic decision modeling that has been done in support of the DOE/Headquarters Office of Environmental Restoration and Waste Management, Environmental Restoration Demonstration Testing and Evaluation Division. Possible applications to the YMP were discussed. A copy of the Purdue software was also demonstrated and a copy of the package was left with DOE for review.

Subactivity 1.6.2.1.2 - Development of calculational models. No progress during the reporting period; this activity was not funded in FY 1993. See related work in Section 2.7.5.3.

Forecast: No activity is planned for FY 1994. See related work in Section 2.7.5.3.

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2.7.5.2 Activity 1.6.2.2 - Verification and Validation

Subactivity 1.6.2.2.1 - Verification of codes.

Appropriateness of One-Dimensional Calculations:

A report entitled "The Appropriateness of One-Dimensional Yucca Mountain Hydrologic Calculations" (Eaton) was written to help in defining the calculational regimes for which one-dimensional calculations are valid for approximating aqueous flow for TSPA-type calculations. The report is in policy review at YMPO, and a summary of the report will be included in the TSPA 1993 report.

Fracture Permeability Effects on Dryout:

The effect of fracture permeability on the dryout of a nuclear waste repository was investigated in a series of calculations using the multiphase code TOUGH2. The material properties used in this study were based on values from Buscheck and Nitao (1993). The calculated saturation results based on these material characteristics for a highly fractured media predicted considerable dryout in the vicinity of buried waste and a large perched water region above the potential repository horizon for times exceeding 10,000 years. However, when the permeability of the fractures were reduced by a factor of 10^4 , the size of the dryout and perched regions were significantly reduced. Furthermore, when the values for fracture permeability were reduced by more than a factor of 10^4 , these regions were essentially nonexistent. The latter reduction represents a decrease in fracture aperture from 100 to 5.1 μm . It should be noted that the algebraic model used to define the material properties can also significantly affect calculated values of water perching and dryout in the vicinity of the repository. These results indicate the importance of accurately modeling fractures when calculating the presence of multiphase flow in the vicinity of a potential repository.

Barometric Pumping Simulations:

The SNL staff have been modeling the amount of water vapor extracted from Yucca Mountain via fluctuations in barometric pressure. A method-of-lines code for two-phase flow in porous media and for modeling barometric pumping of water vapor in a discrete fracture/matrix system has been undergoing testing and application to estimate respired moisture from Yucca Mountain. The code compared well with results obtained by recomputing a heat pipe problem done at LBL using TOUGH. The coupling between fracture and matrix models was tested by simulation of an analytical solution to periodically driven diffusion in a fracture/matrix system. This comparison was also excellent.

Two barometric cycles are being studied: the diurnal cycle and a five-day cycle typically caused by storm fronts. The latter cycle appears to be most effective in transporting moisture out of the upper layers of Yucca Mountain.

Forecast: The results of the fracture permeability study are based on material properties provided by LLNL investigators. Since the time that those property values were

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developed, new information has required some modification of the data set by SNL. The new data set will be used for ancillary calculations to be reported as part of TSPA 1993. In addition, a subset of the calculations reported here will be rerun to determine the degree to which the new data set causes changes in the predicted effects.

Documentation of the results of all of these studies is under way and will be included as ancillary calculations in the SNL report on TSPA 1993.

Subactivity 1.6.2.2.2 - Validation of models.

Flow and Transport Through Single Fractures:

The purpose of this task is to challenge existing conceptual models of fracture flow and explore possible rapid transport mechanisms that may be relevant to performance assessment at Yucca Mountain. The SNL staff made three presentations on the results of this work at the Spring '93 American Geophysical Union Meeting in Baltimore, Maryland, May 24-28, 1993: "Influence of Fracture Saturation and Wetted Structure on Fracture Permeability" (Nicholl and Glass, 1993a), "Infiltration Flow Instability in Unsaturated Fractures" (Nicholl and Glass, 1993b), and "Gravity-Driven Fingering in Rough-Walled Fractures: Analysis Using Modified Percolation Theory" (Glass, 1993).

A paper entitled "Gravity-Driven Infiltration Flow Instability in Initially Dry Non-Horizontal Unsaturated Fractures" (Nicholl et al., 1993) was submitted to the journal Water Resources Research. A copy of the paper was sent to YMPO; and a paper entitled "Behavior of Individual Gravity-Driven Fingers in an Initially Dry Fracture" (Nicholl and Glass) is in SNL internal technical review.

A collaborative effort was established as part of the international cooperative research project work at LBL to consider the effects of gaseous exsolution/dissolution on fracture flow. Questions regarding the potential significance of such effects in the vicinity of excavations have arisen during field testing. A second collaborative effort was also established with LLNL to participate in the nonisothermal large block heater test at the Fran Ridge test site. Fracture connectivity will be examined under natural gradient conditions within the Topopah Spring welded tuff. A third collaborative effort was initiated with staff of the University of Nevada, Reno, to analyze fracture flow data obtained from laboratory experiments in individual analog fractures under both saturated and unsaturated conditions.

Development of a methodology to manufacture analog fractures continued. Numerically controlled milling techniques may be used to directly manufacture analog fracture surfaces to predetermined specifications. Two such surfaces may then be used to create a controlled analog aperture field. The ability to replicate a specific aperture field is limited by the physical dimensions of the cutter and the increment between cutting centers. Methods of moving the cutter head may also impart structural features to the surface. Such physical limitations were explored in preparation for subsequent fracture manufacture.

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Casts of both manufactured fractures and natural fractures will be used for actual experimentation. Methodologies for making transparent casts were further refined. Various casting materials were considered as a means of varying mechanical properties and surface wettability of the analog fracture. A significant effort was directed towards obtaining better control of boundary conditions in the analog fracture. As a result, a technique allowing inflow and outflow manifolds to be machined directly into the fracture surfaces was developed.

Development of experimental techniques to explore the effects of air entrapment on fracture permeability and tracer migration continued. The cooling system for the high-resolution camera was reworked to include filtration of the water supply and a relay to shut off the camera, should the supply of cooling fluid be interrupted during a long term test. The computer actuated solenoids controlling flow through the fracture were restructured to minimize mixing of tracer fluids prior to entry and to also minimize air entrapment around the valves themselves. Aperture field of the analog fracture to be used was characterized using simple light absorption theory. Saturated permeability was measured for a baseline and a sequence of unsaturated experiments were initiated. Results of this sequence will be submitted to the 1994 High-Level Waste Conference.

Fracture/Matrix Interaction:

The purpose of this task is to challenge existing conceptual models describing the transfer of fluids and solutes between fractures and the host matrix (fracture-matrix interaction), and to explore the impact of fracture-matrix interaction on rapid transport mechanisms.

Experimental apparatus allowing observation of fracture wetted structure as a function of matrix pressures was updated and refined. A high resolution digital camera was installed; this system yields 1024 x 1024 pixels of spatial resolution at 4096 gray levels intensity resolution. A relay to shut off the camera if flow of cooling fluid ceases was also fabricated and installed. Low resolution cameras (256 x 256 pixels, 256 gray levels) to provide backup data and monitor manometers were also installed. Software controlling data acquisition and pressure variation was refined and tested. The experiment was slightly reconfigured to allow for a greater range of pressure variation. Additional light shielding was added to attenuate spurious data resulting from internal reflections and light leaks. After collecting a series of test images, the utility of the IP-Lab software package by Signal Analytics for image analysis was explored. First drafts of the experimental procedure and data sheets for the scientific notebook were written.

A large format test chamber for investigating the effect of matrix imbibition on saturated fracture flow has been constructed. Experiments make use of naturally and synthetically fractured slabs of volcanic tuff. The new test chamber is capable of securing multiple fractured rock slabs measuring 60 by 60 cm. Refinement of the experimental technique has also been made to achieve desired boundary conditions (upper flux boundary and lower prescribed tension boundary). A suite of rock slabs have also been cut (from Topopah Spring Tuff) for use in these experiments.

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The enlarged test system has recently been tested using two slabs of Topopah Spring Tuff. X-ray absorption was used to image the transient saturation fields as fluid imbibed into the tuff slabs from a 100 μm slot fracture. Following full saturation of the matrix by a KI solution, deionized water was introduced into the fracture and the transient diffusion of the deionized water into the KI saturated matrix was imaged by x-ray absorption. Tuff slab heterogeneity was noted to have significant influence on the imaged imbibition and diffusion fields.

A Philip's industrial x-ray machine, which was purchased for imaging of flow experiments in the YMP Unsaturated Flow and Transport Laboratory, was temporarily set up at the Non-Destructive Testing Laboratory at SNL. The x-ray unit is currently being utilized in experiments, such as the tuff-slab test. Design of a facility for permanent operation of the x-ray is in progress.

Forecast: Unsaturated flow experiments conducted on a block of fractured welded tuff, performed approximately one year ago by USGS, yielded some unexpected and currently unexplainable results. In an attempt to understand what happened in this experiment, a joint laboratory program involving USGS and SNL was initiated. A suite of experiments are being designed to take advantage of the special capabilities developed by each of the participants in the experiment. In particular, SNL will contribute x-ray imaging capabilities as well as expertise in unsaturated flow experimentation. Current plans call for the USGS tuff block to be shipped to SNL early in FY 1994.

Experiments continue in efforts to develop real-time x-ray analysis capabilities. Currently, investigations are conducted in two systems, a simple x-ray detector/image intensifier system, and the more sophisticated Siemen's Polytron. The goal is to achieve a high image contrast for unsaturated flow systems with short time constants.

Field, Lab, and Numerical Experimentation to Determine Scaling Laws for Effective-Media Properties in Heterogeneous Media:

The purpose of this task is to challenge existing conceptual models for the scaling of effective media properties which are critical to performance assessment at Yucca Mountain. Experiments and analyses are designed to investigate fracture-matrix interaction in the plane of the fracture and in the plane normal to the fracture. These activities provide critical understanding necessary for the formulation of effective media properties that integrate over fracture-matrix interaction subscale processes. Both basic understanding and the effective property formulations are required by other model validation activities, including collaborative initiatives with USGS to examine fracture matrix interactions using x-ray imaging technology developed at SNL in support of this activity.

Several of the activities are aimed at acquiring the understanding necessary to develop models for scaling data collected at one scale and applied to another. This effort will be coordinated with complementary work on geostatistical characterization of heterogeneity (see Section 2.2.3.7).

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To improve measurement precision and facilitate data collection, an automated gas permeameter test system has been constructed. The permeameter consists of four mass flow meters (0-50, 0-500, 0-2000, and 0-20,000 sccm), two pressure transducers (0-100, and 0-350 kPa gauge), a barometer, and temperature sensor that are connected to a regulated source of compressed nitrogen. Operation of the electronic permeameter instruments and solenoids (electronic valves) are controlled by specially adapted personal computer-based software. An x-y positioning system coupled with a pneumatic piston was also automated for positioning and compressing the permeameter tip seal against the rock surface. This system allows over 400 measurements to be made in an eight-hour period, unattended. Data collection routines have also been automated and are used on a periodic basis to assess instrument stability and precision.

Tests have been completed aimed at evaluating permeameter sensitivity, measurement repeatability, and temporal stability. Data collected to date indicate that measurement sensitivity and repeatability are within the specifications of the electronic permeameter equipment (0.5 percent full scale). Calibration of the mass flow meters, and pressure transducers has also been accomplished. An improved seal material has been identified and tested (room temperature vulcanizing silicone rubber) that will facilitate measurements made on rough rock surfaces. Additional permeameter tip seals were designed and constructed. At present a suite of tip seals exist that represent measurement scales spanning five orders of magnitude on a per volume basis.

Forecast: A task order has been established and a statement of work developed for acquiring tuff boulders from the Yucca Mountain site. Four tuff blocks have been identified for experimentation, each exhibiting varying degrees of welding and bedding as well as extent and size of lithic/pumice/lithophysae inclusions. Once the boulders are collected they will be sawed into blocks measuring 1.0 to 1.3 m³. Until the large tuff blocks are received (expected by early October 1993), measurement of gas permeability at multiple scales is being conducted on tuff slabs to be used in the fracture-matrix interaction studies described above.

Fast Pathway Analysis in Unsaturated Fractured Tuff: Analog Field Site Investigation

This study addresses issues concerning the occurrence of localized zones of saturation in otherwise unsaturated media which may act as fast pathways through the unsaturated zone at Yucca Mountain.

Through detailed literature review, a data base was formed that details characteristics of sites in which localized flowing water (seeps or weeps) are present. Efforts were made to correlate various boundary conditions and system parameters with the occurrence of such features. This search has investigated numerous sites across the southwest including the Apache Leap Tuff site in Arizona and the Nevada Test Site.

Caisson Test:

An intermediate-scale experiment is being carried out jointly between SNL and Los Alamos to evaluate instrumentation and models that might be used for transport-model

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validation for the YMP. The experiment involves the detection and prediction of the migration of fluid and tracers (Ni, Li, and Br) through 6-m-high x 3-m-diameter caisson filled with quartz sand.

Caisson design. The final design of the caisson, including locations of time domain reflectometry probes and ceramic and hollow fiber solution samplers, was completed and submitted to Los Alamos prior to filling of the caisson.

Ni sorption and solubility. Systematic studies of sorption of Ni by Wedron 510 sand under atmospheric conditions at two different Ni concentrations (100 ppb and 200 ppb) in the presence and absence of LiBr (17 ppm Li and 200 ppm Br) showed no dependence of Ni sorption on Ni concentration over the range studied, and suggest that Ni sorption under atmospheric CO₂ conditions is equivalent or slightly higher than under CO₂-free conditions. The studies of Ni and Li sorption suggested that Li at high concentration can compete with Ni for sorption sites. Studies aimed at refining the sorption curve for Ni of Wedron 510 sand under nominally CO₂-free conditions yielded data that are being used to calculate surface complexation constants.

A kinetic batch sorption study was run to determine the time dependency of Ni sorption by Wedron 510 sand. After one-half hour, 94 percent of the Ni had been sorbed, suggesting that equilibrium was reached during previous batch experiments, which were mixed for two to three days.

Satisfactory solubility data for Ni has been obtained over the pH range 7-10. The measured solubility exceeds that for crystalline Ni(OH)₂ by an order of magnitude or more, and suggests that there is no danger of precipitation occurring in the batch sorption studies using 100 ng/mL initial Ni for pH <8.5. The precipitate formed in the Ni solubility experiment was identified as predominantly Ni(OH)₂ by x-ray diffraction.

LiBr Sorption. A second systematic study of sorption of Br by Wedron 510 sand under CO₂-free conditions was completed and reduced the uncertainty of the K_d value for the conservative tracer for the caisson experiment. Studies of Li sorption under atmospheric conditions were performed. Measured sorption was close to 0 at pH = 7, and dropped to -5 percent at pH >8. In contrast, experiments run under CO₂-free conditions show sorption of 20-25 percent at pH = 7, dropping to about 5 percent at pH = 10. It is probable that Na added at pH >7 as NaOH, almost certainly acts as an ionization suppressant during AA analysis, increasing the signal for Li in the electrolyte, and causing a spurious drop in the K_d values measured for Li in samples above pH = 8. The offset between the atmospheric and CO₂-free data sets may be due to a similar effect.

LiBr column experiments. Two LiBr pulses were eluted from saturated Wedron 510 sand columns (5-cm diameter by 30-cm tall). Analysis of Br by ion-selective electrode and Li by flame atomic absorption and fitting of the breakthrough curve by CXTFIT determined retardation factors of 1.06 and 0.96 for Li and Br, respectively. Dispersion coefficients were 0.017 and 0.0023, respectively, for Li and Br. The two runs differed in the way the sand columns were packed, the first with micro-layering and the second homogeneously. The

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results indicated that these differences in the packing method did not significantly affect the breakthrough curve. The retardation factor of less than one for Br is consistent with anion exclusion, causing the Br to flow in the center of the pores where the velocity is higher than average. Kinetic batch sorption experiments were conducted for Li with Wedron 510 sand. Preliminary results show that there is a finite sorption rate that would affect breakthrough curves. The column breakthrough data were analyzed with a kinetic sorption expression with the CXTFIT code to compare the extracted reaction rate constant with the rate constant measured in the batch experiments.

Several unsaturated hanging column experiments with Wedron 510 sand and a LiBr tracer were performed. Both a pulse and a continuous feed of LiBr solution were used, and retardation factors and dispersivities for Li and Br were calculated. Similar experiments with different flow conditions are under way, and experiments with Ni transport were designed.

Interlaboratory calibration studies. The atomic absorption results for Ni and Li analyses were independently checked on a number of samples by inductively-coupled plasma mass spectrometry, with good agreement between the two methods. Ni sorption experiments were performed using the batch sorption techniques described in Los Alamos Detailed Technical Procedures TWS-INC-DP-05-R2 and LANL-INC-DP-86-R0. The data from these experiments were compared with those collected in previous studies at SNL. A solution produced by leaching the Wedron 510 sand and adding a Ni spike was prepared for an interlaboratory calibration with the University of Nevada, Las Vegas. Techniques for analysis of Ni, Br, Li, Ca, and Mg used at SNL and the University of Nevada, Las Vegas for the caisson test were compared. In addition, several Li samples were prepared to be run by inductively-coupled plasma spectrometry as an accuracy check on our atomic absorption method.

Forecast: SNL and Los Alamos will complete an intermediate-scale experiment at the Experimental Engineered Test Facility at Los Alamos. The experiment involves the detection and prediction of the migration of fluid, colloids, and tracers (Li, Br, Ni) through unsaturated quartz sand in a 6-m-high x 3-m-diameter caisson. The purpose of the test is to demonstrate a framework for the validation of reactive transport models in saturated and unsaturated porous and fractured media at Yucca Mountain. The experiments will be designed to provide well-controlled conditions and a well-characterized geomedium to allow separation of uncertainties due to chemical and physical processes. Criteria for acceptable agreement between predicted and observed tracer migration will be formulated as part of model validation tests and will reflect various sources of uncertainty in the experimental and model design.

Documentation of procedures is nearly completed. A draft Technical Procedure, "Batch Sorption Experiments Under Atmospheric and CO₂-free Conditions," was prepared and describes the procedures used to perform batch sorption experiments at SNL in support of the caisson experiment. Draft Technical Procedures for Br analysis by ion-specific electrode and the Li analysis technique by flame atomic absorption were prepared.

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Reactive Transport Model Experimentation

Experimental studies to test key assumptions used by performance assessment models to represent geochemical interactions are being designed. Current performance assessment models assume that sorption of radionuclides by heterogeneous mixtures of minerals under unsaturated flow conditions can be estimated or bound by K_d values measured on bulk rock samples obtained under saturated conditions. During the report period, efforts were focused on designing experiments to relate the sorption behavior of bulk rocks to trace minerals by developing a model for sorption by mineral mixtures, and on obtaining sorption data under unsaturated conditions.

Development of methods to carry out in situ batch sorption studies in unsaturated media continued at the Massachusetts Institute of Technology. Several alternate methods to extract pore solutions from unsaturated sand for pH and uranium analyses were compared. Kinetic studies of uranium sorption/desorption were carried out. A dedicated Nd:YAG laser for uranium fluorescence imaging studies was installed and is operational at Massachusetts Institute of Technology. Studies of in situ pH measurements and fracture-matrix interaction using analog materials are being designed in collaboration with SNL.

Efforts directed towards obtaining surface complexation constants for Li and Ni sorption by pure quartz and goethite and Ni sorption onto a Min-U-Sil, a quartz standard, under CO_2 -free conditions continued. In an effort to minimize diffusion of CO_2 through the sample vessels, a glove cabinet (plastic sheeting on a wire frame) was set up with N_2 atmosphere for storage of the samples during equilibration. A measurement protocol was developed for making reproducible pH measurements in batch-sorption systems. Additional modifications to the Ar scrubber for the autotitration system have improved overall system stability by an order of magnitude.

An initial titration curve was measured for raw Wedron 510 sand and showed that the stirrer can effectively suspend a 1:1 solid:solution mixture of electrolyte and sand. The sand settles quite rapidly; therefore, a high stirrer setting is required, possibly leading to grain-to-grain collisions and consequent production of clay-size particles. Shielding the electrode from the direct flow eliminated this problem.

A new 250-mL reactor vessel was built and prepared for the autotitrator. This permitted titrations to be performed on smaller load sizes, typically 100 mL electrolyte + 100 g sand. This factor-of-four decrease conserves specially treated (e.g., carbonate-stripped or acid-washed) sand required for the experiments. A series of alkalimetric titration curves were obtained at ionic strengths of 0.0006, 0.0032, 0.011, and 0.094 M for an aliquot of Min-U-Sil that had been cleaned by boiling in 6 N HCl . Double-extrapolation plots were prepared for Min-U-Sil data obtained from the British Geologic Survey for the CHEMVAL2 modeling exercise. The data support an intrinsic acidity constant in the range $10^{-6.9}$ to $10^{-8.1}$, and an association constant for Na^+ of $10^{-7.4}$ to $10^{-7.7}$, and will be used to verify our technique. Three alkalimetric titrations of acid-washed Wedron 510 sand were performed at ionic strengths of 0.0018, 0.0030 and 0.012. It was determined that leakage of filling solution through the ceramic frit of the pH electrode is significant when titrating systems of low ionic

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strength. At high ionic strength (<0.01) such a change is negligible, but at lower ionic strength this effect must be explicitly accounted for to obtain precise surface acidity constants. The titration protocol has been modified so that the acid burette tip is removed from contact with the solution during alkalimetric titration.

Synthetic goethite was prepared for sorption experiments and analyzed by x-ray diffraction to confirm purity and crystallinity. A batch Ni sorption experiment was run under atmospheric conditions, using the surface area of goethite that is believed to be equivalent to 20 g of Wedron sand, the weight used in previous sorption experiments. A batch Ni sorption experiment was also run using acid-cleaned Min-U-Sil with a grain surface area equivalent to that of 20 g of Wedron sand.

Forecast: Documentation is in preparation. An abstract 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 accepted for oral presentation at the Geological Society of America Annual Meeting.

Reactive Transport Model Development

The LEHGC code is a coupled reaction/transport simulator which solves systems of transport and geochemical equilibrium equations. The chemical processes, assumed to occur under conditions of local equilibrium, include aqueous complexation, adsorption (surface complexation), ion exchange, and precipitation/dissolution. The LEHGC code is currently being modified to improve computational efficiency, add additional sorption and ion exchange sites, and is being ported to a massively parallel computer.

During the past six months, linkage of the new version of EQMOD with the flow module was completed; the new version of the chemical speciation module contains multiple sorption and ion-exchange sites. Four alternative PCG solvers were incorporated into LEHGC1.1. Testing of both the incorporated new EQMOD and the PCG solvers was completed. Preliminary work on adapting the LEHGC code for simulations of colloidal transport in fractured media began. Post-processing software was adapted to produce contours for two-dimensional simulations. Formal technical review of "User's Manual for LEHGC: A Lagrangian-Eulerian Model of HydroGeological Transport in Saturated-Unsaturated Media - Version 1.0" was completed.

A strategy was devised for implementing the LEHGC code on a massively parallel machine. The code was ported to the 1024-node nCUBE, compiled and executed on a single node; results compared well with previous calculations on a SUN work station and CRAY supercomputer. The subroutines and associated data to be distributed to multiple nodes were identified and specific locations were identified for "scatter-gather" operations. Once the code is successfully executing on multiple nodes, timing studies will be carried out to determine the benefits of this massively parallel implementation.

Forecast: SNL will continue development of a coupled reaction/transport simulator which solves a system of both transport and geochemical equations for radionuclide transport.

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The code (LEHGC) will simulate equilibrium chemical processes and will include aqueous complexation, adsorption (surface complexation), ion exchange, oxidation-reduction and precipitation/dissolution. Transport in fractures and transport of contaminants by colloids will be simulated. The code will be adapted to a massively parallel computing architecture enabling simulations of transport that include complex chemical behavior on the time and spatial scales required for regulatory compliance assessments.

Transport predicted by performance assessment codes using retardation factors measured on bulk mixtures will be compared to the tracer behavior predicted by the LEHGC code using surface complexation models. This information will be used to develop probability density functions for K_d determinations for future TSPAs, and will provide input to geostatistical models for K_d determinations at Yucca Mountain.

2.7.5.3 Activity 1.6.3.1 - Analysis of Unsaturated Flow System

Subactivity 1.6.3.1.1 - Unsaturated zone flow analysis. A report entitled "Processes, Mechanisms, Parameters, and Modeling Approaches for Partially Saturated Flow in Soil and Rock Media" (Wang and Narasimhan, 1993) was completed, printed, and distributed.

The M&O and SNL provided an outline for bounding modeling studies for fractured porous materials. Discrete fracture realizations from the Golder Associates Inc. FracMan code obtained by USGS will be combined with SNL measurement of fracture characteristic and relative fluid conductivity to enable doing the subsequent bounding modeling investigations.

A subrepository scale hydrothermal model was developed to provide hydrologic inputs for TSPA 1993. This model uses a two-dimensional axi-symmetric mesh to represent a generic waste-emplacement "panel" and its surrounding drift. Model objectives are to compute temperature histories at the center and the edge of the panel and the associated saturation/flux values. Presently the VTOUGH runs have been completed for one repository panel with areal power densities of 141, 189, and 282 kW/ha (57, 76, and 114 kW/acre).

A member of the M&O performance assessment staff presented a paper entitled "Effective Hydraulic Conductivity in Bounded, Strongly Heterogeneous Porous Media" (Paleologos and Neuman, 1993) at the Spring Meeting of the American Geophysical Union. It is the first time that solutions for bounded domains appear in the stochastic literature and the results generated significant interest.

Dripping fractures are known to occur in underground openings in unsaturated rock. Presumably they are caused by nonequilibrium fracture flow from perched water zones. Using TOUGH2, the M&O investigated the extent to which the condensate front surrounding the repository could feed a perched water zone, thus leading to a relatively early return of liquid water to the cooler regions of the repository. Results indicate the water vapor barrier accompanying perched water partially blocks the upward diffusion of water vapor. This

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effect reduces condensate formation above the perched zone and enhances the downward directed release of vapor and liquid to the saturated zone.

The M&O and USGS staff involved in Study Plan 8.3.1.2.2.8, "Characterization of Fluid Flow in Unsaturated, Fractured Rock," have facilitated scheduling efforts of Golder Associates Inc., who are assisting in application of FracMan/MAFIC analysis capability to obtain discrete fracture realizations using the USGS field fracture mapping data. The Golder software provides the capability for the transfer of discrete fracture realization data for use in either the TOUGH and FEHM coupled multiphase thermal flow codes which will be used in support of the USGS fracture flow study plan.

A Hydrologic Data/Thermal Modeling Interchange at USGS-Denver in May 1993 was jointly chaired by the M&O and YMPO. The meeting provided thermal modeler feedback on the new USGS data set provided in February 1993 for the thermal studies, discussion of long term needs for measurements of the air phase relative permeabilities, and consideration of the potential measurement implications of some initial thermal modeling sensitivity results involving particular ranges of bulk matrix-fracture permeability.

The M&O, LBL, and USGS have coordinated the planned hypotheses testing and sensitivity evaluations concerned with Study Plan 8.3.1.2.2.9, "Site Unsaturated-Zone Modeling and Synthesis." Specific efforts are to better satisfy the following performance assessment needs: demonstrate the rationale for selecting between alternative conceptual models, and provide a basis for testing the abstraction or roll-up methodology for system simulators used in TSPAs.

Geohydrologic Data Development

The M&O performance assessment staff is coordinating the implementation of Study Plan 8.3.1.2.2.3, "Characterization of the Percolation in the Unsaturated Zone - Surface-Based Study," with assistance from the Principal Investigators involved, to enable YMPO to retrieve better data for the spatial infiltration distributions to represent Yucca Mountain. The spatially varying infiltration is needed as basic input to both the USGS/LBL Site Scale Three-Dimensional Flow Model and the Los Alamos Site Scale Three-Dimensional Transport/Retardation Model. Both modeling efforts are to become vital parts of the process level performance assessment evaluations.

Probability Distributions

The SNL staff performing modeling and analysis for TSPA 1993 required probability distributions for both bulk and matrix hydrologic data. In response to the concern that the relatively abundant matrix hydrologic values do not provide the true characterization of Yucca Mountain, information on fracture properties was also developed.

Basic data acquisition, reduction and analysis necessary to provide probability distributions to TSPA analysts were completed. The SNL staff performing TSPA modeling

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were provided with initial basic statistics, beta distribution parameters, and upscaled beta distribution parameters for the matrix material properties.

Data for TSPA analyses were extracted from site and analog data for statistical reduction and depicted as probability distributions. The basic statistics report the number of data, expected value (mean), coefficient of variation, and maximum and minimum of the data. From the basic statistics, beta probability distribution parameters were derived by the RS/1 statistical package. If a normal distribution could not be generated because of the lack of sufficient data, Shannon's maximum entropy routine was employed reporting the mean, the maximum and minimum, and the alpha and beta curve parameters of the distribution. Then the curve parameters were upscaled for the beta probability distribution parameters that account for the vertical correlation length and mean thickness of the hydrogeologic units. Data reported include the mean thickness of the unit, upscaled coefficient of variation, upscaled alpha and beta distribution parameters, and model specific input parameters (p and q). The same approach was used for porosity, conductivity, and bulk density. For the desaturation parameters, Van Genuchten fits were generated for desaturation tests reported in "Fracture and Matrix Hydrologic Characteristics of Tuffaceous Materials from Yucca Mountain" (Peters et al., 1984), "Statistical Analysis of Hydrologic Data for Yucca Mountain" (Rutherford et al., 1992), and the data generated by USGS-OFR-90-569 (Flint and Flint, 1990), currently being used for the INTRAVAL exercise. To support and visually complement the numerical analyses, graphical representations of the basic statistics and beta probability distributions were developed (histograms and beta probability distribution plots, both normal and log normal) for inclusion in the TSPA 1993 report.

The fracture parameters, including fracture frequency, fracture spacing, fracture porosity, fracture hydraulic conductivity, fracture air-entry parameter, fracture orientation and fracture aperture were also completed. Fracture data from downhole measurements were analyzed for fracture distributions from USW G-4 as a test case to evaluate utility to the performance assessment problem. An attempt was initiated to derive the applicable information to correlate fracture aperture size as a function of the second moment of log saturated permeability versus log pore-size, according to an approach developed by LBL staff. The success of the approach would allow the availability of a more realistic range of aperture for the TSPA models.

A program was written to sample fracture frequency and bulk conductivity distributions to create a distribution of fracture apertures using the cubic law. Distributions for the fracture air entry parameter were also generated. A root-finding subroutine was added to help generate varieties from a beta probability distribution and code was added to allow comment input files to be used.

INTRAVAL

The M&O, through Golder Associates Inc. staff, supported YMP participation in the international model validation program, INTRAVAL, through meeting participation and incorporation of data into the modeling process. The YMP INTRAVAL modeling results were presented at a meeting in Seattle, Washington, August 3-4, 1993. The meeting

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participants, USGS, SNL, LBL, the Commission, and State of Nevada, presented the model predictions for the moisture content in the UE-25 UZ#16 well drilled at Yucca Mountain. The predictions were compared, for the first time, with the UE-25 UZ#16 core moisture measured results made available at the meeting. The fracture data are being used on the extension of the FracMan/MAFIC codes for the interpretation of in situ air injection tests as part of YMP in a cooperative effort among the M&O, Golder Associates Inc., and USGS. Specifically, the saturated discrete fracture generation and solution capability of these codes is being extended to evaluate compressible air flow in fractured systems.

At SNL, development has continued on the east-west INTRAVAL cross section. Most of the indicator simulations have been converted to porosities. The north-south cross section was rerun with the third INTRAVAL data set incorporated and other corrections. Graphics were produced for the north-south cross section. Work has continued on the east-west INTRAVAL cross section with the gradational change in porosity in the shaly base added. The adaptive grid algorithm GAG was tried on the cross section, but produced poor results. Changes are being made to GAG to improve the results. A report on the SNL modeling effort for INTRAVAL was completed and submitted for review by the INTRAVAL participants. A presentation of SNL results was prepared for the INTRAVAL wrap-up meeting in Stockholm, Sweden, in late-August 1993. The presentation was given by a representative of the DOE staff who attended the meeting.

Performance Assessment Data Base

Configuration of the INGRES system continues for the Performance Assessment Data Base to facilitate ease of data retrieval and presentation of the data in the format required by the analysis. Assistance has been provided to the analysts for the retrieval and reconfiguration of data. Work is continuing on the configuration of information in ARC/INFO to make use of Yucca Mountain data more flexible. A number of programs were written to link various routines in the geostatistical software from the Stanford (University) Center for Reservoir Forecasting. The Performance Assessment Data Base staff has initiated a review of the data base design and the requirements for the integration of the test results from construction monitoring, thermomechanical testing, and properties testing at Yucca Mountain.

Probability Modeling

Modifications to the entropy fit program were made in response to problems discovered during early generation of the probability distributions for TSPA 1993. The changes included:

- A change in the computation of normalizing constant from adaptive integration to an analytical formula has been made. A more complicated change for bimodal and trimodal beta distributions was also completed.
- Display of the cubic line search iteration was added.

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- The maximum number of nonlinear iterations has been added to the input file so it can be adjusted by the user.
- Error tolerances were adjusted to increase robustness. Step size used in computing derivatives was made more robust.

Staff completed modifications of probability software originally installed on a VAX. Specifications for the user interfaces are being developed for experience gained during the elicitations. A user interface in an RS/1 shell has been written and installed on a personal computer.

Forecast: Documentation is progressing on the parameter generation for TSPA 1993 and for a stand alone document, which will contain more detail on the specifics of the data development. Subjects to be covered in both documents are stratigraphy development, data sources, and probability distribution function development for matrix, bulk, and fracture parameters. The hydrologic data availability has highlighted a critical need for bulk hydrologic conductivity data from the units above the Calico Hills horizon. The available bulk data for the Topopah Spring units are minimal to nonexistent. The relative sensitivity of these parameters will be investigated as part of the TSPA follow up analyses run in FY 1994. This information may then be used to help guide site investigations.

Subactivity 1.6.3.1.2 - Saturated zone flow analysis. An SNL staff member attended the Hydrology Integration Task Force meeting held in Denver, Colorado, May 17-18, 1993. The topic of focus was the C-Well testing, the current results, and future test plans.

A memo on the details of the modeling that will form the basis for flow and transport in the saturated zone for TSPA 1993 was completed and is currently in review by SNL and USGS staff. Information on the SNL saturated zone model was also made available to the M&O at their request.

Forecast: No activity is planned in FY 1994.

2.7.5.4 Activity 1.6.4.1 - Calculation of Pre-Waste-Emplacement Ground-Water Travel Time (GWTT)

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. The SNL participation in the INTRAVAL project centered on verification of numerical approaches for two-dimensional ground-water travel time calculations that were already under development. An extension of the INTRAVAL work, using the insights obtained during that

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exercise, was begun. The calculations were revised to incorporate zeolitic materials that are not included in the shallow calibration cross-section and to deal with some problems identified with the boundary conditions. Documentation of this work has also been started.

Forecast: This work will lead to calculations to predict ground-water travel time, as defined in 10 CFR Part 60. Activities planned for FY 1994 include performing sensitivity studies on parameter fields generated using theoretical and measured scaling models and geostatistical models developed for Yucca Mountain. These results will also be provided to guide future work in constructing experiments on scaling and geostatistics and to continue to support any validation initiative that may be a follow-on to the INTRAVAL studies completed in 1993. The objective of this work is to better conduct uncertainty and sensitivity studies to determine the hydrologic parameters of most importance in estimates on ground-water travel time; to continue the definition and development of an appropriate method for performing two-dimensional ground-water travel time calculations; and to continue work on upscaling of lab scale properties to a scale appropriate for simulating Yucca Mountain.

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. See, however, the description of the thermohydrological calculations being made for the TSPA 1993 exercise in Section 2.7.6, which is related work.

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)

The TSPA combines the effects of the waste package and other engineered barriers and the site to determine the release of radionuclides to the accessible environment due to all significant processes and events. Several evaluations of total system performance have been conducted by a number of organizations. These earlier assessments have included SNL preliminary evaluations reported in the Environmental Assessment (DOE, 1986), which reported the results of performance evaluations by Thompson et al. (1984) and Sinnock et al. (1984). The PNL staff performed a preliminary total system risk assessment in 1988 (Doctor et al., 1992). Independent of the DOE program, NRC completed Phase 1 of their Iterative Performance Assessment in 1990 (NRC, 1990), and the Electric Power Research Institute completed a Phase 1 performance assessment in 1990 (McGuire et. al., 1990), and a Phase 2

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evaluation in 1992 (McGuire et al., 1992). Recent assessments have been performed on behalf of the YMP and reported in TSPA 1991 (Eslinger et al., 1993; Barnard et al., 1992).

The bulk of the work on the recent SNL performance assessment was done in FY 1991, therefore it was named "TSPA 1991." In FY 1992, SNL staff performed a number of sensitivity studies on the TSPA 1991 results (Wilson, 1993a). The results of TSPA 1991 were incorporated in the iterative TSPA process through the planning of the second iteration, TSPA 1993, that was in progress at the end of FY 1993. The participants in the TSPA 1993 calculations are SNL and the M&O. The LLNL staff is providing the source term data and model, and USGS and Los Alamos are providing updated site and experimental data.

The M&O was tasked in FY 1993 to evaluate the probabilistic total-system code Repository Integration Program. The M&O tested the code by benchmarking it against the TSPA 1991 problem. The conclusions (INTERA, 1993) were that the Repository Integration Program approach is a viable method for performing total system assessments. The M&O is applying the Repository Integration Program in TSPA 1993.

The differences between TSPA 1993 and TSPA 1991 include: (1) factoring in nonisothermal conditions to capture the effects of the thermal pulse associated with the disposal of spent fuel in the unsaturated zone, (2) improvements in the conceptualizations of unsaturated and saturated hydrologic flow, (3) enhancement of the radiological source term and the treatment of near-field processes, and (4) inclusion of geostatistical correlations for relevant parameters. The larger of these differences, in terms of affecting system performance, is expected to be the inclusion of thermal effects. The motivation for including these effects is to help answer the question of what the optimal areal mass loading or areal power density may be for a repository in the unsaturated zone.

Beyond TSPA 1993, there are TSPAs planned to support all of the major decision points in the Yucca Mountain Site Characterization Program. In the 1995-1996 timeframe, an interim site suitability evaluation will be done that will be supported by a total system assessment. In the 1997-1999 timeframe, the Environmental Impact Statement scoping process will be under way, and the draft Site Recommendation Report and the draft Safety Analysis Report will be in progress. Each of these major decision-making documents will be supported by TSPAs.

SNL is involved in producing a series of calculations that will form the basis for their contribution to the second iteration of total system performance assessments, TSPA 1993. The SNL document will consist of enhancements and expansions upon simulations reported in TSPA 1991. These will include calculation of radionuclide release and transport by aqueous and gaseous flow, as well as by conditions caused by human intrusion and basaltic volcanism. Of particular interest in this new suite of calculations is: inclusion of a more sophisticated source term and near field models (based on work by LLNL), coupling of thermal effects, enhanced treatments of retardation and solubility, incorporation of more site data and use of geostatistical correlations, and better treatment of disturbed conditions (including climate change). Although SNL will be reporting these results in a SAND document, a separate DOE

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document will be generated to compare and contrast both the SNL and M&O TSPA 1993 results.

Preliminary complementary cumulative distribution functions generated for the aqueous flow and transport portion of TSPA 1993 show a particularly interesting result. When compared to those generated for TSPA 1991, complementary cumulative distribution functions for releases from the engineered barrier system are only slightly different, even though a significantly more sophisticated source term model was used. However, the TSPA 1993 complementary cumulative distribution functions for releases to the accessible environment are quite different from TSPA 1991. The changed infiltration rate distribution appears to be the dominant parameter influencing this change. Specific calculations are discussed in Activities 1.1.3.1 and 1.1.5.1, below.

SNL hosted a meeting in Albuquerque, New Mexico, on September 20, 1993, to discuss preliminary results of the TSPA calculations done by SNL and the M&O. Representatives from LLNL and USGS were also present. A number of areas were identified for refinement and for sensitivity studies that will be incorporated into the final simulations.

The M&O completed the preliminary calculations for its TSPA 1993 contribution. The waste package/engineered barrier system file use in the Repository Integration Program code includes temperature-dependent corrosion rates; spent fuel and high-level defense waste dissolution rates; radionuclide solubilities; saturation- and flux-dependent corrosion rates; radionuclide diffusion from the waste package; and correlation of solubilities. Abstracted results from two-dimensional repository panel scale hydrotherm calculations were provided as input to Repository Integration Program calculations of waste package and far-field performance assessment. The ^{14}C travel time distributions provided by SNL were transformed into Repository Integration Program-usable gas velocity distributions as a function of time of release from the waste package. A set of radionuclide release calculations were completed for waste packages placed in vertical boreholes and in-drift emplacement mode for three areal power densities: namely 28, 57, and 114 kw/acre. The results are to be presented to YMPO October 21-22, 1993.

The M&O supported the Nuclear Waste Technical Review Board meeting in Denver, Colorado, July 13-15, 1993. The meeting agenda was, in part, to present to the full board the progress on TSPA 1993, and support to the National Academy of Sciences study on technical bases for Yucca Mountain standards. The M&O made presentations on "Performance Assessment Efforts in Support of National Academy of Sciences Study" and "Total System Performance Assessment (TSPA) II: Repository Integration Program (RIP) Abstractions Analyzing Nominal Conditions."

The M&O and Golder Associates Inc. submitted a draft document entitled "Application of RIP (Repository Integration Program) to the Proposed Repository at Yucca Mountain: Conceptual Model and Input Data Set" to YMPO for review. The report documents a description of the preliminary data set constructed as a conceptual model for applying the Repository Integration Program to the proposed Yucca Mountain site.

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The M&O completed the first draft of the "YMP Performance Assessment Strategy." The principal objective of the document is to provide a common understanding of the general strategy and methodology for performance assessments, and to outline the need for TSPAs in support of future programmatic needs. The final draft of the Performance Assessment Strategy will be issued as a YMP document with input from all performance assessment participants and YMPO. It is currently being reviewed by the Participants.

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. Work related to this activity is reported under Subactivity 1.1.2.1.2.

Subactivity 1.1.2.1.2 - Preliminary identification of potentially significant release scenario classes. A report entitled "Scenarios Constructed for Basaltic Igneous Activity at Yucca Mountain and Vicinity" (Barr et al.) has completed review comment resolution and has been submitted to the printer for publication.

The definition of nominal case scenarios is in progress at SNL. The M&O worked with SNL to clarify the importance of the "Nominal Flow System Cases," and helped explore ways of simplifying presentation of these scenario classes. The documentation of "Nominal Cases" now in review is the basis for a proposed definition of YMP site and repository hydrologic baseline cases. Such baseline cases are necessary to conduct the combined process hypothesis testing and sensitivity evaluations which establish the detail level conceptual modeling required, provide a testing basis for abstracted TSPA models, and allow prioritization of hydrologic site characterization data.

The SNL staff attended a Nuclear Energy Agency/Organization for Economic Cooperation and Development meeting in Paris, France, June 17-18, 1993. The meeting addressed the possibility of forming an international data base on features, events, and processes related to radioactive waste isolation. The meeting was also attended by representatives from Sweden, Switzerland, Canada, NRC, and the Waste Isolation Pilot Plant project. The consensus of the group was that such a data base could be very useful to the international community. The group agreed to work on several methods of incorporating the information already available in the various programs. A second meeting in November will review the results of these efforts. In conjunction with this trip, visits were made to the radioactive waste isolation programs at Bureau de Recherches Geologiques et Minieres in Orleans, France, and Swiss National Cooperative Society for the Storage of Radioactive Wastes in Switzerland. Presentations were made on TSPA 1991 results and the status of TSPA 1993 at both locations.

Forecast: 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.

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Activities in FY 1994 will include completing the final draft of the Nominal Flow scenario selection document, "Scenarios Constructed for Nominal Flow in the Presence of a Repository at Yucca Mountain and Vicinity" (Barr et al.), incorporating comments from YMPO review; completing the tectonic and human intrusion scenario selection documents, investigating the need for construction of event trees describing disturbances due to repository construction and operation; and participating in the Nuclear Energy Agency/Organization for Economic Cooperation and Development working group to form a data base for features, events and processes. These activities are linked with efforts being conducted by SNL, USGS, Los Alamos, LLNL, and LBL.

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

Subactivity 1.1.3.1.1 - Development of models for releases along the water pathways.

For the TSPA 1993 (see Section 2.7.6.6) composite-porosity flow model, SNL constructed a new set of stratigraphic columns for the three potential repository footprints. The footprints were based on variations in power densities. Reconfiguration of each footprint has required construction of different stratigraphic cross-sections from which to draw the columns used for the one-dimensional calculations. Distributions for the hydrogeologic parameters of the stratigraphic units were incorporated into the total system performance assessment computer code, TOSPAC, input files. The parameter distribution generation is reported in Activity 1.6.3.1.1.

A short "graphic" about TOSPAC was written for inclusion in the SNL Software Catalog. Other modifications to the SNL codes, necessary to complete the TSPA 1993 calculations, were also completed. A new automatic mesh generator for TOSPAC was completed. The mesh generator will allow TSPA 1993 to efficiently calculate flow and transport for problems with different water-table heights and a wide range of percolation rates. This should help minimize mass-balance problems during transport calculations.

The TSPA 1993 "weeps" model was modified to incorporate LLNL's source-term model, Yucca Mountain Integration Model, and to incorporate thermal-effects data provided by SNL. Specifics of the modification include incorporating the number of containers outside the boiling isotherm as a function of time, the volume of rock encompassed by the boiling isotherm, and the temperature histories of representative containers.

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Subactivity 1.1.3.1.2 - Development of a model for gas-phase releases. Disposal Safety, Inc. developed new gas-flow and ^{14}C -travel-time calculations that will be used to modify the gaseous flow model for TSPA 1993. Two-dimensional stratigraphies were generated by SNL for the gas-flow calculations and used by Disposal Safety, Inc. for their simulations. Information on the TSPA problem setups (including repository area and heat output, stratigraphy, and material properties) was also transmitted to Disposal Safety, Inc. Using this input, they completed the gas-flow calculations for TSPA 1993. Upon receipt of this information, SNL distributed the information to the M&O for inclusion in their TSPA 1993 calculations. The calculations are similar to the ones used in TSPA 1991, with two major improvements: gas flow and heat flow are now coupled and the calculations are time-varying rather than steady-state. Extremely short transport times were calculated by Disposal Safety, Inc. for ^{14}C , given the hydrologic parameter values for the model. Subsequent studies are being run that will vary the relevant parameters to determine their relative sensitivities.

Subactivity 1.1.3.1.3 - Development of a model of releases through basaltic volcanism. The thermal pulse calculation to model an igneous dike near a waste package is completed. The calculation involves evaluating transcendental functions, which require the application of numerical analysis techniques. Now the range of temperatures can be approximated that may be expected in rock surrounding a basaltic intrusion. This calculation will be combined with a modified version of the TSPA 1991 VOLCAN program to calculate conditions for waste package failures.

Subactivity 1.1.3.1.4 - Development of a model of releases through human intrusion. A report entitled "Analyses of Releases Due to Drilling at the Potential Yucca Mountain Repository" (Barnard, 1993) was submitted as an invited paper for the 1993 American Nuclear Society winter meeting.

The human intrusion direct release model developed for TSPA 1993 calculates releases due to drilling into a repository where the waste package configuration is based on four variations of the thermal loads and emplacement schemes (defined in Activity 1.5.1.1). The human intrusion analyses also reflect the probabilities of drilling into both glass and spent-fuel waste. Preliminary results of calculations for the in-drift emplacement model indicates that interception of the much larger waste package may lead to releases of very high amounts of radionuclides in any one drilling event. Final analyses and sensitivity studies have been completed.

Forecast: See Section 2.7.6.6, Performance Assessment Activity 1.1.5.1.

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.

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2.7.6.5 Performance Assessment Activity 1.1.4.2 - The Provision of Simplified, Computationally Efficient Models of the Final Scenario Classes Representing the Significant Processes and Events Mentioned in Proposed 10 CFR 60.112 and 60.115

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

Input Parameters for TSPA 1993

Geochemistry. SNL hosted a meeting on April 13, 1993, to elicit distributions for solubility to be used for TSPA 1993 from Los Alamos personnel. Probability density models of the distribution of solubility were generated for 15 radionuclides through elicitation of a panel of experts from Los Alamos. As a result of this interaction, a number of changes to the software used to generate the distributions will be made to facilitate the elicitation process.

The SNL staff coordinated and hosted an elicitation of sorption data for TSPA 1993 in Albuquerque, New Mexico, on June 1, 1993. The geochemistry experts elicited were from Los Alamos, Jacobs Engineering, and SNL with observers from the M&O also present. The K_d distributions were elicited for 15 radionuclides. The solubility and sorption distributions resulting from these elicitations are being used in both SNL and the M&O contributions to TSPA 1993.

Members of SNL staff attended the YMP Colloid Workshop. Results of an SNL analysis were included in a presentation entitled "Colloids: A Performance-Assessment Perspective" (Wilson, 1993b). The purpose of the analysis was to examine the question of whether transport of radionuclides by colloids will be significant for repository performance at Yucca Mountain.

Infiltration and climate change. A meeting was coordinated and hosted by SNL personnel on May 26, 1993, with participants from USGS, Raytheon Services of Nevada, and the M&O. The purpose of this meeting was to discuss the best approach for representing infiltration and water flow at Yucca Mountain resulting from both current and future climatic conditions. The results of this discussion are being used as the basis for the percolation flux used in TSPA 1993.

On June 25, 1993, staff of both SNL and Tech Reps Inc. met to discuss the climate-change information being gathered by the DOE Waste Isolation Pilot Plant project in New Mexico. The Waste Isolation Pilot Plant is using a doubling of precipitation as the upper bound of a climate change in the next 10,000 years. On the basis of information obtained from the Waste Isolation Pilot Plant and USGS, climate change will be represented

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in TSPA 1993 as dry, interpluvial periods (like the present) where ground-water flux is characterized by an exponential distribution with a mean value of 0.5 mm/year; and wet, pluvial periods characterized by an exponential distribution with a mean value of 10 mm/year. The time period under consideration has been extended from 10,000 years (TSPA 1991) to 1,000,000 years (TSPA 1993).

Source Term and Near-field Development

A report entitled "Review of Radionuclide Source Terms Used for Performance Assessment Analyses" (Barnard, 1993b) completed SNL management review and was transmitted to YMPO for policy review.

A meeting was held on May 26, 1993, at LLNL, to formulate a source term for use by the M&O in their contribution to TSPA 1993. The result of the meeting was that the M&O will use the same source term that had been previously determined by interactions occurring between SNL and LLNL in February 1993. Also, a meeting was held in early-June 1993, to correlate the LLNL hydrothermal calculations with SNL thermal data to determine the hydrothermal profiles to be used in the TSPA 1993 source term.

A number of meetings were held at SNL and LLNL to couple the LLNL Yucca Mountain Integration Model source model to SNL transport models for the TSPA (both TOSPAC and WEEPTSA). There were a number of difficulties with this integration, but the collaboration went well and this interface between SNL programs should make future generations of the Yucca Mountain Integration Model easier to incorporate.

The calculations of waste-package lifetimes for the four emplacement configurations analyzed in TSPA 1993: 141 kW/ha (57 kW/acre) for the SCP-reference waste package design, vertical emplacement; 282 kW/ha (114 kW/acre) for the SCP-reference waste package design, vertical emplacement; 141 kW/ha (57 kW/acre) for a larger waste package, in-drift emplacement; and 282 kW/ha (114 kW/acre) for a larger waste package, in-drift emplacement were completed. The calculated range of lifetimes is from about 900 to over 10,000 years.

The SNL staff has also developed a source term that reflects the proper weighting of age and burnup for spent fuel and also includes glassified high-level waste for TSPA 1993. The spent-fuel inventory was built as for TSPA 1991, except that the waste stream that describes the proposed emplacement scheme will be used to determine fuel age and burnup. Data for glass form high-level waste were obtained from the "Characteristics Data Base" (DOE, 1987a). There will be two representations of the source term. The human intrusion source term will be composed of all of the inventory, while the aqueous flow and volcanism calculations will utilize indicator nuclides, as discussed in "Review of Radionuclide Source Terms Used for Performance Assessment Analyses" (Barnard, 1992).

The M&O developed a functional form for the dissolution rate of UO_2 as a function of temperature, pH, and carbonate concentration. This function was obtained for use in the M&O source term calculations for TSPA 1993 using the Repository Integration Program code's engineered system module.

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The SNL staff attended an M&O-sponsored meeting in Richland, Washington, on the continuing development of the AREST source-term code. The plans and capabilities for the code (written by PNL for the M&O) were discussed. Currently, it is anticipated that AREST will have both low-level (process) model capability, as well as higher-level (performance assessment) features. Because of these ambitious requirements, coupled with low available funding, the code will not be available for some time. The waste package and near-field portions of the SNL features, events, and processes diagrams were also discussed. A staff member of PNL has characterized near-field environments in terms of amount and rate of moisture, oxygen, and heat around the waste package. This information is necessary to complete features, events, and processes diagrams.

The SNL staff also participated in the Technical Workshop on Near-Field Performance Assessment, at Cadarache, France, May 11-13, 1993. Attendees included representatives from the United States, Sweden, Switzerland, Germany, France, Finland, United Kingdom, and The Netherlands waste-disposal programs. The purposes of the meeting were to review the aspects of near-field performance assessment, to develop themes that should be pursued, and to identify areas common to the programs that might be appropriate for collaboration. Topics included near-field environment, releases, transport, modeling, and performance assessment integration. The workshop participants were split into interest groups to discuss the topics in detail and develop recommendations. Most of the emphasis was on the European programs (and their design and environmental conditions); consequently, most of the discussion was concerned with saturated repositories with bentonite backfill and reducing ground-water conditions. A member of the SNL staff was in the performance assessment integration group, therefore YMP interests were included in their recommendations. Areas of mutual interest included many of the scenario classes (e.g., near-field hydraulic, radiolytic, and chemical processes; volcanic processes; repository operations), some aspects of the geochemistry (e.g., alteration of near-field hydraulic properties by the engineered barrier system), glass-waste dissolution, and salt-repository characteristics. A survey and review document and a workshop summary are being prepared by the organizers to be published within a few months.

Forecast: A series of sensitivity studies will be performed on the results of TSPA 1993 that were obtained in FY 1993. The final documentation of the second cycle of the SNL contribution to the TSPA, as well as the M&O contribution, will be completed in early FY 1994. At this time, it is expected that TSPA 1993 modelers will make presentations on results of TSPA 1993 to other YMP participants to help guide site characterization studies, and also to other groups for information on progress in performance assessment. In addition, SNL and the M&O will cooperatively produce a document combining all elements of the DOE effort on TSPA 1993 in mid-FY 1994.

These activities are closely integrated with efforts described in Section 2.2.3.6 (geostatistical cross-correlation of parameters, stratigraphy), Section 2.4.1.16 (thermal history), Section 2.7.6 (scenarios for modeling, gas flow models, data sets), Section 2.7.5 (elicited parameters), and Section 2.7.5.2, Subactivity 1.6.2.2.2 (parameters for scaling, information on geochemistry, thermal effects validation experiments) by SNL, the M&O, LLNL, the USGS, Los Alamos, and LBL.

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A number of processes have been identified in TSPA 1991 and TSPA 1993 as potentially important to our understanding of the performance of the site. A number of laboratory validation studies and process modeling exercises describing these processes have reached a sufficient level of maturity to begin integration of the information into performance assessment calculations. Additional developmental work on existing tools is also required. This activity will incorporate the information from these studies into abstracted models that can then be used to expand and enhance the next cycle of TSPA.

Developmental activities are expected to include:

- Developing effective media models for flow through single fractures incorporating data on fingering and in-plane saturation processes described in Section 2.7.5.2, Subactivity 1.6.2.2.2.
- Developing and implementing a strategy for incorporation of nonisothermal processes into total-system simulations. The information for this effort will be provided in part by ongoing experimental and numerical efforts described in Sections 2.7.5.2 and 2.4.1.16.
- Developing an abstracted model for colloid transport of nuclides derived from detailed modeling efforts described in Section 2.7.5.1 with input from LLNL and Los Alamos.
- Including unit gradient method in TOSPAC to approximate two-dimensional streamlines using a one-dimensional code.
- Continued development of the detailed process level, AREST, and integrating level (Yucca Mountain Integration Model) source-term codes.

Contingent upon funding levels and YMP direction, the M&O and SNL may also begin initial problem definition for the next iteration of the TSPA in late FY 1994. Developmental studies performed in other performance assessment activities will form the basis for the next cycle of the TSPA. Also, the increased availability of data from site characterization activities will allow us to revise and expand the analyses performed during the first two cycles. This cycle will be the basis for the use of the total system in the Advanced Conceptual Design, and some of the analyses to be conducted during this cycle will be identified by examining the needs of that design phase.

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

No progress during the reporting period; this was an out-year activity. Related work is reported in Section 2.7.6.6 because ground-water pathway dose calculations are part of the TSPA 1993 exercise.

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Forecast: No activity is planned for FY 1994; however, see Section 2.7.6 for related work.

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; this was an out-year activity. Work related to this activity is reported under Section 2.7.6.3, Activity 1.1.3.1.2.

Forecast: No activity is planned for FY 1994. See Section 2.7.6.6, Performance Assessment Activity 1.1.5.1, for related work.

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

The TSPA 1993 exercise includes calculations of ^{14}C doses in the accessible environment, as was reported in Section 2.7.6.3, Subactivity 1.1.3.1.2.

Forecast: No activity is planned for FY 1994. See Section 2.7.6 for related work.

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.

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.

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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)

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

Forecast: No activity is planned for FY 1994.

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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 U.S. Nuclear Regulatory Commission, the State of Nevada, and others; and the work scope described in the SCP and the more-detailed study plans. In January 1990, the schedule presented in the Secretary's report to Congress was finalized by the Office of Civilian Radioactive Waste Management 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 Yucca Mountain Site Characterization Project (YMP) as of the end of this reporting period (September 30, 1993). More detailed schedules are maintained at the Yucca Mountain Site Characterization Project Office, 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 YMP. 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>ESF</u>		
Start Final ESF Title II Design	10/91	10/91
Start ESF Site Preparation	11/92	11/92
Start ESF In Situ Test Phase	6/96	
Complete ESF 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 EIS Notice of Intent	5/97	
Issue EIS Implementation Plan	2/98	
Notify State of Proposed Site Selection	10/99	
Issue Draft EIS	10/99	
Issue Final EIS	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 the NRC	10/01	

^aTable shows approved Program Schedule Baseline and actual completion dates as of September 30, 1993. The baseline schedule is currently under review and will be revised and published in the near future.

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CHAPTER 4 - EPILOGUE

This section provides a brief summary of key events that occurred after the close of the reporting period on September 30, 1993 and prior to final editing of this report.

On October 7, 1993, the U.S. Senate confirmed Dr. Daniel H. Dreyfus as the new Office of Civilian Radioactive Waste Management Director.

On October 27, 1993, the U.S. Congress approved an Office of Civilian Radioactive Waste Management budget for fiscal year 1994 at \$380 million. The Nuclear Waste Fund provided \$260 million; the Defense Nuclear Waste Disposal Account provided \$120 million.

The Nuclear Waste Technical Review Board report entitled "Underground Exploration and Testing at Yucca Mountain" was received by the Project in October 1993. The Project's response was submitted to U.S. Department of Energy/Headquarters on December 3, 1993, with the response to the Review Board scheduled for February 1994.

On November 18, 1993, the U.S. Department of Energy responded to the U.S. Nuclear Regulatory Commission concerns with respect to the Exploratory Studies Facility design process expressed in the Commission's letter dated August 20, 1993.

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ACRONYMS, ABBREVIATIONS, AND SYMBOLS

ACNW	Advisory Committee on Nuclear Waste
AECL	Atomic Energy of Canada Limited
ASTM	American Society for Testing and Materials
ATM	Approved Testing Material
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
ESF	Exploratory Studies Facility
FY	fiscal year
GSLIB	Geostatistical Software Library and User's Guide
HRL	Hard Rock Laboratory (Sweden)
ITE	Integrated Test Evaluation
LBL	Lawrence Berkeley Laboratory
LLNL	Lawrence Livermore National Laboratory
Los Alamos	Los Alamos National Laboratory
MC	Management Control
MGDS	Mined Geologic Disposal System
M&O	Civilian Radioactive Waste Management System Management and Operating Contractor
NAGRA	Swiss National Cooperative Society for the Storage of Radioactive Wastes
NAS	National Academy of Sciences
NRC	U.S. Nuclear Regulatory Commission
OCRWM	Office of Civilian Radioactive Waste Management
PNL	Pacific Northwest Laboratory
QA	quality assurance
QARD	Quality Assurance Requirements Document
REEC _o	Reynolds Electrical & Engineering Co., Inc.
RSN	Raytheon Services Nevada
SCP	Site Characterization Plan
SCPB	Site Characterization Program Baseline
SCP-CDR	Site Characterization Plan - Conceptual Design Report
SD	Geostatistical/Systematic Drilling Program
SNL	Sandia National Laboratories
TSPA	Total System Performance Assessment
TSw1	densely welded devitrified lithophysal-rich tuff
TSw2	densely welded devitrified lithophysal-poor tuff
USGS	U.S. Geological Survey
YMP	Yucca Mountain Site Characterization Project
YMPO	Yucca Mountain Site Characterization Project Office

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ACRONYMS, ABBREVIATIONS, AND SYMBOLS (Continued)

Metric (SI) 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)

Other (non-SI) Scientific/Engineering Terms and Units

bar	unit of barometric pressure
ca.	circa
cu. yd	cubic yard
ft	foot
gpm	gallons per minute
in	inch
ka	kiloannum (thousand years ago)
Ma	megannum (million years ago)
mi	mile
mil	1/1000th of an inch
mmol	millimolar
MN	meganeutons
pH	negative log of hydrogen ion concentration (acidity/alkalinity)
ppb	parts per billion
ppm	parts per million
psi	pounds per square inch
T	temperature
yr	year

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All technical reports and research products published by participating organizations on the YMP 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 YMP 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

Annotated outlines of YMP-sponsored reports can be found in the YMP Bibliography (DOE, 1987b). Updates are published approximately every six months.

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