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***Nuclear Waste Policy Act***  
***(Section 113)***

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***Site Characterization Progress Report:***  
***Yucca Mountain, Nevada***

***October 1, 1992 - March 31, 1993***

***Number 8***

***August 1993***

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

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***Office of Civilian Radioactive Waste Management***  
***Washington, DC 20585***

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## Department of Energy

Washington, DC 20585

### 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 eighth in a series of progress reports focused on site characterization at the Yucca Mountain candidate site in Nevada. The document is entitled "Site Characterization Progress Report: Yucca Mountain, Nevada" and covers the period from October 1, 1992, through March 31, 1993.

The Civilian Radioactive Waste Management Program made significant progress during the reporting period at the Yucca Mountain Site Characterization Project. Several important advances were made in the surface-based testing, design, and Exploratory Studies Facility programs, including drilling utilizing the state-of-the-art LM-300 drill rig, exploratory trenching studies to assess quaternary faulting, issuance of the erosion topical report to address the issue of extreme erosion, and site preparation and initiation of north portal construction for the Exploratory Studies Facility.

Advanced conceptual design of the waste package commenced in October 1992. Detailed thermal, criticality, and shielding evaluations have been initiated on the seven concepts selected for advanced conceptual design. Advances have been made in the hydrologic modeling of Yucca Mountain. Planning has moved forward on the large block heater test and the engineered barrier system field tests. Scientific studies have continued on container and waste form testing as well as integrated testing.

The Yucca Mountain Site Characterization Project Office (Project Office) has started an Issue Resolution Process to help in the identification, clarification, and resolution of technical and regulatory issues raised during site characterization.

Formal interactions were conducted between the Project Office and the Nuclear Waste Technical Review Board in October 1992 and January 1993. The Project Office held a workshop in Albuquerque, New Mexico, in November 1992 to discuss the use of expert judgment as a decision tool and in the resolution of scientific issues. The Project Office participated in a workshop on alternative design concepts and construction activities sponsored by the Nuclear Waste Technical Review Board's Panel on Structural Geology and Geoen지니어ing.

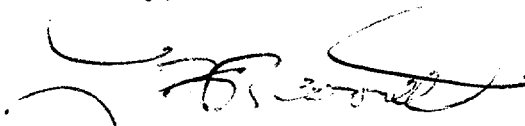
On October 24, 1992, the President signed into law the Energy Policy Act of 1992 (Public Law 102-486). Site characterization at Yucca Mountain will continue during the National Academy of Sciences review and repromulgation of environmental standards for a repository system by the U.S. Environmental Protection Agency as mandated by that Act. The scope and direction of the site characterization program will be evaluated when new standards are promulgated.



Public outreach activities by the Project Office continue to expand public awareness regarding nuclear waste disposal concepts and the Yucca Mountain Site Characterization Program. During the period covered by this progress report, 76 tours of Yucca Mountain were held for about 3,700 members of the public and other interested parties. Numerous programmatic and technical workshops and presentations were conducted by U.S. Department of Energy staff. Meetings were held in various communities in southern Nevada to update the public and appropriate agency personnel regarding progress on site characterization.

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

Sincerely,

A handwritten signature in dark ink, appearing to read "Lake H. Barrett", written over a horizontal line.

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

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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 October 1, 1992, through March 31, 1993. This report is the eighth 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.

In November 1992, a major program milestone was reached when the Office of Civilian Radioactive Waste Management received approval from the Department of Energy's Energy System Acquisition Advisory Board to start construction of an Exploratory Studies Facility. This facility is to be an underground laboratory designed to enable scientists and engineers to examine, in situ, 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 (two-mile) -long main tunnel oriented at N 34° E in the potential repository level, the Topopah Spring level. 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 in a lower level in the Calico Hills level. Various side tunnels will be driven to provide access to fault zones and other areas of potential interest. In total, 23,400 meters (76,900 feet) of tunnel will be excavated, resulting in approximately 1,550,000 metric tons (1,700,000 tons) of excavated rock.

Mechanical excavation methods will be used when possible. Conventional (drill and blast) excavation will be used only when necessary. In the Topopah Spring level the rock is fairly hard; 158 megapascals (23,000 pounds per square inch) compressive strength. Thus, up to 61 meters (200 feet) of the first ramp will be excavated by drill and blast. A large diameter tunnel boring machine will be employed to excavate the remainder of the material in the main ramps and tunnels. A conveyor belt system will carry the excavated rock out of the underground and to the rock storage area. (See Figure 2-2 for a typical cross section of the ramp.) Side tunnels on the upper level will be excavated by either the tunnel boring machine, other similar mechanical means, or by drill and blast. In the Calico Hills level the rock is not as hard, and can be mechanically excavated by any of several different types of machines. Since late November, topsoil has been removed for the construction of access roads and rock storage pads, drainage ditches have been graded, and North Portal pad and access ramp have been started. Tunnel design continued, including work on access ramps, tunnel boring machine procurement, electricity supply, and more detailed engineering design of the facility.

Advanced conceptual design of the waste package commenced in October 1992. Detailed thermal, criticality, and shielding evaluations have been initiated on the seven concepts selected for advanced conceptual design. Advances have been made in the

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hydrologic modeling of Yucca Mountain. Planning has moved forward on the large block test and the engineered barrier system field tests. Scientific studies have continued on container and waste form testing as well as integrated testing.

The Yucca Mountain Site Characterization Project Office has started an Issue Resolution process to help in the identification, clarification, and resolution of technical and regulatory issues raised during site characterization. Issue resolution is directed toward receiving guidance and comment from the U.S. Nuclear Regulatory Commission 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. This process includes U.S. Nuclear Regulatory Commission staff review of Yucca Mountain Site Characterization Project Office reports, technical exchanges of information, and the preparation of topical reports by the project which are reviewed by the U.S. Nuclear Regulatory Commission staff. By letter dated November 2, 1992, the Commission notified the U.S. Department of Energy that, based on information provided in the "Exploratory Studies Facility Alternatives Study: Final Report" (Dennis, 1991) and "Risk/Benefit Analysis of Alternative Strategies for Characterizing the Calico Hills Unit at Yucca Mountain" (DOE, 1991a) reports, it was lifting Objection 1 from the "NRC Staff Site Characterization Analysis of the U.S. Department of Energy's Site Characterization Plan, Yucca Mountain, Nevada," (NRC, 1989) and considered Comments 12, 16, 35, 57, 72, 127, 128, 132, and Question 61 resolved. On February 8, 1993, the U.S. Nuclear Regulatory Commission agreed that the Department had provided the technical basis to resolve Site Characterization Analysis Comments 100, 104, 106, 108, 110, 112, and 113.

On March 9, 1993, the Topical Report, "Evaluation of the Potentially Adverse Condition 'Evidence of Extreme Erosion During the Quaternary Period' at Yucca Mountain, Nevada," (DOE, 1993e) (hereinafter referred to as the Erosion Topical Report) was sent by the Department to the U.S. Nuclear Regulatory Commission. This report concludes that evidence of extreme erosion during the Quaternary period is not present at Yucca Mountain. Based upon a comparative evaluation of Yucca Mountain hillslope erosion and stream incision with erosion rates in other analogous geologic and climatic regimes, the project found that extreme erosion has not occurred at Yucca Mountain during the Quaternary.

The Civilian Radioactive Waste Management System Management and Operating Contractor released an internal review draft of a report entitled "Review and Selection of Unsaturated Flow Models" to other performance assessment contractors for comment. This review concluded that fracture-matrix interactions and nonequilibrium flow were not adequately addressed in codes currently in use within the Yucca Mountain Site Characterization Project. From among the codes available in the Yucca Mountain Site Characterization Project several were recommended to serve as host structures for the development needed to address these identified technical needs.

In November 1992, Pacific Northwest Laboratory, a participant in the Yucca Mountain Site Characterization Project, issued the report "Preliminary Total System Analysis of a Potential High-Level Nuclear Waste Repository at Yucca Mountain" (Eslinger et al., 1992). This document describes work performed by Pacific Northwest Laboratory as part of the

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Department's 1991 Total System Performance Assessment. Pacific Northwest Laboratory's study included calculation of source term releases from the potential repository at Yucca Mountain, liquid-phase and gas-phase fluid and solute transport in the unsaturated zone and liquid-phase flow and solute transport in the saturated zone. These calculations were performed for nominal conditions and for disruptive events (volcanism and human intrusion) for which probabilities of occurrence were estimated. Ultimately, this information was integrated to compute human doses from the potential repository and the Complementary Cumulative Distribution Function.

In support of Exploratory Studies Facility and surface-based testing design, the Civilian Radioactive Waste Management System Management and Operating Contractor has completed 23 analyses addressing specific actions in terms of their potential impacts on the ability of a potential repository at Yucca Mountain to isolate waste.

Before it can conduct some of its site characterization activities, the project must obtain permits and approvals from other federal and State of Nevada agencies in order to be in compliance with the applicable regulations of these agencies. Within the reporting period, the project obtained a Free Use Permit for the Fran Ridge gravel pit from the U.S. Department of Interior, Bureau of Land Management, on January 8, 1993. The permit allows for the extraction of 305,822 cubic meters (400,000 cubic yards) of sand and gravel necessary for construction of the Exploratory Studies Facility. In October 1992, the State of Nevada issued a point source permit for dust control for the Cone Gravel Screening Plant. This plant will be used during Exploratory Studies Facility site preparation and construction activities.

As part of site characterization research, trenches and test pits are excavated to expose subsurface layers of soil and rock to allow evaluation of possible geologic faults and volcanic features. Since July 1991, trenches and test pits have been excavated at the Lathrop Wells cinder cone to allow evaluation of the past basaltic volcanic activity in the vicinity of Yucca Mountain. During the reporting period, four trenches previously dug at the Lathrop Wells cone were deepened to examine stratigraphic and geochronologic relations. Revised stratigraphic descriptions are now consistent with most previously obtained geochronology data, and questions about the anomalously young thermoluminescence age for one of the lava flows associated with the Lathrop Wells cone have been resolved.

Boreholes are drilled into Yucca Mountain to obtain information on geological structure, faults, rock characteristics, depth to the water table, water quality, infiltration, and water movement in soil and rock. During the reporting period, eight Phase II boreholes for the Neutron Access Program were completed. The most noteworthy was the completion of Borehole UE-25 UZ #16 to a depth of 507.5 meters (1,665 feet) with the LM-300 drill rig. In addition, drilling of Boreholes UE-25 NRG-1 to 46 meters (150 feet), UE-25 NRG-2 to 65.5 meters (215 feet), UE-25 NRG-3 to 101 meters (330 feet), and USW NRG-6 to 335 meters (1,100 feet) was completed.

Experiments were conducted by Los Alamos National Laboratory staff in response to a 1987 U.S. Nuclear Regulatory Commission position paper request for experiments to determine whether batch sorption coefficients obtained using crushed tuff rock material from



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Yucca Mountain could be used to accurately model radionuclide sorption behavior along potential release pathways in the mountain. Findings of this study were released during the reporting period in the document "Dependence of Radionuclide Sorption on Sample Grinding, Surface Area, and Water Composition" (Rogers and Meijer, 1993). The study concluded that: (1) particle grinding does not influence the sorption behavior of tuff sample studies until particle size becomes smaller than about 40 micrometers, (2) there should be no experimental artifacts caused by sample grinding in previous work as long as samples were washed after preparation, and (3) neptunium sorption onto tuff is very limited.

During the reporting period, the Department issued the Annual Air Quality Report for calendar year 1991. Air quality is monitored at and around Yucca Mountain to develop an understanding of ambient conditions and concentrations of atmospheric pollutants.

The Department's Civilian Radioactive Waste Management System must comply with a large number of requirements imposed upon it by applicable laws, regulations, and U.S. Department of Energy orders. To facilitate compliance with this wide range of requirements, the U.S. Department of Energy has developed a system of identifying and documenting them in "System Requirements" documents. System requirements documents have been prepared for the overall radioactive waste management system with major components of the system being: waste acceptance, transportation, monitored retrievable storage facility, mined geologic disposal system and the interfaces between each of these major components. During the reporting period, the Department released Revision 0 of the system requirements documents on the overall radioactive waste management system, waste acceptance, and mined geologic disposal system.

On October 24, 1992, the President signed into law the Energy Policy Act of 1992 (U.S. Congress, 1992). This Act includes several actions for the Office of Civilian Radioactive Waste Management. Section 801 of the Act directs the U.S. Environmental Protection Agency to "...prescribe the maximum annual effective dose equivalent to individual members of the public from releases to the accessible environment from radioactive materials stored or disposed of in the repository." Section 801 also directs the agency to contract with the National Academy of Sciences to conduct a study to provide findings and recommendations on "(A) whether a health-based standard based upon doses to individual members of the public from releases to the accessible environment ... will provide a reasonable standard for protection of the health and safety of the general public; (B) whether it is reasonable to assume that a system for post-closure oversight of the repository can be developed, based upon active institutional controls, that will prevent an unreasonable risk of breaching the repository's engineered or geologic barriers ... ; and (C) whether it is possible to make scientifically supportable predictions of the probability that the repository's engineered or geologic barriers will be breached as a result of human intrusion over a period of 10,000 years." Section 803 of the Act requires the Secretary of the U.S. Department of Energy to report to Congress and the President, within one year, on the adequacy of current nuclear waste management disposal plans to accommodate additional volumes of spent fuel and high-level waste in the event of an expanded nuclear power industry.

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Site characterization at Yucca Mountain will continue during the National Academy of Sciences review and repromulgation of environmental standards for a repository system by the U.S. Environmental Protection Agency. The amount and type of data and analyses that would be needed to show compliance with a new standard would be similar to the U.S. Department of Energy's current program. The scope and direction of the site characterization program will be evaluated in light of the standard that is promulgated.

In March 1993, the Nuclear Waste Technical Review Board issued a "Special Report to Congress and the Secretary of Energy," (NWTRB, 1993). Based on its evaluation of technical aspects of the radioactive waste management system, the Nuclear Waste Technical Review Board believed that three critical concerns should be addressed to increase integrity of scientific and technical aspects of the system, and to improve the program's effectiveness. The Board's major concerns were: (1) the program's unrealistic deadlines, (2) the need for an integrated overall nuclear waste management plan, and (3) the effectiveness of program management. The Department plans to respond to the Board's observations and recommendations.

Formal interactions were conducted between the Yucca Mountain Site Characterization Project Office and the Nuclear Waste Technical Review Board in October 1992 and January 1993. The project and affiliated contractors made presentations to the full Technical Review Board meeting in Las Vegas October 14-16, 1992. On January 5-6, 1993, the project and affiliated contractors made presentations to the full Board meeting in Arlington, Virginia.

The Yucca Mountain Site Characterization Project Office held a workshop in Albuquerque, New Mexico, November 18-20, 1992, to discuss the use of expert judgment as a decision support tool and in the resolution of scientific issues 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 120 interested people. Participants included the Program Director, several members of the Nuclear Waste Technical Review Board, representatives from the regulatory agencies, other federal and state government entities, project personnel, and other parties interested in the program.

The Yucca Mountain Site Characterization Project Office participated in a three-day workshop November 4-6, 1992, in Las Vegas, Nevada, on alternative design concepts and construction activities sponsored by the Nuclear Waste Technical Review Board's Panel on Structural Geology and Geoengineering. The workshop included discussions on a range of key issues and was attended by the majority of the Board members and its technical staff. The Board also invited several experts in underground tunneling and construction who provided valuable insight and comments on the Exploratory Studies Facility design. In addition, representatives from the local trade unions, test site contractors, regulatory agencies, and project personnel participated in the workshop.

The Office of Civilian Radioactive Waste Management's international program continued to cooperate with a number of countries and international organizations to exchange information of mutual interest, work towards achieving consensus on common issues, and develop and conduct cooperative activities of mutual benefit. On December 23, 1992, the

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Department announced that the Office of Civilian Radioactive Waste Management had signed new agreements with Sweden and Spain. The Office of Civilian Radioactive Waste Management and the Swedish Nuclear Fuel and Waste Management Company will conduct joint experimental and analytical development activities related to spent nuclear fuel and high-level waste disposal. These activities will be conducted at the Hard Rock Laboratory facility on Aspo Island, Sweden. The agreement is an extension of an ongoing cooperative relationship the Department has maintained with Sweden since 1977. Work to be performed under the agreement will provide scientists access to research facilities not readily available in the United States. The new bilateral agreement between the Office of Civilian Radioactive Waste Management and the Spanish Nuclear Waste Management Company will allow for information exchange on radioactive waste management technologies. The agreement established mutually beneficial activities, including characterization of geologic formations, repository design and operational issues, and surface and subsurface storage of radioactive waste.

Public outreach activities by the Yucca Mountain Site Characterization Project Office continued to expand public awareness regarding nuclear waste disposal concepts and the Yucca Mountain site characterization program. Seventy-six tours of Yucca Mountain were conducted for about 3,700 members of the public and other interested parties, such as U.S. Council for Energy Awareness, United Kingdom Defense Contractors, Nuclear Waste Technical Review Board, Japan Nuclear Safety Research Association on Nuclear Waste, Japan Electric Power Corporation, two Nuclear U.S. Regulatory Commission commissioners, National Association of Regulatory Utility Commissioners, several Nevada State Senators and staff members, and guests of the Nevada Nuclear Waste Study Committee Advisory Board. Numerous programmatic and technical workshops and presentations were conducted by U.S. Department of Energy staff. Meetings were held in various communities in southern Nevada to update the public and appropriate agency personnel regarding progress on site characterization.

## 1. INTRODUCTION

### 1.1 PURPOSE AND SCOPE

In accordance with Section 113(b)(3) of the Nuclear Waste Policy Act of 1982 (NWPAA), as amended (NWPAA, 1987) and 10 CFR 60.18(g), the U.S. Department of Energy (DOE) has prepared this report for the U.S. Nuclear Regulatory Commission (NRC) on the progress of site characterization activities at Yucca Mountain, Nevada, for the period October 1, 1992, through March 31, 1993. This report is the eighth 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 high-level radioactive waste. A geologic repository is a major component of DOE's Civilian Radioactive Waste Management System (CRWMS).

NWPA Section 113(b)(3) 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 NWPAA 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 (PR) 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, the PR is the vehicle for documenting and discussing changes to the Office of Civilian Radioactive Waste Management's (OCRWM) site characterization program resulting from ongoing collection and evaluation of site information, development of repository and waste package designs, and results of performance assessment (PA) activities.

Information in this PR is conveyed in a summary form for convenient information exchange. The report is not the mechanism for controlling and documenting technical or policy changes in schedules or the testing program but does identify points reached and modifications to schedules where appropriate. Changes to the site characterization program,

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and the technical rationale for them, are controlled through Yucca Mountain Site Characterization Project Office (YMPO) change-control procedures that are part of the quality assurance (QA) program.

The PR consists of two main sections: (1) an introduction, which briefly describes the purpose and scope of the PR, provides basic background information on the Yucca Mountain site and highlights major initiated, ongoing, and completed activities during the reporting period and (2) a section on the status of site characterization activities, which follows the format of Chapter 8 of the Site Characterization Plan (SCP) for the Yucca Mountain site (DOE, 1988a). Additionally, Section 3. (Schedule) contains the current summary schedule for the Yucca Mountain Site Characterization Project (YMP) and Section 4. presents an Epilogue which provides an overview of key events and decisions that occurred after the close of the reporting period on March 31, 1993, but prior to printing of the PR. Commencing with this PR, status of implementing recommendations of the Nuclear Waste Technical Review Board (NWTRB) with regard to site characterization activities at Yucca Mountain is presented. This status is included in Section 2.1.6.2.

Documents cited in the text are available for inspection at DOE public reading rooms in Washington, D.C. and Nevada. They can also be obtained through DOE's 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 NWPA Section 113, OCRWM is conducting a program of detailed site-specific investigations and evaluations to assess whether Yucca Mountain is suitable for development as a high-level radioactive nuclear waste repository. The plans, activities, and results of the site characterization program are reviewed by the State of Nevada, the NRC, the NWTRB, and other external organizations and interested parties.

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

The OCRWM's plans for site characterization are described in the SCP. More detailed information is presented in study plans for the various site characterization studies and their component activities. The SCP has been accepted by the NRC and over 5,000 comments from the NRC, State of Nevada, affected units of local government, other interested parties

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and agencies, and the public have received replies from OCRWM. The OCRWM continues to respond to all written inquiries received on the site characterization program. Changes to the statutory SCP are documented in YMPO technical baseline documents, primarily Section 2.1.8 of the Site Characterization Program Baseline (SCPB) (DOE, 1993b).

Activities planned for site characterization consist of surface-based studies, underground studies conducted in an Exploratory Studies Facility (ESF), laboratory tests, modeling, and analyses. PAs 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 Section 3.0), all site characterization activities are to be completed by the end of the year 2001. 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 geological repository, selected surface-based and underground tests will continue beyond the site characterization phase. Appropriate new tests and monitoring will also be initiated and continued while OCRWM is constructing the repository and during nuclear waste emplacement, until there is adequate confidence that the repository is performing as expected, and the NRC issues a license amendment to permanently close the repository.

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 SITE CHARACTERIZATION HIGHLIGHTS DURING REPORTING PERIOD**

Specific details regarding site characterization activities during the period October 1, 1992, to March 31, 1993, are presented in Section 2. Figures 1-1 and 1-2 show the locations where such activities are being performed. The following are the major highlights:

#### **1.3.1 Exploratory Studies Facility**

In November 1992, a major program milestone was reached when OCRWM received approval from the Energy System Acquisition Advisory Board to start ESF construction. The ESF is to be an underground laboratory designed to enable scientists and engineers to examine, at depth, the geologic, hydrologic, geoengineering, and geochemical characteristics of the potential repository host rock. The current ESF configuration is shown as an artist's rendering in Figure 1-3. The facility will consist of two main access ramps from the surface

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("North Ramp" and "South Ramp") to either end of a 3.2-km (2-mi) -long main tunnel oriented at N 34° E in the potential repository level, the Topopah Spring level (TSL). Two additional smaller diameter ramps will extend from the main ramps to either end of a second main drift lying directly below the TSL main drift in a lower level in the Calico Hills level (CHL). Various side tunnels will be driven to provide access to fault zones and other areas of potential interest. In total, 23,400 m (76,900 ft) of tunnel will be excavated, resulting in approximately 1,550,000 metric tons (1,700,000 tons) of excavated rock.

Mechanical excavation methods will be used when possible. Conventional (drill and blast) excavation will be used only when necessary. In the TSL the rock is fairly hard; 158 MPa (23,000 psi) compressive strength. Thus, up to 61 m (200 ft) of the first ramp will be excavated by drill and blast. A large diameter tunnel boring machine (TBM) will be employed to excavate the remainder of the material in the main ramps and tunnels. A conveyor belt system will carry the excavated rock out of the underground and to the rock storage area. (See Figure 2-2 for a typical cross section of the ramp.) Side tunnels on the upper level will be excavated by either the TBM, other similar mechanical means, or by drill and blast. In the CHL the rock is not as hard, and can be mechanically excavated by any of several different types of machines. Important aspects associated with the ESF that occurred during the period include the following:

- Commencement of construction, on November 30, 1992, of the North Portal pad of the ESF. To date, ESF activities include: removal of topsoil from the topsoil storage pad access road, rock storage pad, north ESF access road and sections of the drainage ditches; placement of subgrade material on the topsoil storage pad access road; stabilization of the subgrade of the north ESF access road; grading of drainage ditches at the topsoil storage pad just east of Alice Ridge; continuation of cut and fill at the ESF North Portal access road; continuation of hauling of topsoil from the ESF North Portal pad area to the topsoil storage pad just east of Alice Ridge; and the completion of hauling of common fill from the Fortymile Wash borrow pit to the ESF North Portal access road.
- The ESF ramp size study was submitted to YMPO by Raytheon Services Nevada (RSN) in October 1992. The study considered parameters such as haulageway configuration, conveyor location, underground clearance for various support methods, and ventilation considerations. Results of the study were used by YMPO to determine an appropriate diameter for a TBM Request for Proposal (RFP). The study recommended a diameter of 8.53 m (28 ft), if two-way traffic is desired in the ramp and a diameter of 7.62 m (25 ft) for single-lane traffic.
- All review comments on the ESF Design Package 1A Technical and Management Design Review have been resolved. The RSN Design Verification Review and the design specifications and drawings were completed and submitted to YMPO for acceptance and review. The YMPO reviewed and accepted these documents in November 1992. The ESF Design Packages 1B and 2, which include designs of a majority of the ESF surface facilities and North Ramp, are scheduled to undergo a 50 Percent Complete Technical and Management Review in early April 1993.

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- Design work on means to provide electrical power to the ESF in order to allow TBM operations is ongoing. RSN is currently designing the preliminary system which is to be 69 kV, with an upgrade of the system to 138 kV. Design of the 69-kV system is approximately 30 percent complete, and is scheduled to be in place and working on December 20, 1993. Design of the 138-kV upgrade just began.
- The RFP for a TBM to be used in excavating the ESF at Yucca Mountain was released on December 16, 1992. TBM vendor proposals were received on February 8, 1993. All submitted bids for a 7.62-m (25-ft) -diameter TBM are currently being evaluated.
- The CRWMS Management and Operating Contractor (CRWMS M&O) ESF Design Group assumed responsibility from RSN for ESF Title II Design, effective October 1, 1992. Early activities included initiating preparation of the Basis for Design document and the Fiscal Year 1993 Engineering Plan.
- The ESF Floodplain Assessment and Statement of Findings were finalized, approved, and published in the Federal Register on October 23, 1992.

More detailed discussion of ESF design and construction is contained in Section 2.1.2.



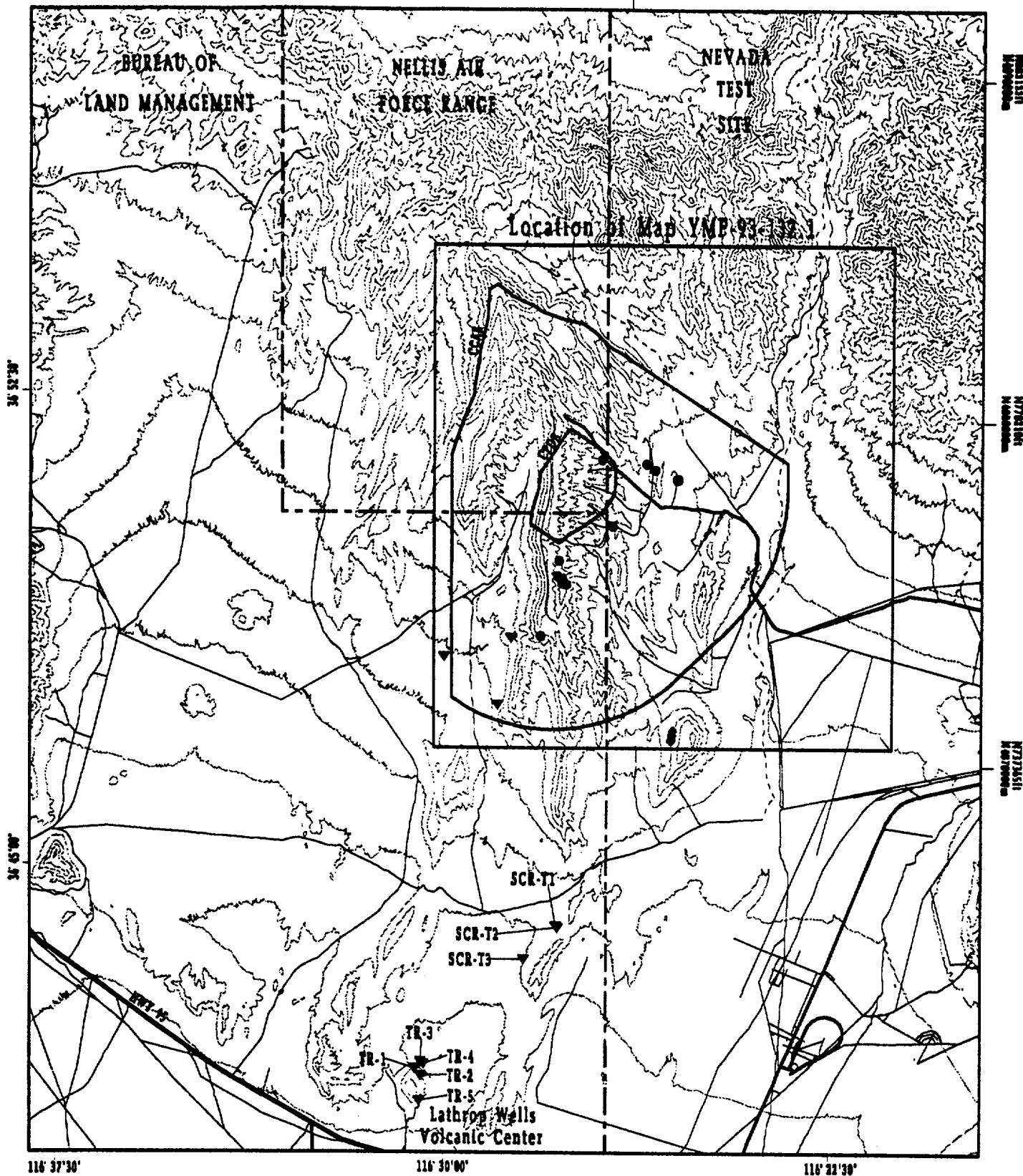
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**Figure 1-1.** Map YMP-93-133.2 Site characterization surface activities undertaken during the reporting period in the Yucca Mountain area including the Lathrop Wells volcanic center.

Areas enclosed by black lines define the following:  
large area (CCAB) = boundary of the accessible environment;  
small area (CPDB) = potential repository block.

13330000

13330000



## SURFACE ACTIVITIES

1 October 1992 TO 31 March 1993

- Borehole
- ▼ Trench
- ◆ Pavement

Contour Interval 200 Feet



N

**YUCCA MOUNTAIN**  
**SITE CHARACTERIZATION PROJECT**  
 Reported activities completed between 1 October 1992  
 and 31 March 1993 (Far Field)

EG&amp;G YMP-93-133.2

## PROGRESS REPORT #8

**Figure 1-2.** Map YMP-93-132.1 Site characterization surface activities undertaken during the reporting period in the Yucca Mountain area.

Areas enclosed by black lines define the following:

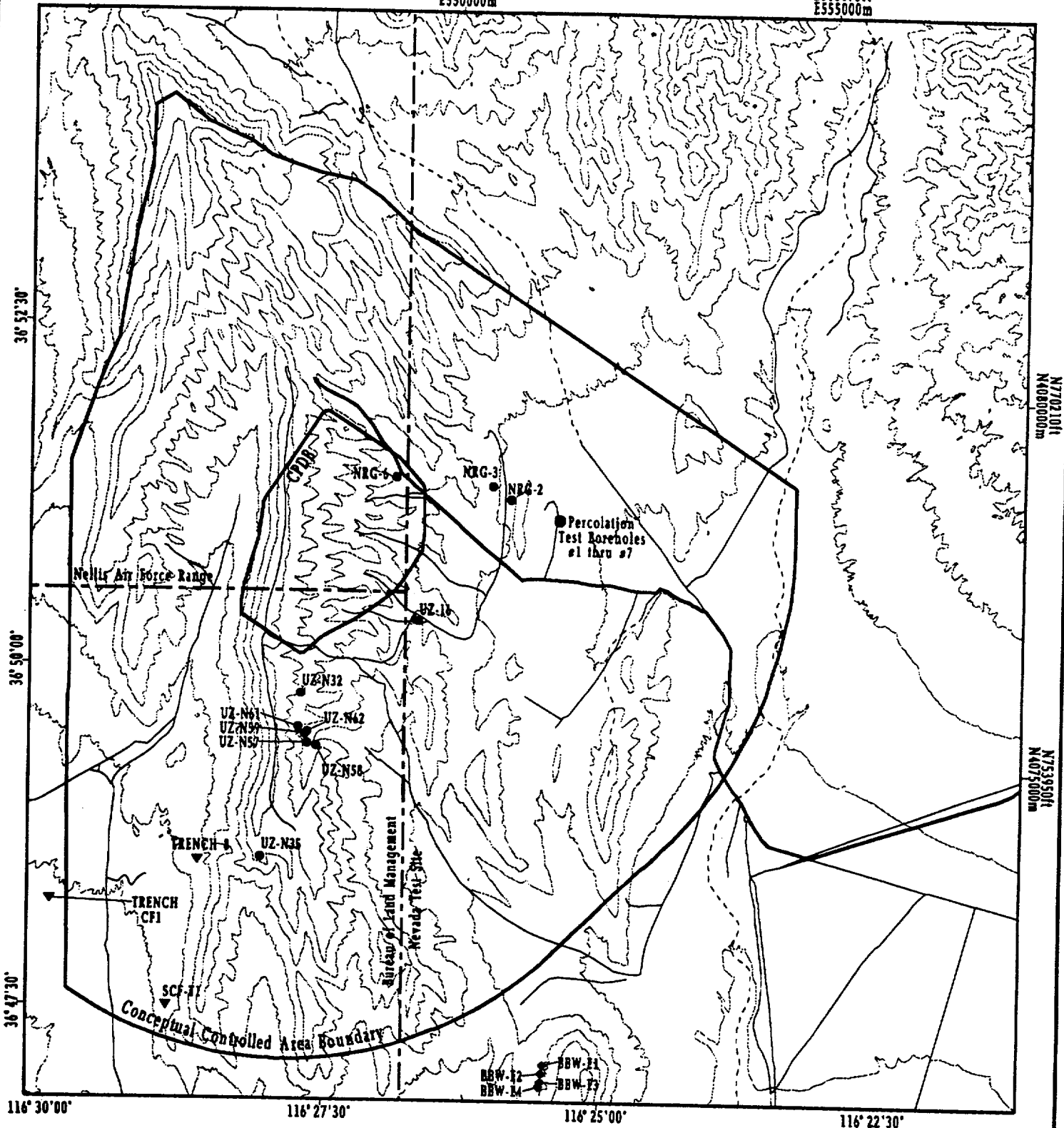
large area (CCAB) = boundary of the accessible environment

small area (CPDB) = potential repository block

E550245ft  
E545000m

E566660ft  
E550000m

E583075ft  
E555000m



#### SURFACE ACTIVITIES

1 October 1992 TO 31 March 1993

- Borehole
- ▼ Trench
- ◆ Pavement

Contour Interval 200 Feet

**YUCCA MOUNTAIN  
SITE CHARACTERIZATION PROJECT**  
Reported activities completed between 1 October 1992  
and 31 March 1993 (Near Field)

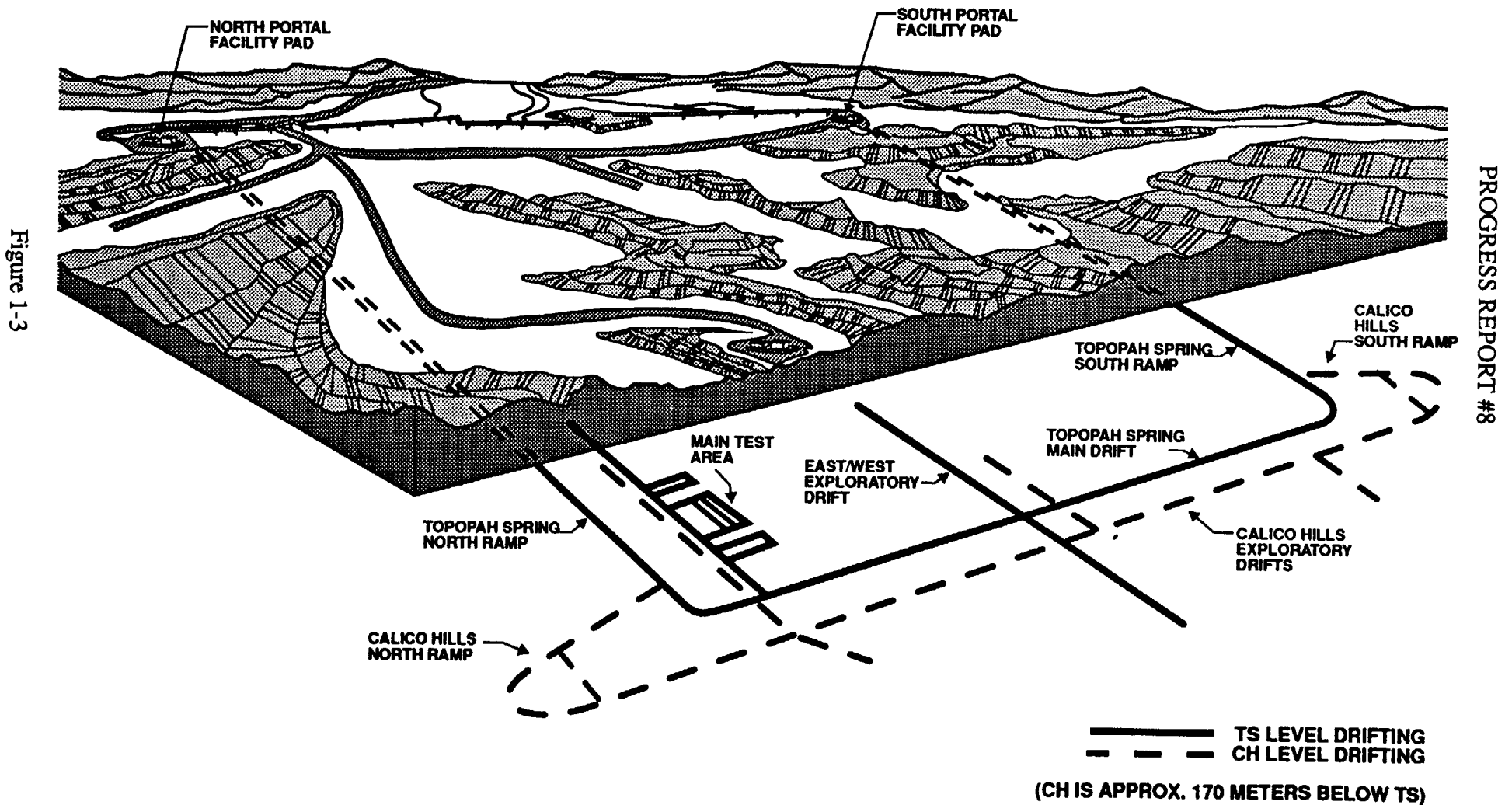


YMP-93-132.1

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**Figure 1-3.** Pictorial Representation of Current ESF Configuration

# PICTORIAL REPRESENTATION OF CURRENT ESF CONFIGURATION



### 1.3.2 Waste Package

Advanced conceptual design (ACD) of the waste package (WP) commenced in October 1992. Detailed thermal, criticality, and shielding evaluations have been initiated on the seven concepts selected for ACD. Advances have been made in the hydrologic modeling of Yucca Mountain. Planning has moved forward on the Large Block Test (LBT) and the Engineered Barrier System (EBS) Field Tests. Scientific studies have continued on container and waste form testing as well as integrated testing.

The design effort has focused on the initiation of thermal, criticality, and shielding evaluations of the seven design concepts which include: metallic multibarrier, metallic shielded, small metallic multibarrier borehole, overpacked multipurpose canister (MPC), universal cask, and the Site Characterization Plan-Conceptual Design Report (SCP-CDR) (single container). Also included is a high-level waste glass package that would incorporate glass canisters from the producers.

The study plan for characterization of chemical and mineralogical changes in the postemplacement environment was thoroughly revised to more accurately reflect the current plans for the work. EQ3/6 calculations to consider precipitation and dissolution effects on pore and fracture properties continued.

The magnitude of repository-heat-driven buoyant convection in the saturated zone (SZ) was analyzed in a series of cases for 30-year-old spent nuclear fuel (SNF) at various thermal loadings and repository acreage. The temperature effects in the SZ were found to be potentially quite significant. The calculations also show considerable condensate drainage below the repository. The impact of bulk hydrologic permeability was evaluated and found to be important. For example, large permeability corresponds to situations in which fracture density and connectivity are large enough to allow large-scale, buoyant, gas-phase gradients to dominate the local boiling pressure gradients, causing significant asymmetry in the vertical temperature distribution.

The Scientific Investigation Plan (SIP) for the LBT of coupled thermalmechanical-hydrologic-chemical processes is in internal review. These tests will be conducted in the laboratory and the field. The outcroppings at Fran Ridge are being evaluated. The draft study plan for the engineered barrier field tests is being revised as a result of internal review.

Dissolution testing of uranium dioxide and spent fuel and the oxidation testing of spent fuel are continuing. Thermogravimetric analysis (TGA) of spent fuel is being restarted to obtain transition kinetics of partially oxidized fuel that is needed for the oxidation-degradation model. A new dry bath test is being evaluated at 225°C to further explore transition kinetics. Leach testing of high-level waste glass is continuing. Changes have been made to the core flow-through experiment to improve the response of the system.

Work is continuing on compiling information on carbon steels, low alloy steels, and cast irons for a degradation mode survey on these materials. Laboratory equipment was moved and reinstalled in readiness for performing some experimental work. Procurement of a

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TGA system will permit determination of the corrosion and oxidation rates of metals as a function of temperature and humidity.

Additional discussion of WP design can be found in Section 2.6.

### **1.3.3 System Requirements Documents**

The OCRWM 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, YMPO has developed a system of identifying and documenting them in "System Requirements" documents. System requirements documents are being prepared for the overall CRWMS and each major component of the CRWMS (i.e., waste acceptance, transportation, monitored retrievable storage facility, the mined geologic disposal system (MGDS), and the interfaces between each of these major components). During the reporting period, YMPO released "Civilian Radioactive Waste Management System Requirements Document" (DOE, 1992d), "Waste Acceptance System Requirements Document" (DOE, 1992h), and "Mined Geologic Disposal System" (DOE, 1993a).

### **1.3.4 Issue Resolution**

The OCRWM has started 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 the 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" without rulemaking during this precicensing period, and any issue can be revisited based on new information, it is important to seek clarification and come to resolution with NRC staff on as many areas of uncertainty as possible as early as is feasible. This clarification is accomplished by frequent interaction and communication with the NRC. These interactions may be in the form of reports sent to the NRC staff for review and comment (topical or technical reports), letters, submittals of the Annotated Outline (AO) for License Application (LA) (see Section 2.1.13), or meetings. In addition, the resolution of the "NRC Staff Site Characterization Analysis of the U.S. Department of Energy's Site Characterization Plan, Yucca Mountain, Nevada" (SCA) (NRC, 1989) open items is being coordinated within the Issue Resolution process. Issue resolution activities during the reporting period include the following:

- **SCA Open Items:** By letter dated November 2, 1992, the NRC notified OCRWM that, based on the Commission staff's review of information provided by OCRWM in relevant portions of the "Exploratory Studies Facility Alternatives Study: Final Report" (ESFAS) (Dennis, 1991) and "Risk/Benefit Analysis of Alternative Strategies for Characterizing the Calico Hills Unit at Yucca Mountain"



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(DOE, 1991a) reports, the NRC considers Objection 1 lifted and SCA Comments 12, 16, 35, 57, 72, 127, 128, 132, and SCA Question 61 resolved. On February 8, 1993, the NRC agreed that OCRWM had provided the technical basis to resolve SCA Comments 100, 104, 106, 108, 110, 112, and 113.

- **Volcanism:** Evaluation of the potential effects of basaltic volcanism on the proposed repository to address the regulatory requirements is a project priority. A copy of the preliminary draft of the Los Alamos National Laboratory (Los Alamos) technical report (LA-9325, Volume III) on the status of YMP volcanism studies was forwarded to the NRC for review and comment on March 9, 1993. The primary goal in developing the technical report is to initiate discussion concerning the methodology and logic of approaches in OCRWM's volcanism studies.
- **Erosion:** On March 9, 1993, the Erosion Topical Report (DOE, 1993e) was issued by OCRWM. The report was prepared to address 10 CFR Part 60.122(c)(16), and provides evidence that extreme erosion has not occurred at Yucca Mountain during the Quaternary period. This conclusion is based, in part, on a comparative evaluation of Yucca Mountain hillslope erosion and stream incision with erosion rates in other analogous geologic and climatic regimes.
- **Seismic Hazards:** Comments on the NRC proposed revisions to 10 CFR Parts 100, 50, 52, and related Regulatory Guides were transmitted to the NRC on March 24, 1993. Although the appendices to 10 CFR 100 do not directly apply to the repository program, NRC acceptance of a probabilistic methodology as applied to the seismic hazard analysis is important to investigations at Yucca Mountain. Clarification of analysis methods in the regulatory guides was recommended, plus justification of the geologic reconnaissance distance from a proposed site.

**Forecast:** During the last half of fiscal year (FY) 1993, the YMPO issue resolution effort intends to accomplish the following: (1) receive an NRC safety evaluation of the OCRWM topical report on extreme erosion, (2) transmit to the NRC, for their information, an OCRWM technical report on methodologies to determine the origin of calcite-silica deposits at Trench 14 and Busted Butte, (3) interact with the NRC in Technical Exchanges on volcanism and geophysical program integration, (4) issue to the NRC for review, the Los Alamos final report on probability of eruptive events through the repository, and (5) continue to resolve additional SCA open items.

### **1.3.5 Total System Performance Assessment**

The CRWMS M&O performed a limited Total System Performance Assessment (TSPA) to show readiness, to test Golder Associates Inc.'s Repository Integration Program (RIP) code, and to evaluate Sandia National Laboratories' (SNL) TSPA-1991 data base. A number of sensitivity studies were included. A preliminary draft report, "A Comparative Application of the Repository Integration Program (RIP) to Total System Performance

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Assessment - 1991," (INTERA Inc., 1993) was submitted to YMPO for review on March 30, 1993.

In November 1992, Pacific Northwest Laboratory (PNL) issued the report "Preliminary Total System Analysis of a Potential High-Level Nuclear Waste Repository at Yucca Mountain" (Eslinger et al., 1992). This document describes work performed by PNL as part of YMPO's 1991 TSPA. PNL's study included calculation of source term releases from the potential repository at Yucca Mountain, liquid-phase and gas-phase fluid and solute transport in the unsaturated zone (UZ) and liquid-phase flow and solute transport in the SZ. These calculations were performed for nominal conditions and for disruptive events (volcanism and human intrusion) for which probabilities of occurrence were estimated. Ultimately, this information was integrated to compute human doses from the potential repository and the Complementary Cumulative Distribution Function (CCDF).

More detailed discussion of PA, including TSPA is contained in Sections 2.1.9 and 2.7.6.

### **1.3.6 Permits and Approvals**

Before it can conduct some of its site characterization activities, YMPO must obtain permits and approvals from other federal and State of Nevada regulatory agencies in order to be in compliance with the applicable regulations of these agencies. Within the reporting period, YMPO obtained the following permits:

- A Free Use Permit for the Fran Ridge gravel pit was received from the U.S. Department of Interior, Bureau of Land Management (BLM), on January 8, 1993. The permit allows for the extraction of 305,822 m<sup>3</sup> (400,000 cu. yd) of sand and gravel necessary for construction of the ESF.
- In October 1992, the State of Nevada issued a point source permit for dust control for the Cone Gravel Screening Plant. This plant will be used during ESF site preparation and construction activities.

More detailed discussion of compliance with environmental requirements is contained in Section 2.1.4.

### **1.3.7 Trenches and Test Pits**

Trenches and test pits are excavated to expose subsurface layers of soil and rock in order to allow evaluation of possible geologic faults and volcanic history. Since July 1991, trenches and test pits have been excavated at the Lathrop Wells cinder cone to allow evaluation of the past basaltic volcanic activity in the vicinity of Yucca Mountain. During the reporting period, four trenches previously dug at the Lathrop Wells cone were deepened to

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examine stratigraphic and geochronologic relations. Revised stratigraphic descriptions are now consistent with most previously obtained geochronology data.

### **1.3.8 Boreholes**

Boreholes are drilled into Yucca Mountain to obtain information on geological structure, faults, rock characteristics, depth to the water table, water quality, infiltration, and water movement in soil and rock. During the reporting period, eight Phase II boreholes for the Neutron Access Program were completed. The most noteworthy was the completion of Borehole UE-25 UZ #16 to a depth of 507.5 m (1,665 ft) with the LM-300 drill rig. In addition, drilling of Boreholes UE-25 NRG-1 to 46 m (150 ft), UE-25 NRG-2 to 65.5 m (215 ft), UE-25 NRG-3 to 101 m (330 ft), and USW NRG-6 to 335 m (1,100 ft) was completed.

### **1.3.9 Sorption Coefficients**

Los Alamos staff conducted experiments in response to a 1987 NRC position paper request for experiments to determine whether batch sorption coefficients obtained using crushed tuff rock material from Yucca Mountain could be used to accurately model radionuclide sorption behavior along potential release pathways in the mountain. Findings of this study were released during the reporting period in the document "Dependence of Radionuclide Sorption on Sample Grinding, Surface Area, and Water Composition," (Rogers and Meijer, 1993). The study concluded that (1) particle grinding does not influence the sorption behavior of tuff sample studies until particle size becomes smaller than about 40  $\mu\text{m}$ , (2) there should be no experimental artifacts caused by sample grinding in previous work as long as experiment samples were washed after preparation, and (3) Np sorption onto tuff is very limited.

### **1.3.10 Air Quality**

During the reporting period, the annual air quality report entitled "Particulate Matter Ambient Air Quality Data Report for 1991" (SAIC, 1992) was issued. Air quality is monitored at and around Yucca Mountain in order to develop an understanding of ambient conditions and concentrations of atmospheric pollutants.

## **1.4 PROGRAMMATIC HIGHLIGHTS DURING REPORTING PERIOD**

During the reporting period of October 1, 1992 to March 31, 1993, other OCRWM program activities occurred that have implications concerning Yucca Mountain site characterization. These are highlighted below:

#### **1.4.1 Energy Policy Act of 1992**

Congress passed the Energy Policy Act of 1992 (U.S. Congress, 1992) (hereinafter referred to as "the Act" or "the Energy Policy Act of 1992") and the President signed it into law on October 24, 1992.

- Section 801 of the Act directs the U.S. Environmental Protection Agency (EPA) to "...prescribe the maximum annual effective dose equivalent to individual members of the public from releases to the accessible environment from radioactive materials stored or disposed of in the repository."
- Section 801 of the Act also directs the agency to contract with the National Academy of Sciences (NAS) to conduct a study to provide findings and recommendations on "(A) whether a health-based standard based on doses to individual members of the public from releases to the accessible environment ... will provide a reasonable standard for protection of the health and safety of the general public; (B) whether it is reasonable to assume that a system for post-closure oversight of the repository can be developed, based upon active institutional controls, that will prevent an unreasonable risk of breaching the repository's engineered barriers ... ; and (C) whether it is possible to make scientifically supportable predictions of the probability that the repository's engineered or geologic barriers will be breached as a result of human intrusion over a period of 10,000 years."
- Section 803 of the Act requires the DOE Secretary to report to Congress and the President, within one year after the date of the enactment of the Act, on the adequacy of current nuclear waste management disposal plans to accommodate additional volumes of spent fuel and high-level waste from an expanded nuclear power industry.

#### **1.4.2 Expert Judgment Workshop**

The Department's YMPO held a workshop in Albuquerque, New Mexico, November 18-20, 1992, to discuss the use of expert judgment in quality decision-making and resolution of scientific issues as recommended by the NWTRB in its fourth report. The workshop was open to the public and was attended by over 120 interested people. Participants included the Program Director, several members of the NWTRB, representatives from the regulatory agencies, other national and state government entities, project personnel, and other parties interested in the program.

#### **1.4.3 International Program**

The OCRWM international program continued to cooperate with a number of countries and international organizations to exchange information of mutual interest, work towards

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achieving consensus on common issues, and develop and conduct cooperative activities of mutual benefit.

- On December 23, 1992, DOE announced that OCRWM signed new agreements with Sweden and Spain. The OCRWM and the Swedish Nuclear Fuel and Waste Management Company will conduct joint experimental and analytical development activities related to the SNF disposal and high-level waste at the Hard Rock Laboratory facility on Aspo Island, Sweden. The agreement is an extension of an ongoing cooperative relationship DOE has maintained with Sweden since 1977. Work to be performed under the agreement will provide scientists with access to research facilities not readily available in the United States. The new bilateral agreement between OCRWM and the Spanish Nuclear Waste Management Company will allow for information exchange on radioactive waste management technologies. The agreement established mutually beneficial activities, including characterization of geologic formations, repository design and operational issues, and surface and subsurface storage of radioactive waste.
- The Natural Analogue Review Group (NARG), convened under the auspices of the YMP, has submitted its report, "Applications of Natural Analogue Studies to Yucca Mountain as a Potential High Level Radioactive Waste Repository." To focus attention on the proper role of natural analogues the report states, "natural analogue studies should be process-oriented and should basically address the issues resulting from the perturbation of a natural system (the geologic site) by the introduction of a technological system (the repository)." This can be paraphrased to state that a natural (or anthropogenic) analogue is a process that is analogous to the perturbation of a natural system by a technological system. The YMP has subsequently accepted this statement as a definition of natural analogue for use during site characterization. The definition is to be applied broadly, not merely to natural analogues of hydrothermal systems in tuff, which is the subject of SCP Section 8.3.1.3.3.1.

Additional statements in the NARG report clarify the role and limitations on natural analogue studies as they will be used by the YMP. The report states, "one should clearly discriminate such studies from those which, following the classical approach of earth sciences, are based on the comparative study of geological sites or situations. In particular, all investigations normally part of site characterization, even when considering comparisons with similar remote sites, such as (paleo)hydrology, etc., should not be considered as natural analogue studies." This statement should not be construed as meaning that normal geoscience studies will not be conducted. The studies described in the SCP and in various study plans will be carried out; however, most of them will not be designated as natural analogue studies.

**Forecast:** The YMPO will plan and form a natural analogue project design team comprising elements from the PA groups, public relations groups, and the geochemistry program managers.

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### 1.4.4 Public Outreach

Public outreach activities by YMPO continued to expand public awareness regarding nuclear waste disposal concepts and the Yucca Mountain site characterization program.

- Seventy-six tours of Yucca Mountain were conducted for about 3,700 members of the public and other interested parties. Groups involved included the U.S. Council for Energy Awareness, United Kingdom Defense Contractors, NWTRB, Japan Nuclear Safety Research Association on Nuclear Waste, Japan Electric Power Corporation, two NRC commissioners, National Association of Regulatory Utility Commissioners, several Nevada State Senators, and guests of the Nevada Nuclear Waste Study Committee Advisory Board. Numerous programmatic and technical workshops and presentations were conducted by YMP staff. Meetings were held in various communities in Nevada to update 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 YMP staff.

## 2. STATUS OF SITE CHARACTERIZATION

### 2.1 PREPARATORY ACTIVITIES

#### 2.1.1 Quality Assurance Program

The OCRWM Office of QA issued the document, "Quality Assurance Requirements and Description for the Civilian Radioactive Waste Management Program" (QARD) (DOE, 1992b). The QARD represents the highest level QA requirements within the Civilian Radioactive Waste Management Program. It incorporates requirements from regulatory commitments and appropriate guidance documents. Implementing documents will translate QARD requirements into administrative work processes; therefore, the QA program will consist of the QARD plus the implementing documents from all affected organizations.

Upon the issuance of the QARD, Yucca Mountain QA Division (YMQAD) completed a review of YMPO implementing procedures to determine which procedures needed to be revised to be brought in line with the new requirements document. Thirty of the 48 procedures reviewed were identified as needing revision. As a joint effort with line management, an estimated date of September 1993 was established for transition to the new QARD. YMQAD continues to support this procedure revision effort.

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 (QAL), the need for a project-level QAL was eliminated and the selection of QA controls is now determined based on the Q-List designation of the item to which these activities are related. The project is currently in a transition period for implementation of these changes.

The QAL was a controlled document, originally issued in 1990, which progressed through a fifth revision in 1991. All revisions were supported by evaluation packages prepared, reviewed, and approved by the Quality Review Board. The QAL evaluation packages, which provide the rationale for items contained on the QAL, are included in the "Supporting Documentation for Evaluation of Activities for the Quality Activities List," (DOE, 1990a). The activities considered for the QAL were defined in the YMP Work Breakdown Structure and other baseline documents.

The "Yucca Mountain Project Q-List" (DOE, 1990b) is a controlled document originally issued on July 24, 1990. It was developed under a quality procedure requiring review and approval by the Quality Review Board. Revision 0 is the current revision although a revision is in process to include items reflecting the revised ESF design activities. The "Supporting Documentation for Evaluation of Items Important to Safety" (DOE, 1990c) and the "Supporting Documentation for Evaluation of Items Important to Waste Isolation" (DOE, 1990d) provide the rationale for the current Q-List.

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During the reporting period, YMQAD conducted seven audits. The audits were conducted of Lawrence Livermore National Laboratory (LLNL), Los Alamos, CRWMS M&O/TRW Environmental Safety Systems Inc., Reynolds Electrical & Engineering Company, Inc. (REECo), SNL, Technical and Management Support Services (T&MSS), and U.S. Geological Survey (USGS). The audits evaluated the QA programs for compliance with OCRWM requirements and effectiveness of QA program implementation.

YMQAD conducted 16 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 NRC is kept informed of the status of OCRWM's QA program, bimonthly NRC-OCRWM QA meetings continue to be held. 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.

### **2.1.2 Exploratory Studies Facility Design and Construction**

The design of the ESF and plans for its construction have changed significantly from those associated with the shaft-based concept presented in the SCP (DOE, 1988a). This section provides a brief description of the mechanism for reporting changes in the ESF design followed by a brief discussion of the new ESF configuration. Design and construction activities for the current reporting period are provided in Sections 2.1.2.1 and 2.1.2.2, respectively. Changes in ESF design that occurred during the reporting period and any changes to tests planned for the facility are reported in Section 2.1.8, SCPB.

The SCPB, released in February, 1991, was produced to contain the latest information regarding site characterization activities, including changes to the SCP ESF configuration and supporting design information. Revision 1 of the SCPB incorporated the current ESF configuration from Option 30 in the ESFAS (Dennis, 1991). Since then, all changes related to ESF design and testing have been reported in subsequent revisions to the SCPB (DOE, 1993b), which in turn have been reported in each PR published since PR 4 (DOE, 1991b). The following is a summary of changes reported in previous PRs:

PR 4 , Section 2.1.10, reported that the SCPB was being revised to baseline the new ESF configuration.

PR 5 (DOE, 1992e), Section 2.1.10, noted that the ESF design concept presented as Option 30 in the ESFAS had been incorporated into the SCPB.

PR 6 (DOE, 1992f), Section 2.1.2, provided further updates on the status of the new ESF design.



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PR 7 (DOE, 1992g), Section 2.1.8, reported that Revision 6 to the SCPB included an update to the ESF design description to make it consistent with the ESF Title I Design. In addition, Section 2.1.2 cited the ESF Title I Design Summary Report (DOE, 1992a) as a formal reference to PR 7.

The ESF Title I design, completed during 1991, provides preliminary design for the entire ESF and forms the basis for proceeding into Title II design. The concept for the complete ESF/repository layout was evaluated during Title I and was determined to be an adequate concept providing access to the bulk of the potential repository block while maintaining the flexibility needed to accommodate potentially changing needs (i.e., heat load). Title II design consists primarily of "fleshing out" the Title I concept and developing the detailed design drawings and construction specifications required to build the facility.

The ESF Title II design started in October 1991. A phased approach to the design and construction of the facility was adopted. The phased approach, as well as ESF related issues of potential repository design, is described in the SCPB. Design of those systems which do not lend themselves to a phased design are being developed for the entire facility. Examples of this include design of the ESF ventilation system and the conveyor haulage system. Design of these systems is currently under way, taking into account the needs of the entire facility.

Between May 1992, and November 1992, the ESF Title I Design Summary Report was divided into two documents. Three volumes (Vols. 2, 4 and 5) of the original five volume report remained the ESF Title I Design Summary Report, but control was shifted from the Change Control Board (CCB) to Document Control. The remaining two volumes (Vols. 1 and 3) were designated as Volumes 1 and 2 of the ESF Technical Baseline (DOE, 1993c) and placed under CCB control. The intent was to separate the Title I Design Summary Report, which represented the ESF at the culmination of the Title I Design, from the ESF Technical Baseline, which is intended to represent the ESF design as it progresses and is now accepted by YMPO as the current baseline.

The ESF Technical Baseline was transmitted to the NRC on May 19, 1993 (DOE, 1993d). Since its release the ESF Technical Baseline has been updated as Title II design progresses and as various changes are implemented during construction. As of the end of this reporting period, the Technical Baseline has been updated through Revision 2.

The current ESF configuration is shown in Figure 2-1. The facility will consist of two main access ramps from the surface ("North Ramp" and "South Ramp") to either end of a 3.2-km (2-mi) -long main tunnel oriented at N 34° E in the potential repository level, the TSL. Two additional smaller diameter ramps will extend from the main ramps to either end of a second main drift lying directly below the TSL Main Drift in a lower level in the CHL. Various side tunnels will be driven to provide access to fault zones and other areas of potential interest. In total, 23,400 m (76,900 ft) of tunnel will be excavated, resulting in approximately 1,550,000 metric tons (1,700,000 tons) of excavated rock.

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Mechanical excavation methods will be used when possible. Conventional (drill and blast) excavation will be used only when necessary. In the TSL the rock is fairly hard; 158 mPa (23,000 psi) compressive strength. Thus, up to 61 m (200 ft) of the first ramp will be excavated by drill and blast. A large diameter TBM will be employed to excavate the remainder of the material in the main ramps and tunnels. A conveyor belt system will carry the excavated rock out of the underground and to the rock storage area. (See Figure 2-2 for a typical cross section of the ramp.) Side tunnels on the upper level will be excavated by either the TBM, other similar mechanical means, or by drill and blast. In the CHL the rock is not as hard, and can be mechanically excavated by any of several different types of machines.

Surface facilities will be built in three primary areas. The North Portal area will consist of a 4.3 ha (10.5 acre) pad with the primary office/warehouse complex, data acquisition system building, visitor center, portal control building, shop facility, and substation. For reference, the North Portal is located on the east-facing slope of Exile Hill, in the area where the Central Surface Facilities area was shown in the SCP reference potential repository description. The South Portal will have a 2 ha (5 acre) pad with the primary ventilation fan installation and several smaller structures. The South Portal is located on the east-facing slope of Boundary Ridge, approximately 3.2 km (2 mi) south of the North Portal area. The optional shaft area, if constructed, will consist of a 1 ha (2 acre) pad, hoist and headframe, and the administrative/maintenance building.

Tunneling will begin at the North Portal, initially by the drill and blast method to create a Starter Tunnel for the TBM assembly. The Starter Tunnel will be constructed using the New Austrian Tunneling Method (NATM). (See Figure 2-3.) NATM involves the excavation of large diameter tunnels in stages; first opening a small "pilot drift", installing a sensitive ground movement monitoring network, and then enlarging, or "slashing" the tunnel to its full size while installing the permanent ground support system. Consistent with this method, YMPO will use information gained from each segment of the tunnel excavated to improve excavation and support methods in succeeding tunnel segments.

Due to funding constraints, consideration is being given to changing the baseline construction logic from the utilization of four TBMs to two TBMs. The change is expected to be implemented in the baseline documentation during the next reporting period, and is described below.

TBM excavation will proceed down the North Ramp to the TSL, along the main TSL drift, and up the South Ramp, breaking out on the surface at the South Portal. This initial effort will cover a distance of approximately 8 km (5 mi), provide a good first look at the TSL, penetrate the Ghost Dance fault, and provide two separate means of ingress and egress to the underground facility.

Upon completion of the initial loop, excavation will begin on the Main Test Area (MTA) and the lateral tunneling on the TSL. When all excavation is complete on the TSL, the South Ramp to the CHL will be started. Similar to the TSL loop, this excavation will proceed down the South Ramp, along the CHL Main Drift, and up the Calico Hills North

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Ramp, connecting into the Topopah Spring North Ramp. Side tunneling in the CHL will be completed after the Calico Hills loop is done.

Scientific testing will be performed on a limited basis from the start of tunneling operations, with substantially greater activity after the completion of the initial loop and the MTA.

### 2.1.2.1 ESF Design

Title II ESF Design is underway. The first half of Design Package 1 (referred to as Package 1A) was completed in November, 1992. This package includes design of the North Portal site preparation work, selected utilities, and the Starter Tunnel for the TBM. Title II Design of the remainder of Package 1, termed 1B, containing design of all surface structures on the North Portal pad, and all of Package 2, including the design of the North Ramp from the surface to the TSL, started on October 1, 1992 and is currently underway. The initial design review, at the 50 percent point, is scheduled to occur early in the next reporting period. These design packages are scheduled to be completed by the end of FY 1993.

Other significant activities in the ESF design area include the completion of an ESF ramp sizing study, and the commencement of the design work to bring both temporary and permanent electric power service to the ESF area.

The ramp sizing study, "ESF Ramp & Main Drift Sizing Analysis" (RSN, 1992) was submitted in October, 1992. The study considered parameters such as haulageway configuration, conveyor locations, underground clearance of various support methods, and ventilation considerations. Results of the study were used by YMPO to determine an appropriate diameter for the TBM RFP issued two months later.

Title I and II design activities were started in October, 1992 for a 69 kV temporary power system and 138 kV permanent system. Construction of the 69 kV system, utilizing an existing line along most of its length, is scheduled to be complete in December, 1993. The permanent 138 kV system is currently expected to come on line in late FY 1995.

### 2.1.2.2 ESF Construction

Construction of the ESF began on November 30, 1992, with the commencement of site preparation. Site preparation activities have included construction of a topsoil storage area, rock storage area, access road, construction of a 4.3 ha (10.5 acre) facility pad and access road at the North Portal, and excavation of a rock cut or "slot" in the east side of Exile Hill in preparation for development of a TBM Starter Tunnel. Excavation of the actual Starter Tunnel is to begin early in the next reporting period.

Procurement of the first TBM was begun during the period. An RFP was released in December 1992. Proposals were received in February 1993; the proposals were evaluated; and the contract award is expected early in the next reporting period.

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**Figure 2-1. Current ESF Configuration**

# ESF CONFIGURATION

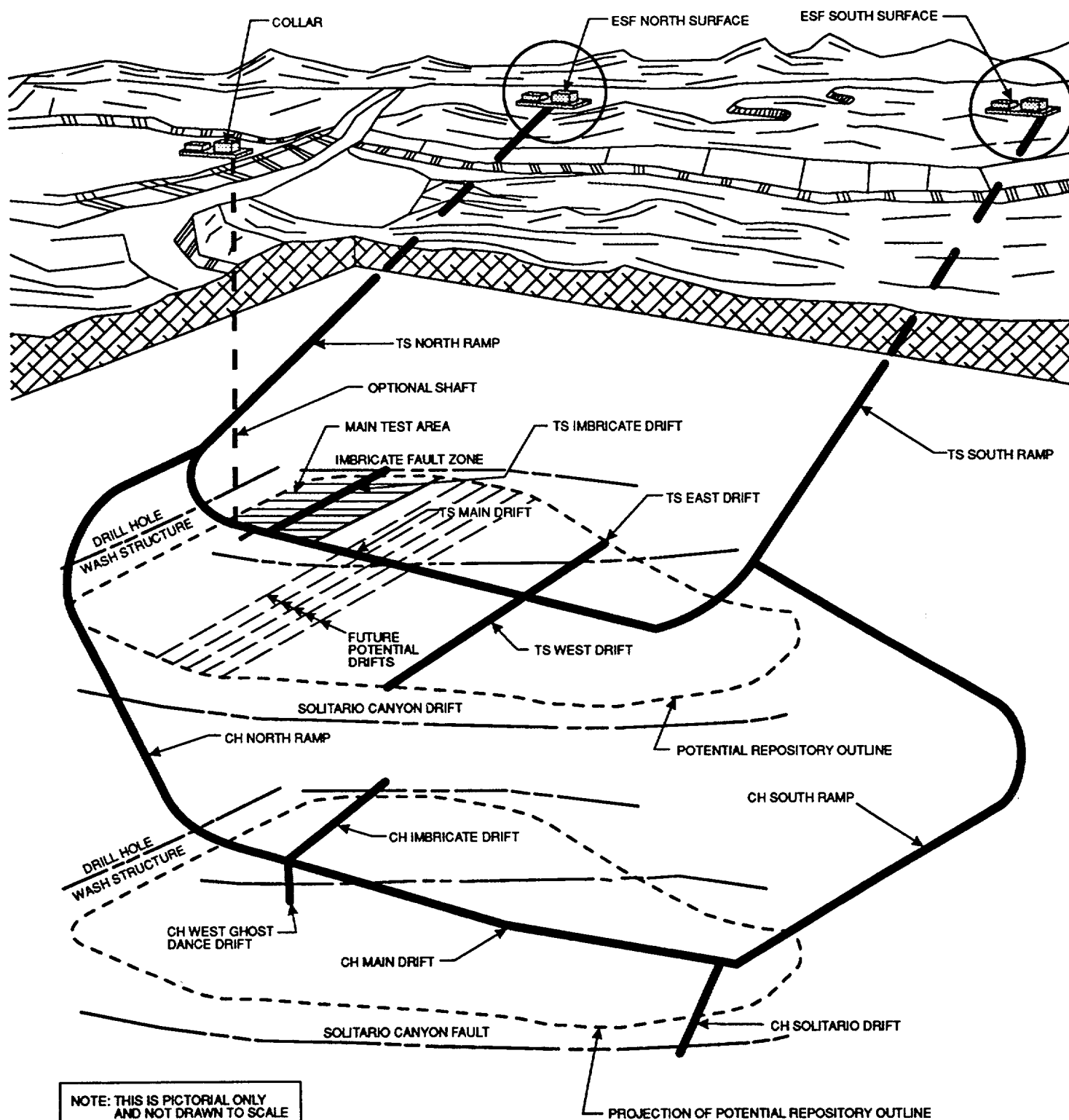


Figure 2-1

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**Figure 2-2. Typical Ramp Cross Section**

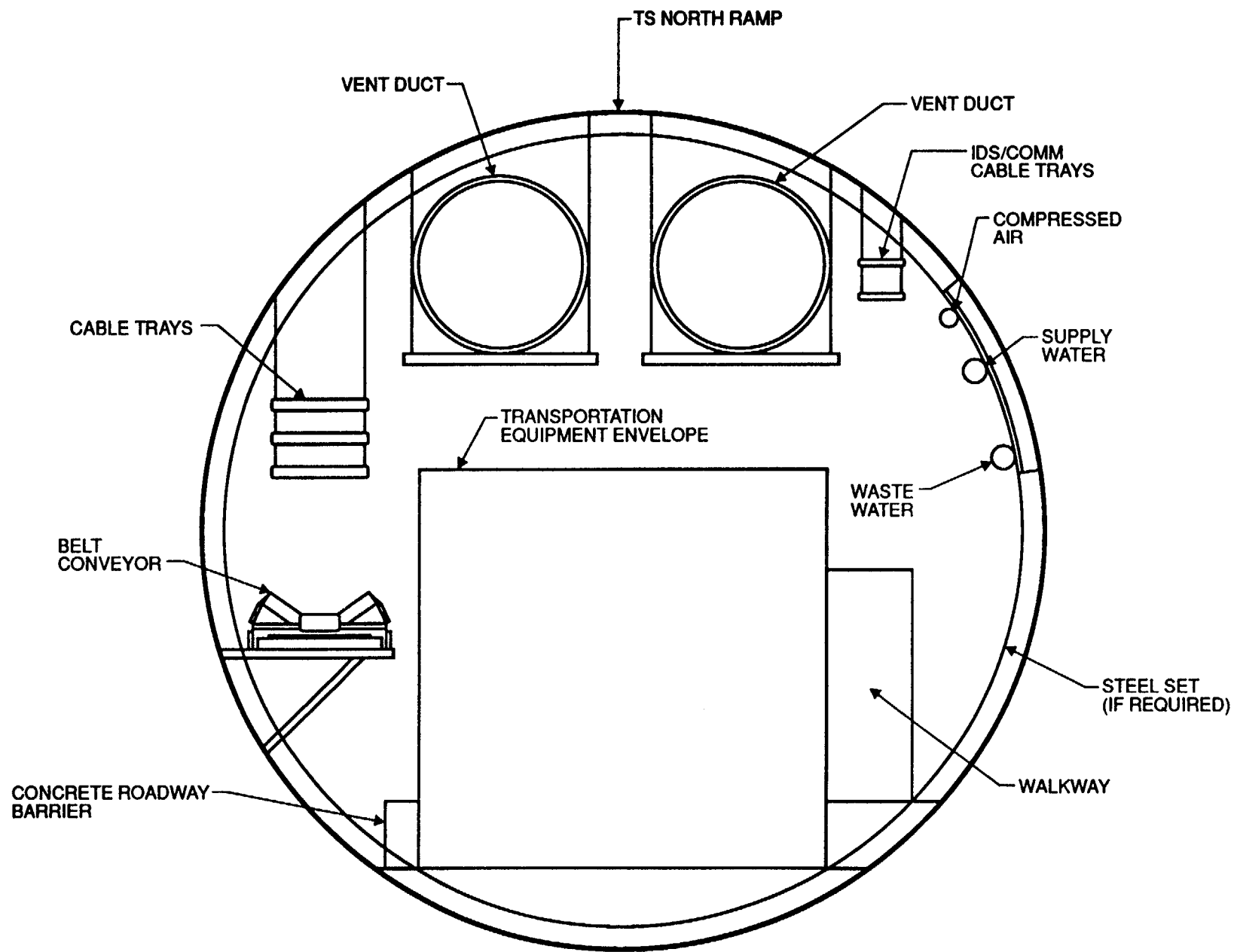


Figure 2-2

## 7.6 METER (25 FT.) RAMP CROSS SECTION

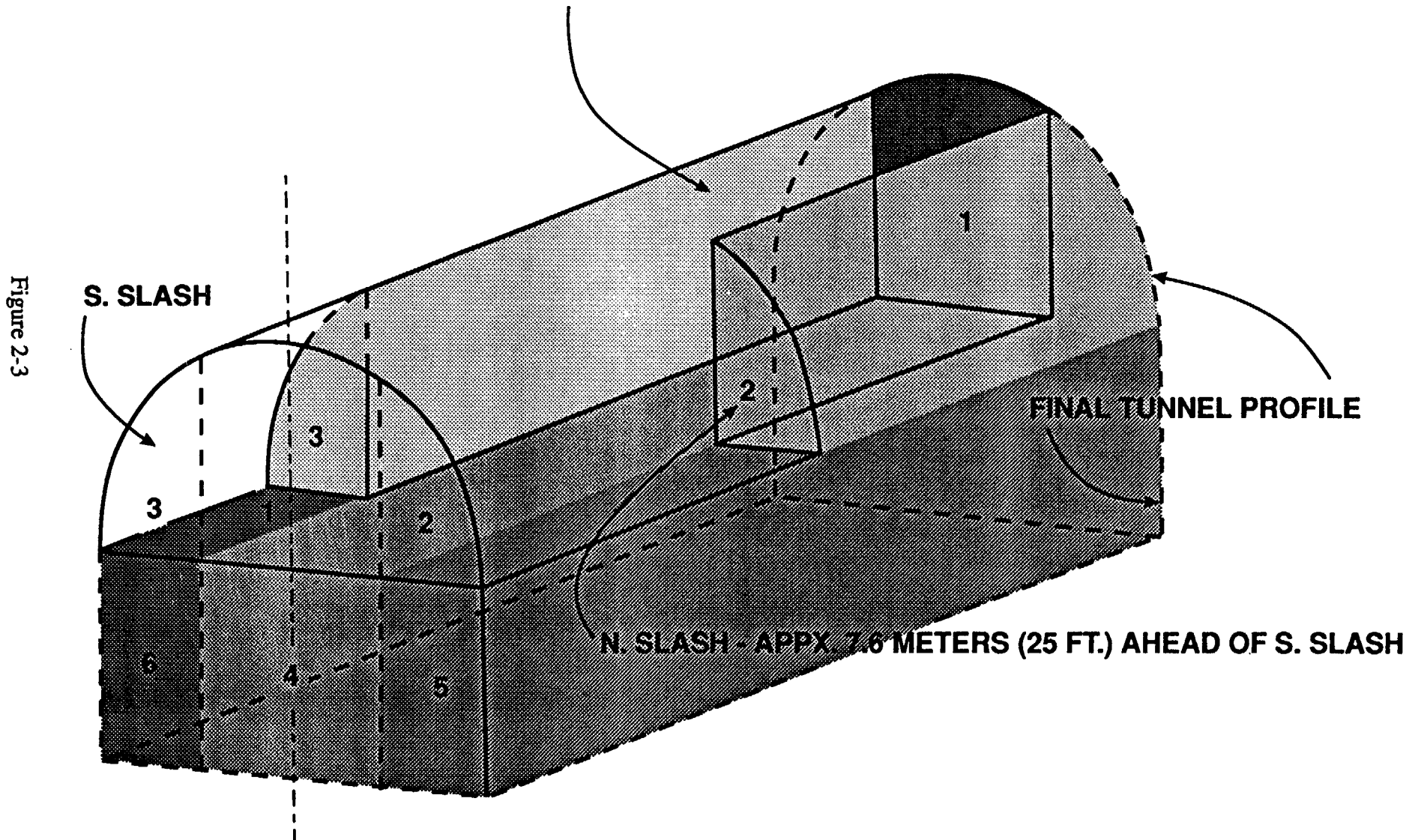
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**Figure 2-3. Tunnel Excavation Sequence**



# ESF STARTER TUNNEL EXCAVATION SEQUENCE

PILOT DRIVE - APPX. 15 METERS (50 FT.) AHEAD OF N. SLASH



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### **2.1.3 Initiatives in Surface-Based and Underground Testing**

#### **2.1.3.1 Early Site Suitability Evaluation**

In the last PR, OCRWM provided a description of the Early Site Suitability Evaluation (ESSE) (Yunker et al., 1992) report, a chronology of activities related to the ESSE, a brief description of the comments received, and OCRWM's plans for comment response. A comment response document has been completed and is being reviewed for OCRWM approval prior to responding to all commenting organizations.

#### **2.1.3.2 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. Two milestones were completed in the reporting period. The initial phase of the ITE was completed by the submittal of the Executive Summary: Draft Final Report Integrated Test Evaluation Framework for Prioritizing Tests for the Yucca Mountain Site on September 18, 1992 (Revised November 3, 1992) and the submittal of the Reference Notebook: Draft Final Report Integrated Test Evaluation Framework for Prioritizing Tests for the Yucca Mountain Site Characterization Project on November 12, 1992.

Scoping is under way for a Phase 2 ITE effort which includes design as a criterion for prioritizing testing. A preliminary parameter list is being developed to aid in this scoping effort.

#### **2.1.3.3 Site Investigations Annual Plan**

The YMPO, with assistance from the CRWMS M&O Site Characterization Group, developed the "Fiscal Year 1993 Annual Plan for Site Characterization" (WCFS, 1993) for the YMP. The plan describes the planning, integration, and coordination of all activities that support surface-based testing (SBT) and testing in the ESF for Site Investigations. An overview of the planned SBT and ESF testing goals for FY 1993 are also discussed in the context of the overall goals of the YMP. Appendices to the plan provide additional data on the status, prioritization, and funding of each work element funded for FY 1993, a look back at accomplishments for FY 1992, and a look forward to planned FY 1994 work scopes. Compilations of data for boreholes, trenches, and test pits planned for FY 1993 are also included in the appendices.

**Forecast:** The Site Investigations Annual Plan will be revised yearly.

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### 2.1.4 Permits

#### 2.1.4.1 Compliance with Federal Environmental Requirements

During this reporting period, YMPO coordination with Federal agencies regarding clearances for all site characterization activities and necessary permits resulted in the publication in the Federal Register (October 23, 1992) of a Statement of Findings from the Floodplain Assessment of Site Characterization Activities at the Yucca Mountain Site and the issuance from the BLM of a Free Use Permit for the excavation of sand and gravel from the newly established Borrow Pit #1 at Fran Ridge.

Consultations continue with Native American tribes and bands, as specified in the Programmatic Agreement with the Advisory Council on Historic Preservation.

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

**Forecast:** Within the next 6-12 months, there is a potential need for a Free-Use Permit for 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.

During the reporting period, the State of Nevada issued to YMPO a change approval to the ground-water appropriation for Well USW VH-1, a six month extension of the ground-water appropriation waiver to drill and complete Borehole UE-25 UZ #16, and two air quality permits. The approval for Well USW VH-1 allows a change to the manner of use not to exceed  $2.8 \times 10^4 \text{ cm}^3/\text{s}$  (1.0 cu. ft/s) and not to exceed  $7.6 \times 10^4 \text{ m}^3$  (61.38 acre-ft) annually. Air quality permits to construct were issued for a cone screening plant and a diesel hydraulic screening plant.

**Forecast:** The YMP permit applications projected over the next 6-12 months may include four air quality permits, two National Pollutant Discharge Elimination System (NPDES) permits, permits for drinking water and sewage disposal, and Underground Injection Control tracer permit modifications for the C-Well tests. Air quality permits will include those needed for the ESF batch plant and its support equipment, possible power generators at the C-Well complex, and a rock conveyer system at the ESF. The NPDES permits may be required for tests at the C-Well complex and at Well USW G-2.

### 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

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

Seventeen participant requests to initiate site characterization activity were processed during the period. Fifteen of these requests have been completed and access authorization granted. The remaining two requests are awaiting the preparation of right-of-way applications to BLM. Additionally, two participant requests from the last reporting period were completed; a right-of-way for trench excavations at Bare Mountain, Nevada, and a right-of-way for the Stateline surface-water monitoring station. Four 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 surface-water monitoring stations; two right-of-way applications to the Barstow Resource Area BLM office for seismic stations; two right-of-way applications to the Stateline Resource Area BLM office for a seismic reflection program; and five right-of-way applications to the Tonopah Resource Area BLM office for seismic stations.

### **2.1.6 Interactions with the U.S. Nuclear Regulatory Commission and Oversight Organizations**

#### **2.1.6.1 U.S. Nuclear Regulatory Commission Interactions**

During the reporting period OCRWM participated in the following interactions with the NRC:

- |                   |  |
|-------------------|--|
| October 28, 1992  | The OCRWM and the NRC met in Rockville, Maryland, to discuss the new QA Requirements Document and the audit process.   |
| October 29, 1992  | The OCRWM and the NRC conducted a Technical Exchange in San Antonio, Texas, to discuss the application of systems engineering to a potential high-level radioactive waste repository program. The NRC discussed the Center for Nuclear Waste Regulatory Analysis (CNWRA) functional analysis of 10 CFR Part 60, activities related to regulatory and institutional uncertainties, guidance of regulatory requirements, guidance on technical issues, and the NRC's license application format and content guidance document. |
| November 24, 1992 | The YMPO and the NRC conducted a Management Meeting by video-conference in Las Vegas, Nevada, and Washington, D.C., to discuss, plan, and agree on the subject and content of OCRWM-NRC interactions during January through June 1993.   |
| December 9, 1992  | The OCRWM and the NRC went on a site visit to the Vitreous State Laboratory at Catholic University in Washington, D.C. to discuss research conducted by the laboratory on vitrified high-level waste.  |

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- December 15, 1992      NRC Commissioner Curtiss and NRC Region 5 Director Martin toured Yucca Mountain.
- December 14-15, 1992      The OCRWM and the NRC conducted a Technical Exchange in Bethesda, Maryland, to discuss OCRWM's 1991 TSPA and the NRC's Iterative PA, Phase 2.
- December 18, 1992      The Director of OCRWM, briefed the NRC on activities during the last six months, and emphasized, as the most significant accomplishment, the November start of site preparation for the ESF.
- January 13, 1993      The YMPO conducted a meeting with representatives from the Waste Isolation Pilot Plant (WIPP) project to discuss PA activities at each project so the NRC could observe the interaction and gain an understanding of the similarities and differences in their approach to PA.
- January 26, 1993      The OCRWM and the NRC met in Rockville, Maryland, to discuss QA activities.

### 2.1.6.2 Nuclear Waste Technical Review Board Interactions

In March 1993, the NWTRB issued a "Special Report to Congress and the Secretary of Energy" (NWTRB 1993). Based on its evaluation of technical aspects of the program, the NWTRB believes that three critical concerns should be addressed to increase integrity of scientific and technical aspects of the CRWMS, and to improve the program's effectiveness. The Board's major concerns were: (1) the program's unrealistic deadlines, (2) the need for an integrated overall nuclear waste management plan, and (3) the effectiveness of program management.

During the reporting period YMPO participated in the following interactions with the NWTRB:

- October 14-15, 1992      Full Board Meeting in Las Vegas, Nevada. The YMPO and affiliated contractors made presentations to the Full Board Meeting on various matters, including: (1) test results on the process by which radionuclides may enter the repository environment and react with the host rock, (2) defining a "source term" for use in nuclear waste management studies, (3) use of the source term in efforts to model total system performance in a geological repository, and (4) progress on small-scale surface geologic mapping of the Ghost Dance fault in the Yucca Mountain area.
- October 16, 1992      Tour of the Yucca Mountain site.

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- November 4-6, 1992      Structural Geology and Geoengineering Panel workshop in Las Vegas, Nevada, to discuss ESF alternative design and construction strategies.
- January 5-6, 1993      Full Board Meeting in Arlington, Virginia. The YMPO and affiliated contractors made presentations to the Full Board Meeting on interim storage of nuclear waste, dual purpose casks, the MPC concept, and system engineering activities. Of particular concern to activities at Yucca Mountain is the repository design and operational implications of possible MPC use.
- January 12, 1993      Tour of WIPP site, Carlsbad, New Mexico.

The project has also continued its efforts to address many of the 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 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 ACD work for the WP as recommended in the Board's Third, Fourth, and Fifth Reports; and (4) planning for a follow-up workshop on EBS concepts to be held in the Fall of 1993 as recommended in the Board's Fourth Report. The project also welcomed the participation of the Board and its staff at various project meetings, internal workshops, and scientific symposiums.

### **2.1.6.3    Advisory Committee on Nuclear Waste Interactions**

Also during this reporting period YMPO participated in the following interactions with the Advisory Committee on Nuclear Waste (ACNW):

- October 20, 1992      A Working Group Meeting on Natural Resources in Las Vegas, Nevada.
- October 21, 1992      The ACNW 47th Meeting in Las Vegas, Nevada. This meeting was the first full committee meeting of the ACNW held in Nevada. The meeting included a briefing on YMPO site characterization activities and budget, an overview of the Little Skull Mountain earthquake, a review of the working group activities from the previous day, and presentations from the State of Nevada and local governments.
- October 22, 1992      Tour of the EG&G Remote Sensing Laboratory and Geographic Information System (GIS) facility. Following the tour, the ACNW attended a briefing on InfoSTREAMS and a mandatory tunnel training session in preparation for a tour of X-Tunnel in Area 25 of the Nevada Test Site (NTS).

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- October 23, 1992      Tour of X-Tunnel, an underground facility approximately 1 mi from the Little Skull Mountain earthquake epicenter, the Yucca Mountain Field Operations Center, Crest of Yucca Mountain, the LM-300 drill rig site, the Ghost Dance fault area, the Bow Ridge fault trenching site, the Midway Valley trenching site, and the Sample Management Facility (SMF).
- November 18, 1992      A Working Group Meeting on Climate in Bethesda, Maryland. Presentations included discussions of the potential impacts of long-range climate changes in the Southern Basin and Range.
- December 16, 1992      A Working Group Meeting on PA in Bethesda, Maryland. This meeting was a follow-on to the OCRWM-NRC Technical Exchange on PA held the previous two days.
- December 17-18, 1992      The ACNW 49th Meeting in Bethesda, Maryland. Topics discussed were the Expert Judgment Workshop, SCA Objection No. 1, and CNWRA activities.
- January 28, 1993      The ACNW 50th Meeting in Bethesda, Maryland. Topics discussed were the Energy Policy Act of 1992 and the use of natural analogs in radioactive waste disposal.

### **2.1.7 Resolution of U.S. Nuclear Regulatory Commission Open Items**

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

The project continues to work toward resolving the 122 SCA open items that remain from the NRC's July 1991 evaluation of the December 1990 SCA responses. During this reporting period, OCRWM forwarded documentation to the NRC claiming resolution of SCA comments 21 and 22 (letter dated January 7, 1993), Comment 53 and Questions 14 and 15 (letter dated February 5, 1993), and Questions 17 and 57 (letter dated March 24, 1993).

During this reporting period the NRC accepted a number of the proposed resolutions. The NRC lifted SCA Objection 1 (design control process), as well as accepted resolutions for SCA Comments 12, 16, 35, 57, 72, 127, 128 and 132, and Question 61 in a letter dated November 2, 1992. The NRC also informed OCRWM that they accepted resolutions for Comments 100, 104, 106, 108, 110, 112 and 113 in a letter dated February 8, 1993. The project awaits NRC action on seven SCA open items to which the NRC, as of the close of this reporting period, had yet to respond.

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For NRC comments on SCP study plans, YMPO and the NRC follow agreements resulting from May 7-8, 1986, and December 15, 1988, meetings on study plans. Within 90 days of receipt of the OCRWM-approved study plans, the NRC performs what they term a Phase I review of the study plan and notifies the project whether or not they accept the study plan. Phase I reviews are also the opportunity for the NRC to state if there are any objections to starting work under the study plan. During Phase I reviews, the NRC sometimes also expresses various concerns that can be of a technical or procedural nature. The project responds to these inquiries. The NRC also reserves the option to perform what they term a Phase II review during which technical comments are made or questions posed. The project responds to these comments and questions. The NRC performs Phase II reviews on study plans chosen at their discretion. The State of Nevada receives copies of all OCRWM-approved study plans at the time they are sent to the NRC. The state also offers comments on study plans at their discretion, to which the project responds. The status of study plan comment responses is reported in Chapter 2.2, under sections pertaining to the study plan at issue.

During the reporting period, OCRWM and the NRC reviewed the May 7-8, 1986 agreement on the format and content for study plans in light of how the program has evolved since 1986. Using the experience gained through the preparation and review of study plans since 1986, OCRWM and the NRC established a revised agreement on the format and content of study plans in March 1993. The new format and content guidance should aid preparation and review of study plans especially those where modeling, synthesis activity, or interpretation are the primary focus. The OCRWM also initiated a revision of Administrative Procedure (AP) 1.10Q (Preparation, Review, Approval, and Revision of Site Characterization Plan Study Plans) to implement the new study plan agreements. This revision will be approved early in the next reporting period.

Table 2-1 identifies all remaining SCA open items. For those items remaining open, 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. Status of Site Characterization Analysis Open Items

Open Item #	Description of Open Item
<b>COMMENTS</b>	
1	<p>A systematic, iterative approach to identify and collect data for a license application.</p> <p><u>Further Action Required:</u> Complete a convergence approach for using licensing strategy with key milestones associated with iterative PA and the development of the LA AO to identify and collect the data required.</p>
2	<p>Confidence in performance allocation goals.</p> <p><u>Further Action Required:</u> Prepare and issue TSPA documentation for 1991 and 1992.</p>
3	<p>Reliance on expert judgment for supplying licensing information.</p> <p><u>Further Action Required:</u> Issue the summary of the Expert Judgment Workshop.</p>
4	<p>Rationale for testing needs; integration of testing with design and PA.</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>WP: Interpretation of "substantially complete containment."</p> <p><u>Further Action Required:</u> Develop a topical report which addresses 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. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
COMMENTS (Continued)	
6	PA: Hypothesis Testing Table and alternative conceptual models.  <u>Further Action Required:</u> Conduct iterative PAs and address the conceptual models uncertainties.
7	Use of expert judgment versus peer review.  <u>Further Action Required:</u> Issue summary of Expert Judgment Workshop.
8	Alternative Tectonic Models.  <u>Further Action Required:</u> Prepare and issue Study Plan 8.3.1.17.4.2 (Tectonic Models and Synthesis).
9	Use of Expert Judgment during the development of Hypothesis Testing Tables.  <u>Further Action Required:</u> Address the hypothesis testing through the TSPA activities and document work performed in 1991 and 1992.
10	Assessment of significance of site hydrologic characteristics.  <u>Further Action Required:</u> Resolution of Comment 1.
11	No hypothesis on the thermal effects of waste emplacement in hydrologic environment.  <u>Further Action Required:</u> Address the thermal effects on the hydrologic system and the total repository system by emplaced waste.

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Table 2-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
<b>COMMENTS (Continued)</b>	
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> Prepare and issue Study Plan 8.3.1.2.2.4 (Characterization of the Yucca Mountain Unsaturated Zone - ESF Investigation).</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>SZ work is not adequate for SZ testing.</p> <p><u>Further Action Required:</u> Develop a plan to sufficiently test and define the saturated aquifer.</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. Conduct a technical exchange on Geophysical Integration.</p>
21	<p>SZ: Tc-99 and I-129 are not included to characterize ground-water flow and nuclide background concentrations.</p> <p><u>Further Action Required:</u> None. The OCRWM has submitted a supplemental response to close the item. Awaiting NRC confirmation.</p>

## PROGRESS REPORT #8

Table 2-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
<b>COMMENTS (Continued)</b>	
22	<p>SZ: Hydrochemical sampling.</p> <p><u>Further Action Required:</u> None. The OCRWM has submitted a supplemental response 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 8.3.1.3.2.2 (History of Mineralogical and Geochemical Alteration of Yucca Mountain).</p>
25	<p>WP degradation products and interactions between radionuclides on sorption.</p> <p><u>Further Action Required:</u> Prepare and issue Study Plan 8.3.1.2.4.1 (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 Column Experiments).</p>
32	<p>Integration of geophysics and discussion is not included.</p> <p><u>Further Actions Required:</u> Issue the strategy developed by the Geophysics Integration Task Force. Conduct OCRWM-NRC Technical Exchange on Geophysical Integration.</p>

## PROGRESS REPORT #8

Table 2-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
<b>COMMENTS (Continued)</b>	
33	<p>Engineering rock characteristics are not integrated into three-dimensional models.</p> <p><u>Further Action Required:</u>            Prepare and issue Study Plans 8.3.1.4.2.3 (Three Dimensional Geologic Modeling) and 8.3.1.4.3.1 (Systematic Acquisition of Site Specific Subsurface Information).</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 in the Site Area) and 8.3.1.2.2.4 (Characterization of the Yucca Mountain Unsaturated Zone - 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 an OCRWM-NRC Technical Exchange which discusses 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 the NRC to close the item. Awaiting NRC confirmation.</p>
43	<p>Adequacy of numerical goals in erosion, postclosure tectonics, and preclosure tectonics PA tables.</p> <p><u>Further Action Required:</u>            None. Supplemental response submitted to the NRC to close the item. Awaiting NRC confirmation.</p>

## PROGRESS REPORT #8

Table 2-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
<b>COMMENTS (Continued)</b>	
45	<p>Volcanic rate calculations independent of underlying volcanic tectonic processes.</p> <p><u>Further Action Required:</u> Complete and issue revisions of Study Plans 8.3.1.8.1.1, Revision 2 (Probability of Magmatic Disruption of the Repository) and 8.3.1.8.5.1, Revision 1 (Characterization of Volcanic Features).</p>
47	<p>Relationship of postclosure tectonics to the WP and EBS requirements.</p> <p><u>Further Action Required:</u> Prepare and submit to the NRC a supplemental response.</p>
48	<p>Use of fault slip rates on the repository facilities are not conservative.</p> <p><u>Further Action Required:</u> Prepare and issue topical report "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> Prepare a report on the integration of geophysical activities. (See Section 2.2.3.2, Activity 8.3.1.4.1.2 - Integration of Geophysical Activities.)</p>

## PROGRESS REPORT #8

Table 2-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
<b>COMMENTS (Continued)</b>	
52	<p>Use of geophysics in evaluating basaltic volcanism.</p> <p><u>Further Action Required:</u> Revise and issue Study Plan 8.3.1.8.1.1 (Probability of Magmatic Disruption of the Repository). Conduct OCRWM-NRC Technical Exchange on Geophysical Integration.</p>
53	<p>Adequacy of natural resource assessment; consideration of ore deposition models</p> <p><u>Further Action Required:</u> None. The OCRWM submitted a supplemental response to close this item. Awaiting NRC concurrence.</p>
55	<p>Adequacy of geostatistical approach to geomechanical and thermal properties.</p> <p><u>Further Action Required:</u> Prepare a supplemental response and submit to the NRC..</p>
56	<p>Validation of models for mechanical and thermal properties.</p> <p><u>Further Action Required:</u> Prepare and issue Study Plans 8.3.1.15.1.5 (Excavation Investigations), 8.3.1.15.1.6 (In Situ Thermomechanical Properties), and 8.3.1.15.1.7 (In Situ Design Verification).</p>
59	<p>Preclosure tectonics activities to be performed and timing of activities</p> <p><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). Conduct OCRWM-NRC Technical Exchange on Geophysical Integration .</p>

## PROGRESS REPORT #8

Table 2-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
<b>COMMENTS (Continued)</b>	
60	<p>Adequacy of preclosure design and performance goals and characterization parameters.</p> <p><u>Further Action Required:</u> Resolve comment 1.</p>
61	<p>Assumption that future faulting will follow previous faulting.</p> <p><u>Further Action Required:</u> Prepare and issue Study Plan 8.3.12.17.2.1 (Faulting Potential at the Repository).</p>
62	<p>Use of standoff distances in preclosure tectonics for surface facilities.</p> <p><u>Further Action Required:</u> Prepare and issue Study Plan 8.3.1.17.2.1 (Faulting Potential at the Repository).</p>
63	<p>Use of pre-existing and unavailable information for the preclosure tectonics program and the surface facilities.</p> <p><u>Further Action Required:</u> Prepare a supplemental response and submit to the NRC.</p>
64	<p>Adequacy of study of faults for design and performance.</p> <p><u>Further Action Required:</u> Conduct an OCRWM-NRC Technical Exchange on Geophysical Integration.</p>



## PROGRESS REPORT #8

Table 2-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
<b>COMMENTS (Continued)</b>	
66	<p>Release via a single event (10,000 year cumulative slip earthquake).</p> <p><u>Further Action Required:</u>            Prepare and issue report on how the facility will withstand an event exceeding the design basis ground motion.</p>
68	<p>Adequacy of treatment on detachment faulting affects.</p> <p><u>Further Action Required:</u>            Prepare and issue Study Plan 8.3.1.17.4.12 (Tectonic Models and Synthesis).</p>
69	<p>Synthesis of data on the northwest trending of faulting.</p> <p><u>Further Action Required:</u>            Prepare and issue Study Plan 8.3.1.17.4.12 (Tectonic Models and Synthesis).</p>
71	<p>Adequacy of technologies in assessing faulting for construction, operation, and closure.</p> <p><u>Further Action Required:</u>            Prepare and issue topical report on "Seismic Hazards Methodology."</p>
73	<p>Adequacy of required backfill hydraulic conductivity.</p> <p><u>Further Action Required:</u>            Complete "Site Design and Requirements Document." Advance the work on seals program. Prepare the study plan for the hydraulic conductivity of the backfill.</p>
74	<p>Testing of seal components.</p> <p><u>Further Action Required:</u>            Prepare and issue Study Plan 8.3.3.3.3.3 (In Situ Testing of Seal Components).</p>

## PROGRESS REPORT #8

Table 2-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
<b>COMMENTS (Continued)</b>	
75	Definition of and inconsistent use of "geologic setting."  <u>Further Action Required:</u> Prepare supplemental response and submit to the NRC.
77	Adequacy of consideration of retrieval operations.  <u>Further Action Required:</u> During the development of the ACD evaluate the effects of credible accidents on radiological exposures during retrieval operation.
79	Adequacy of WP corrosion tests for the repository.  <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 the NRC with LLNL report entitled "Metal Barrier Selection and Testing" LLNL SIP CM-01.
80	Performance goals consistent with interpretation and intent of "substantially complete containment."  <u>Further Action Required:</u> Prepare a supplemental response and submit to the NRC.
81	WP: Adequacy of program in stress corrosion cracking behavior of WP.  <u>Further Action Required:</u> Complete the Metals Barrier SIP and initiate the study. Evaluate the extended dry concept for the repository.

## PROGRESS REPORT #8

Table 2-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
<b>COMMENTS (Continued)</b>	
82	<p>WP: Adequacy of WP 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 EBS and WP.</p> <p><u>Further Action Required:</u> Evaluate the effect of unanticipated processes and events on the overall system during the issue resolution process.</p>
85	<p>PA: Accounting of temporal changes in state of stress due to corrosion of container.</p> <p><u>Further Action Required:</u> Complete the Metals Barrier SIP and initiate the study. Evaluate the extended dry concept with drift emplacement.</p>
86	<p>WP: Adequacy of degradation models of copper-based alloys.</p> <p><u>Further Action Required:</u> Complete the degradation mode surveys for candidate materials.</p>
87	<p>WP: Adequacy of effect of the contact of dissimilar metals causing corrosion.</p> <p><u>Further Action Required:</u> Advance the WP design until the number of package options is down to three designs.</p>

## PROGRESS REPORT #8

Table 2-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
<b>COMMENTS (Continued)</b>	
88	<p>WP: Assumption of reduced uncertainties because of the UZ.</p> <p><u>Further Action Required:</u> Supply the NRC with LLNL report "Metal Barrier Selection and Testing" (LLNL SIP CM-01).</p>
89	<p>WP: Effect of introduction of materials that affect performance of WP 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>WP: Consideration of varying oxygen concentrations on corrosion of WP.</p> <p><u>Further Action Required:</u> Provide details on how the effect of oxygen on the WP will be considered in the Metal Barriers SIP. Complete the evaluation of the drift emplacement alternative.</p>
91	<p>WP/PA: Consideration of alternate canisters for reduction of C-14 releases.</p> <p><u>Further Action Required:</u> Evaluate and describe the performance of alternative WP designs to be considered on the ACD.</p>
95	<p>PA: Adequacy of logic to screen and develop release scenarios.</p> <p><u>Further Action Required:</u> Prepare a supplemental response and submit to the NRC.</p>

## PROGRESS REPORT #8

Table 2-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
<b>COMMENTS (Continued)</b>	
96	<p>Adequacy of the use of <math>K_d</math> for modeling heterogeneous medium.</p> <p><u>Further Action Required:</u>            Prepare and issue Study Plans 8.3.1.3.4.1 (Sorption Studies), 8.3.1.3.5.1 (Development of Sorption Models), and 8.3.1.3.5.1 (Dissolved Species Concentration Limit).</p>
98	<p>PA: Appropriateness of weighting CCDF by expert judgment.</p> <p><u>Further Action Required:</u>            Further the alternative conceptual modeling. Address the CCDFs through the TSPA process.</p>
99	<p>PA: Quantification of all release modes.</p> <p><u>Further Action Required:</u>            Issue the notes from the Technical Exchange on Scenario Development.</p>
101	<p>Adequacy of SCP equation 8.3.5.13-21.</p> <p><u>Further Action Required:</u>            Prepare a supplemental response and submit to the NRC.</p>
102	<p>Adequacy of Ross sequences in comparison to the hydrologic flow model.</p> <p><u>Further Action Required:</u>            Prepare and issue technical documents on scenario development.</p>
103	<p>Ross sequences addressing anticipated conditions and not scenarios.</p> <p><u>Further Action Required:</u>            Prepare and issue those technical documents which define the scenarios.</p>

## PROGRESS REPORT #8

Table 2-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
<b>COMMENTS (Continued)</b>	
105	<p>PA: Rationale for elimination of scenarios.</p> <p><u>Further Action Required:</u> Conduct interactions with SNL for elimination of scenarios, and prepare and issue documentation.</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 CCDF in terms of scenario classes.</p> <p><u>Further Action Required:</u> Conduct interactions with SNL to develop methods for expanding CCDF's in terms of scenarios.</p>
116	<p>Individual exposures via potable water may need to be expanded.</p> <p><u>Further Action Required:</u> Awaiting the issuance by the EPA of new standard (40 CFR 191) for individual exposure standards per Energy Policy Act of 1992. Revise issue resolution strategy for SCP Issue 1.2.</p>
117	<p>Individual exposure rates of C-14 may need to consider advective and diffusive flow rates.</p> <p><u>Further Action Required:</u> Address the behavior of C-14 through the iterative TSPA process and continue to update.</p>

## PROGRESS REPORT #8

Table 2-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
<b>COMMENTS (Continued)</b>	
118	<p>Conduct of long-term in situ laboratory WP activities.</p> <p><u>Further Action Required:</u> Determine the testing requirements after site characterization has advanced far enough to define the performance program.</p>
119	<p>Adequacy of performance confirmation testing (10 CFR 60).</p> <p><u>Further Action Required:</u> Conduct an OCRWM-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 Mined Geologic Disposal System Requirements Document (MGDSRD), which will include the requirements for computer codes. Prepare and issue the model and computer code validation strategy.</p>
121	<p>Adequacy of seismic design of ESF.</p> <p><u>Further Action Required:</u> Include the seismic design criteria in the Exploratory Studies Facility Design Requirements Document (ESFDRD).</p>
122	<p>Demonstration and acceptability of the dry coring method.</p> <p><u>Further Action Required:</u> Prepare a supplemental response on the current information on the dry coring methods being used.</p>

## PROGRESS REPORT #8

Table 2-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
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### COMMENTS (Continued)

- 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.
- 130      Design Acceptability Analysis.
- Further Action Required:  
Ensure the ESFDRD document addressees all 55 requirements in 10 CFR 60 that are applicable to the ESF.

### QUESTIONS

- 1      Integration of mapping efforts.
- Further Action Required:  
None. The OCRWM has submitted a supplemental response to the NRC to close the item. Awaiting NRC confirmation.
- 3      Area of repository development.
- Further Action Required:  
Evaluate exiting 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.
- Further Action Required:  
Prepare a supplemental response and submit to the NRC.



## PROGRESS REPORT #8

Table 2-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
<b>QUESTIONS (Continued)</b>	
8	<p>Rock properties: level of detail and uncertainty in 3D model.</p> <p><u>Further Action Required:</u> Prepare and issue Study Plans 8.3.1.4.3.1 (Systematic Acquisition of Site Specific Subsurface Information) and 8.3.1.4.3.2 (Three-Dimensional Rock Characteristics Models) and issue.</p>
9	<p>Systematic drilling program: adequacy of sampling same specimens for rock properties.</p> <p><u>Further Action Required:</u> Prepare and issue Study Plan 8.3.1.4.3.1 (Systematic Acquisition of Site Specific Subsurface Information) and issue.</p>
12	<p>Rationale for exclusion of lunar crater basaltic field as analogue.</p> <p><u>Further Action Required:</u> Prepare a supplemental response which confirms there are no arbitrary limits on investigations of volcanic processes, such as the Lunar Crater Field.</p>
14	<p>Natural resources: adequacy of evaluation of previous mining and drilling leases on the site.</p> <p><u>Further Action Required:</u> None. The OCRWM submitted a supplemental response to the 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. The OCRWM submitted a supplemental response to the NRC to close the item. Awaiting NRC confirmation.</p>

## PROGRESS REPORT #8

Table 2-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
<b>QUESTIONS (Continued)</b>	
20	Discussion on vertical or horizontal emplacement.  <u>Further Action Required:</u> Prepare a supplemental response describing the content of SNL report SAND88-3073 and submit to the NRC.
21	Parameters for radiation shielding properties of the host rock.  <u>Further Action Required:</u> Prepare a supplemental response and submit it to the NRC.
22	Parameters related to repository construction and operation.  <u>Further Action Required:</u> Develop the performance goals during the ACD of the repository.
23	Computer code verification and validation.  <u>Further Action Required:</u> Prepare and issue the MGDSRD with the requirements for the computer codes.
25	Heterogeneous air flow characteristics for seal program.  <u>Further Action Required:</u> Prepare a supplemental response and submit to the NRC.
28	ES-1 penetration of the Calico Hills Unit: impacts of the current sealing program and issue resolution strategy 4.4.  <u>Further Action Required:</u> Prepare seal design concepts. Conduct PA of seal program.

## PROGRESS REPORT #8

Table 2-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
<b>QUESTIONS (Continued)</b>	
30	WP: Water quality as related to WP design.  <u>Further Action Required:</u> Complete the activities in the Metal Barriers SIP and Waste Form SIP. Complete evaluation of the drift emplacement alternative needs.
31	Integrity of spent fuel cladding.  <u>Further Action Required:</u> None. The OCRWM has submitted a supplemental response to the NRC to close the item. Awaiting NRC confirmation.
32	Container "similarity" for boro-silicate glass waste versus spent fuel.  <u>Further Action Required:</u> Advance the WP design and narrow the design options to three designs.
33	Emplacement hole drainage concerns.  <u>Further Action Required:</u> Evaluate the water-vapor interface, crevice corrosion, and galvanic corrosion testing on the Metal Barriers SIP during ACD. Complete the drift emplacement alternative.
34	Meaning of undetected defective closures.  <u>Further Action Required:</u> Prepare and submit a supplemental response and submit to the NRC.
35	Acceptance criteria for helium leak tests.  <u>Further Action Required:</u> Complete the leak rate calculation using current industry standards.

PROGRESS REPORT #8

Table 2-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
<b>QUESTIONS (Continued)</b>	
36	Contact of canisters with corrosive elements during shipping and handling.  <u>Further Action Required:</u> Advance the WP 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 to the NRC.
38	Basis for 1 mm of thinning of canister due to impact or handling.  <u>Further Action Required:</u> Prepare a supplemental response and submit to the NRC.
39	Definition of "unusual process history" of canister.  <u>Further Action Required:</u> Advance the WP 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.
41	Consideration of 10 CFR 60.132 (a) in resolution of 2.4.  <u>Further Action Required:</u> Incorporate regulation 10 CFR 60.132 into the Repository Design Requirements Document.

## PROGRESS REPORT #8

Table 2-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
<b>QUESTIONS (Continued)</b>	
42	Assumption of stability of vertical emplacement hole.  <u>Further Action Required:</u> Advance the ACD.
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. Prepare information on the TSPA. Advance the ACD down to three candidate designs.
45	Investigation of particulate source terms, retention factors, and plate-out of WP during accident conditions.  <u>Further Action Required:</u> Develop source terms for radionuclide release from breached WP during iterative PAs.
46	Basis for stricter containment of long-half-life isotopes.  <u>Further Action Required:</u> Prepare and issue the Engineered Barrier Design Requirements Document (EBDRD).
47	Assumption on breaches of waste containers.  <u>Further Action Required:</u> Prepare and issue the EBDRD.

## PROGRESS REPORT #8

Table 2-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
<b>QUESTIONS (Continued)</b>	
49	Effects of low-temperature oxidation on containers.  <u>Further Action Required:</u> Prepare and issue the Metals Barriers SIP. Advance the WP down to three options
51	Design and research criteria for accepting waste from Idaho National Engineering Laboratory and Hanford.  <u>Further Action Required:</u> Prepare a supplemental response and submit it to the NRC.
53	Specification of cooling rate of the glass waste.  <u>Further Action Required:</u> Prepare a supplemental response and submit it to the NRC.
55	Interference at the ESF by water storage tanks, septic field, and waste water lagoon.  <u>Further Action Required:</u> Prepare the ESFDRD and the Surface-Based Testing Facilities Requirements Document. Conduct an evaluation of the water uses by the ESF on test interference and waste isolation.
56	Basis for 5 cm of fault displacement in WP environment  <u>Further Action Required:</u> Prepare and issue the ESFDRD.

## PROGRESS REPORT #8

Table 2-1. Status of Site Characterization Analysis Open Items (Continued)

Open Item #	Description of Open Item
<b>QUESTIONS (Continued)</b>	
57	Effects of drilling multipurpose boreholes.  <u>Further Action Required:</u> Prepare a supplemental response and submit to the NRC.
58	Flexibility of ESF to accommodate in situ testing of WP  <u>Further Action Required:</u> Prepare and issue the ESFDRD.
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 152.4 m (500 ft) of separation of ESF from waste emplacement and 30 m (98.5 ft) of separation from ESF and waste emplacement.  <u>Further Action Required:</u> Prepare and issue the MGDSRD.

### **2.1.8 Site Characterization Program Baseline**

The SCPB identifies OCRWM's 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.

During this reporting period, Revisions 9 and 10 of the SCPB were issued; these revisions are summarized as follows:

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Revision 9 (October 2, 1992) - In FY 1992, YMPO reviewed the extent of text that had been baselined in prior SCPB revisions which, in effect, consisted of "full text" baselining of Chapter 8 of the SCP. YMPO assessed (1) the effectiveness of the process for changing the SCPB since Revision 0 was issued in February 1990, (2) whether or not "full text" baselining was an appropriate level of control for the conduct of site studies by the YMPO Change Control Board (CCB), and (3) whether duplication of controlled items was occurring between the SCPB and other project documents. This management evaluation concluded that: (1) "full text" baselining was not an appropriate level of control for the YMPO CCB and (2) there is duplication of controlled items occurring between the SCPB and other project documents (i.e., study plans). As a result of this management evaluation, Revision 9 was completed to change the scope of the SCPB in the following ways:

1. Rather than controlling site characterization study and activity descriptions in two documents, descriptions were removed from the SCPB. Descriptions of site characterization studies are controlled in study plans. Study objectives will still be controlled in the SCPB. Each draft study plan is reviewed against the testing objectives in the SCPB for consistency. A proposed change in a study or testing objective must first be approved by the CCB and implemented in the SCPB before the study plan can be approved.
2. The CCB controlled text for sections of the SCPB covering design and performance activities was limited to the performance allocation tables for design and PA. These tables represent a licensing strategy for the site that is satisfied by the scope and direction of the site program.
3. The site characterization parameter tables were removed from the SCPB and placed in a separate controlled document, the "Site Characterization Parameter Tables" (DOE, 1992c), which was issued along with Revision 9 of the SCPB. When a CCB-approved change is made to a performance allocation table in the SCPB, an affected document notice will be issued to revise the Site Characterization Parameter Tables document if the change affects a site characterization parameter.
4. The hypothesis-testing tables have also been removed from the SCPB. These tables were developed for the SCP to document a range of conceptual processes and conditions at the site. These working hypotheses are indeed working and preliminary. They will evolve conceptually throughout site characterization as additional data are collected and interpreted. Each remains a potential alternative until analyzed with site characterization data in participant technical reports or in OCRWM issue resolution documentation.
5. Analyses supporting test control in the SCPB were removed. The analyses are supported by published references attributed to Section 8.4 of the SCP. As revised analyses are produced, the test control requirements in the SCPB may be impacted.



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These modifications provide a baselined and traceable record of changes to site characterization study testing objectives, performance allocation tables, and test controls that is much more amenable to managing a complex geotechnical program than full text baselining of a very large document.

The following changes to the site characterization testing program were also included in Revision 9 of the SCPB:

Activity 8.3.1.2.2.4.6 (Calico Hills test in the ESF): The scope of work was deleted from this activity because it presumed the old shaft configuration of the ESF. Plans for testing in the Calico Hills will be defined in future revisions to ESF study plans and the testing objectives will be baselined in the SCPB.

Activity 8.3.1.5.2.1.2 (Quaternary unsaturated-zone hydrochemical analysis): The scope of work was deleted from this activity and moved to Activity 8.3.1.2.2.7.2 (Aqueous-phase chemical investigations).

Activity 8.3.1.5.2.2.1 (Analysis of future surface hydrology due to climate change): The title of this activity was changed to "Analysis of future surface-water hydrology due to climate change."

Activity 8.3.1.5.2.2.2 (Analysis of future unsaturated-zone hydrology due to climate change): The scope of work was deleted from this activity and moved to Activity 8.3.1.2.2.9.5 (Site unsaturated-zone integration and synthesis).

Activity 8.3.1.5.2.2.3 (Synthesis of effects of possible future recharge due to climate changes on the hydrologic characteristics of the Yucca Mountain saturated zone): The title of the Activity was changed to "Evaluation of possible future changes of the climate and regional geologic framework on the regional saturated-zone hydrology." In addition, the following objective was added to the activity: 3) Evaluate possible regional tectonic and thermal events that may produce prolonged or transient effects on the regional water level.

Study 8.3.1.3.7.2 (Demonstration of Applicability of Laboratory Data to Repository Transport Calculations): This study was subdivided into four activities to better organize the existing scope of work in the study. (See Section 2.2.2.15 for definition of activities.)

Investigation 8.3.1.7.1. (Rates of dissolution of crystalline and noncrystalline components of tuff): This investigation was deleted from the SCPB and forward references were provided to Study 8.3.4.2.4.1 (Chemical and Mineralogical Changes in the Postemplacement Environment) for the study of near-field chemical and mineralogical changes, and to Section 8.3.1.3 (Geochemistry Program) for studies of mineral stability.

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Study 8.3.1.8.1.1 (Probability of Magmatic Disruption of the Repository): Minor editorial changes were made for consistency with a revision to the study plan.

Study 8.3.1.8.1.2 (Physical Processes of Magmatism and Effects on the Repository): Activity 8.3.1.8.1.2.3 (Magma system dynamics) was added to the study and minor editorial changes were made to the text for consistency with the study plan.

Study 1.10.4.3 (Mechanical Attributes of the Waste Package Environment): The title of this study was changed to "Characterization of the Geomechanical Attributes of the Waste Package Environment" and the scope of work was subdivided into three activities: 1.10.4.3.1 (Block stability analysis), 1.10.4.3.2 (Borehole damage analysis), and 1.10.4.3.3 (Geomechanical properties analysis).

Revision 10 (January 14, 1993) provided the following changes to the SCPB:

Study 8.3.1.2.2.4 (Characterization of Yucca Mountain Percolation in the Unsaturated Zone--Exploratory Shaft Facility Study): The title of this study was changed to "Characterization of the Yucca Mountain Unsaturated Zone in the Exploratory Studies Facility." In addition, the scope of Activity 8.3.1.2.2.4.9 (Multipurpose borehole testing) was deleted from this study. Under current ESF design with two ramps, this activity will only be conducted if the project proceeds with an optional scientific shaft, and then only if testing is considered necessary based on prior testing results.

Activity 8.3.1.8.5.2.2 (Chemical and physical changes around dikes): This activity was deleted; the work identified in it will be completed under Study 8.3.1.8.1.2 (Physical Processes of Magmatism and Effects on the Repository).

Activity 8.3.1.15.2.2 (Characterization of site ambient thermal conditions): The objective of this activity was changed to "evaluate available thermal data"; thermal data will be collected under Study 8.3.1.8.5.2 (Characterization of Igneous Intrusive Features).

Activity 8.3.1.17.4.3.2 (Evaluate Quaternary faults within 100 km of Yucca Mountain): A task in this activity was moved to create a sixth activity 8.3.1.17.4.3.6 (Analysis of rotation [drag] of bedrock along or over suspected wrench faults based on rotation of paleomagnetic declinations).

Activity 8.3.1.17.4.4.3 (Evaluate the Stagecoach Road fault system): This activity was deleted; the Stagecoach Road fault system is a southern extension of the Paintbrush Canyon fault which will be investigated in Study 8.3.1.17.4.6 (Quaternary Faulting Within the Site Area).

Section 8.3.5.13 (Issue resolution strategy for Issue 1.1): The performance measure, Estimated Partial Performance Measure, was replaced with CCDF throughout this section for consistency with current planning in the PA program.

### **2.1.9 Performance Assessment**

The CRWMS M&O PA function is responsible for conducting analyses that support programmatic decision-making and that address the determination of compliance with regulatory performance objectives. In addition, the PA function, through its management and integration role, aids YMPO in the direction and management of scientific work and computer code development.

The Transition Plan for PA identifies the scope of PA work to be transferred from various participants within YMP to the CRWMS M&O in FY 1993. This plan was implemented in November 1992. As part of the implementation of the PA transition plan joint meetings with SNL, CRWMS M&O, YMPO, and LLNL, were held in January and March 1993 to discuss the respective roles of all participants in PA and coordination of future tasks.

The CRWMS M&O was tasked to perform a limited TSPA by March 30, 1993. This exercise accomplished several goals. The first was to show readiness for performing TSPAs in future years. The TSPA process has an iteration period of about 18 months. In addition to demonstrating the CRWMS M&O's ability to perform a TSPA, this work was designed to accomplish three other objectives: testing the RIP code developed by Golder Associates Inc., evaluating the data base used in SNL's 1991 TSPA (Bernard et al., 1992), and performing sensitivity studies to identify data and modeling features important to total system performance.

Studies were performed for an initial sensitivity simulation using RIP, with parameters taken from Bernard et al. (1992). Specifically the purpose was to verify that a change in a SZ parameter produced the expected change in the results. The sensitivity simulations were continued to quantitatively describe the effects of certain parameters (ground-water velocity, dispersivity, retardation, and porosity) on the RIP results. The study also included variation of parameters (e.g., time step, water contact modes, diffusion coefficient) affecting the release of radionuclides from the WP. All domains (i.e., WP/EBS, unsaturated aqueous flow and transport, unsaturated gaseous flow and transport, saturated flow and transport, and external processes/events) compare very favorably between CRWMS M&O and SNL calculational results. The preliminary draft referred to as "RIP/TSPA-1991 Comparison Document," (INTERA, 1993) was completed and submitted to YMPO on March 30, 1993.

The CRWMS M&O PA staff is participating in technical and management design reviews of ESF and SBT facilities. This involves the inspection of design analyses, drawings, and specifications from a PA viewpoint to ensure that the facilities will not impact waste isolation and to recommend design changes if necessary. In support of SBT, the review of designs of facilities such as access roads, drill pads, and water lines are included. For the ESF, reviews of the following ESF design packages being prepared during FY 1993 are included: the North Ramp Starter Tunnel, the North Portal surface facilities, the North Ramp, the South Portal, and the TSL main drift.

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During FY 1993, CRWMS M&O PA staff is conducting the following three generic evaluations in support of ESF design and SBT: (1) an evaluation of ESF and SBT 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 TBMs) with respect to potential repository preclosure radiological and postclosure waste isolation impacts.

Twenty-two Waste Isolation Evaluations were completed by the CRWMS M&O in this period: "Waste Isolation Evaluation - Liner for Exploratory Studies Facility (ESF) Phase 1A Rock Storage Area\*" (Brandstetter), "Waste Isolation Evaluation - Plugging of Existing Drillhole NRG-1\*" (Bruch), "Meet with Involved Organizations to Discuss Internal and External Coordination" (Brandstetter), "Waste Isolation Evaluation - Fran Ridge Borrow Pit No. 1\*" (Brandstetter, et al.), "Waste Isolation Evaluation - Exploratory Studies Facility (ESF) Phase 1A Tracers, Fluids and Materials (TFMs)\*" (Brandstetter and Paleologos), "Waste Isolation Evaluation - Plugging of Existing Drillholes RF-3, 3B, 5, 9, 10 and 11\*" (Bruch), "Waste Isolation Evaluation - Cement to be Used in Plugging of Existing Drillhole NRG-1\*" (Bruch), "Waste Isolation Evaluation - UZ-1/UZ-14 Hydrocarbon Spill Remediation\*" (Brandstetter), "Waste Isolation Evaluation - C-Well Complex Testing\*" (Paleologos), "Waste Isolation Evaluation - Prototype Ponding and Infiltration Tests at Existing Neutron Borehole UZN-85\*" (Houseworth), "Waste Isolation Evaluation - Data Acquisition Phase of Drillhole UZ-16, Including Geophones and Sealing\* - Status Report" (Bruch), "Prepare Prioritized List of PA Evaluations in Support of ESF Design and Testing (Brandstetter), "Input to Test Planning Package (TPP) Process Improvement Recommendations" (Brandstetter), "Formulate Constraints on Organic Fluid Leakage and on Water Use for Dust Control by First ESF Tunnel Boring Machine" (Brandstetter and Houseworth), "Waste Isolation Evaluation - Drilling of Drillhole UZ-14\*" (Bruch), "Waste Isolation Evaluation of TFMs for Starter Tunnel Testing\* (Brandstetter), "Waste Isolation Evaluation - Construction of Drillhole NRG-4 Road and NRG-5 Road and Pad" (Paleologos), "Waste Isolation Evaluation - Hydrocarbon Spill at C-Well Complex" (Houseworth), "Tracer Use in Fill Compaction and Dust Control Water (Houseworth), "Waste Isolation Evaluation, Electrical Grounding Grid for NRG-5" (Houseworth), "Waste Isolation Evaluation, Drilling of NRG#2A" (Houseworth), "Evaluation of Potential Impacts Due to Use of Lithium Bromide in the ESF\*" (Houseworth).

These analyses have, up to this time, addressed design issues and construction actions that have had little potential for adverse impacts on waste isolation. In some cases, however, uncertainties led to recommendations for controls on activities to further minimize potential impacts.

During FY 1993, CRWMS M&O PA staff is conducting a probabilistic preclosure radiological risk assessment of the ESF underground openings to determine which ESF underground components are important to preclosure radiological safety, and therefore, should be included in the Q-List. A plan for this assessment has been prepared and the collection of the necessary data has started. The assessment will involve the computation of radiation doses to the maximally exposed individual of the public as a result of potential repository

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accidents. ESF components which could become permanent components of a potential repository and whose failure would result in radiation doses exceeding specified criteria would be recommended for placement on the Q-List. Section 2.1.1 contains more detailed discussion of the Q-List.

The CRWMS M&O PA staff was also asked by YMPO to conduct analyses of Yucca Mountain to determine the importance of individual natural barriers (e.g., hydrostratigraphic units of the UZ, faults, and the SZ) to waste isolation. A plan for this evaluation was drafted. Gaseous and liquid flow and radionuclide transport computations are planned to determine the relative importance of each natural barrier and the lateral extent of each barrier that may be important to waste isolation. A barrier would be recommended for placement on the Q-List if its potential disturbance by site characterization activities, including ESF construction and operation, would make it difficult for a potential repository to meet the EPA and NRC postclosure performance criteria.

The CRWMS M&O PA staff is participating in the study of thermal loading alternatives for the repository, specifically in the areas of near-field environments (NFE). The exercise includes consideration of the data available for modeling, evaluation of applicable conceptual models for the proposed repository, and interpretation of modeling results for independent evaluation of the thermally loaded repository. The USGS provided updated measurements/data in February 1993, as an important complementing data set for the previously available model inputs. Also in February, a summary paper covering fuel loading alternatives for the MPC with drift emplacement was provided by the CRWMS M&O. Following receipt and careful scrutiny of the data and resolution of any data inconsistencies, modeling activities began in five planned areas. PA staff will perform analyses focusing on the response of the near field and far field to emplacement of various areal loadings. Emphasis will be on migration of the thermal front from the WPs in space and time as a function of thermal-loading, WP emplacement and package design, and the nature of the thermal-load-induced fluid flow in the near field. Participants include USGS, Lawrence Berkeley Laboratory (LBL), LLNL, Los Alamos, CRWMS M&O, and SNL with modeling results to be presented to YMPO in June 1993. Written reports are to be completed in July and August of 1993.

Six subcontracts are now in place to support FY 1993 efforts. The subcontracts are with Brookhaven National Laboratory, Golder Associates Inc., PNL, Risk Engineering, Inc., University of California, Berkeley, and University of Minnesota. Brookhaven provides support in the modeling of natural radon release at the proposed repository in order to quantify the total radionuclide release. Golder provides support in the upgrade of the RIP code, in modeling of fractures and supports involvement in the international PA program. PNL is developing the next generation of the AREST (Analyses of the Repository Source Term) computer code. The AREST code is used in evaluations of radionuclide release from the EBS of the geologic repository. The output from the application of this code provides the input or source term to the natural barrier system models that are used to represent the repository. A draft of the specification requirements document for the next version of AREST has been completed and has been presented to potential users within the YMP. Risk Engineering, Inc. is providing an upgraded version of the TSPA computer code IMARC

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(Integrated Multiple Assumption and Release Calculation) that will extend the models of unsaturated hydrologic flow to better represent variability in flow across the repository, provide for more realistic representations of the range of temperature-time profiles, and provide more realistic representations of source terms to include those from robust WPs emplaced in a drift. The University of California, Berkeley is providing general support to total system and WP PA. This support includes providing analytical solutions to bound heat pipe effects created by a warm to hot thermal environment and a more detailed look at the NFE as a function of temperature and time. The University of Minnesota is refining environmental definition and degradation mode definition for the candidate corrosion-resistant materials for the WP and developing a mechanistic understanding of the formation of protective oxide layers on the corrosion-allowance materials being considered.

The CRWMS M&O PA staff contributed to two additional YMP efforts during this reporting period: the Regulatory and Licensing Function is being supported in its effort aimed at resolving three of NRC's open items from the SCA; and a YMP workshop on Expert Judgment was supported with two sessions on the use of expert judgment in data and model formulations and applications.

The CRWMS M&O wrote a draft plan to perform a preclosure probabilistic risk assessment on the Items Important to Safety (IITS) for the MGDS components present in the ESF. This plan was presented to OCRWM and members of the Assessment Team. The plan entails conducting additional justification for accident scenario probabilities, to include radiological pathways, as well as performing sensitivity/uncertainty analysis of consequences associated with any likely or unlikely accidents.

The CRWMS M&O used the radiological pathways code GENII and a spreadsheet program to calculate 50-year committed dose-conversion factors for drinking water pathways containing multiple radionuclides of importance to long-term releases from the MGDS. To enhance inhalation dose models analytical approximations were developed for empirical plume depletion graphs contained in NRC Regulatory Guides. These will allow inclusion of depletion parameters in uncertainty and sensitivity analysis.

The CRWMS M&O initiated review of previously published preclosure MGDS accident-induced releases. Accident/reliability data was obtained for underground structures and equipment.

Spreadsheet calculations were begun using dose conversion factors generated by GENII (the radiological pathways code), to calculate the dose consequences outside the controlled area of an accidental underground release at the MGDS. The CRWMS M&O began integrating spreadsheets containing the following: (1) radionuclide inventories of solid and volatile components of SNF (Pressurized Water Reactor [PWR] and Boiling Water Reactor [BWR]) at selected burnup levels and decay times, high-level defense waste, and fuel assembly crud, (2) inhalation 70-year committed dose conversion factor for each organ and each isotope, and (3) a spreadsheet to calculate atmospheric dispersion coefficients for user-defined atmospheric stability conditions, wind speeds and building wake effects. The above data area was used to identify the set of radionuclides that contribute 99.9 percent of the dose

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to the four highest exposed organs. The results showed that over the short term (to the sealing of the repository) the full inventory of the SNF can, without loss of accuracy, be reduced to eight isotopes and that the most important organ is the bone surface for particulate releases. The radioisotope inventories (from Characteristics Database) were defined to be used in ESF investigation for range of SNFs and high-level defense waste requested by the Assessment Team.

The CRWMS M&O developed a simple three-dimensional transport model of two WP designs and emplacements for parametric evaluations using the MCNP (Monte Carlo Neutral Particle) transport code and is currently evaluating results by comparison to MicroShield-4 calculations. The calculations represent Neutron Dose, Neutron generated Secondary Photon Dose, and primary Photon Dose for a wide variety of WP capacities and thickness. The results indicate that the borehole design can be modified such that radiation doses in the access drifts will be low enough to allow for manned operations. The analyses completed to date indicate a high value in commencing quality assured radiation dose rate calculations to provide the guidance necessary to focus Repository and EBS ACD.

PA activities supporting specific studies or activities are discussed in the appropriate portions of Section 2.7.

**Forecast:** These efforts will continue to be refined during FY 1993 and presented to the Assessment Team as part of a Probabilistic Risk Assessment.

### **2.1.10 Transition to the Civilian Radioactive Waste Management System Management and Operating Contractor**

With transitions directed to become effective at the beginning of FY 1993 (October 1, 1992), almost all transition activity is complete. During this reporting period, direction was received for the transition of YMP Property and Space, Planning and Management. The transition is currently in the process of being defined.

### **2.1.11 Public Outreach**

The following public outreach activity summary for this reporting period reflects the extensive efforts being made by Institutional and External Affairs (IEA) to provide a broad-based, thorough, and extensive public information program. These activities have been met with a high degree of public approval and have resulted in a heightened public understanding of the program.

The IEA staff coordinated six Public Open House tours to Yucca Mountain, which were attended by approximately 1,400 guests. Additionally, 70 special group tours were held, with a total of approximately 2,310 participants. These special tours consisted of tours for private groups, VIPs, media, and educational tours for schools. The IEA staff coordinated YMP Public Update Meetings, which were held in Amargosa Valley, Reno, and Las Vegas,

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Nevada, with a total of approximately 400 guests attending these three meetings. A total audience of over 14,800 people attended 197 speaking presentations during this reporting period. These included 11 technical presentations, 77 general project overview presentations, and 109 educational presentations. The YMP exhibit was set up and staffed for 20 events, plus six Public Open Houses. Exhibits were also on display at the three Public Update Meetings in November.

The YMP General Exhibit was set up at the Mineral County Library in Hawthorne, Nevada. It is being displayed in conjunction with the Rural Nevada Outreach program and will remain on display for approximately three months. The IEA staff developed a YMP overview exhibit specifically designed for permanent display at DOE/Headquarters in Washington, D.C. The exhibit features photographs, graphs, and organization charts to illustrate site characterization activities at Yucca Mountain. IEA staff distributed over 7,000 new folders and fact sheets. The folders, "Why are scientists studying Yucca Mountain?" and 14 new fact sheets are part of the new product line and are all printed on recycled paper. A total of approximately 8,000 visitors toured the Yucca Mountain Information Offices (YMIO) in Las Vegas, Beatty, and Pahrump, Nevada.

The Project Manager (PM), gave a State of the Project presentation to the Las Vegas participants in November and to the USGS in Denver, Colorado, in December. FY 1992 past accomplishments and FY 1993 goals were discussed. Approximately 600 people attended. The PM gave an ESF media briefing, with representatives from local radio and television stations in the audience. Some members of the media were given a site tour of the ESF North Portal location and related areas. The PM and other YMP technical staff gave presentations to local businesses on the ESF at an Industry Day event coordinated by IEA staff. Approximately 100 people attended.

The IEA staff produced the video, "The Yucca Mountain Studies--ESF." The 20-minute video, intended for a technical audience, explains Yucca Mountain site characterization elements with special attention paid to the ESF. The video uses computer animation to depict the underground design and tests planned for the ESF. The IEA staff created a 90-second excerpt from the ESF video for news media representatives. The IEA staff completed a short video compilation on work completed in FY 1992 and to-date in FY 1993 for use in a presentation to the NRC. Due to the pace of work in the field, YMPO plans to produce updates to this video every other month. The 32-page booklet, "DOE's Yucca Mountain Studies," providing general information about Yucca Mountain site characterization activities, was printed and distributed. The IEA staff prepared and distributed a community calendar press release to announce various YMP events. In turn, the community bulletins prompted much public interest in tours. The IEA graphics staff completed development of a Yucca Mountain visual data base which allows convenient access to over 5,500 separate selections of appropriate viewgraph, slide, and photo images to support presentations and other needs. The CRWMS M&O staff submitted a draft of the YMPO University Relations Plan to OCRWM.

Various activities were developed, coordinated, and implemented by the YMPO Education Program. Among the events were two Boy Scouts Atomic Energy Merit Badge



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Workshops, four Girl Scouts Geology Merit Badge Workshops, five Yucca Mountain Lecture Series presentations, and school field trips and tours to the Las Vegas YMIO and to the Yucca Mountain site.

The YMP and CRWMS M&O staff met with the State Superintendent of Instruction to discuss the math and science reforms conference and with a representative of RSN to plan involvement in the Business Roundtable statewide education initiatives. The IEA staff organized the first meeting of the Teacher Educational Steering Committee, a brainstorming organizational meeting to establish goals and objectives. The purpose of the committee is to evaluate existing YMP educational programs and to develop applicable new programs for grades kindergarten through 12. The CRWMS M&O staff completed development of educational materials in support of the IEA Educational Program on energy and electricity. These materials are used during visits by Clark County School District (CCSD) students to the Las Vegas YMIO. The students also are taken on a tour of the YMIO and learn about radiation, geology, and nuclear waste.

The CRWMS M&O staff organized and managed the first meeting of the planning committee for a national conference on math and science education reform. The committee, chaired by University of Nevada, Las Vegas, Dean of Education, includes representatives from business, education, and government. The CRWMS M&O also sponsored, and IEA staff coordinated, two hands-on science workshops for more than 70 elementary and middle school teachers. The T&MSS and YMPO staff met with the principal of Orr Junior High School and a science teacher at Orr and initiated the YMP/Orr Junior High Partnership Program. Various YMP staff supported the DOE Nevada Regional High School Science Bowl. A total of 32 teams competed to advance to national competition. Meadows School from Las Vegas took first place.

The YMP staff supported the JASON Project telepresence broadcasts. The JASON Project uses state-of-the-art technology so that students can experience, by remote broadcast, the excitement of undersea scientific discovery as it happens. During the two-week JASON IV expedition, 25,000 fifth-through-eighth-grade CCSD students and their teachers were invited to take part in the broadcast from Baja, California.

Papers were presented at the American Nuclear Society Winter Meeting in Chicago, Illinois, and at the Waste Management '93 Conference in Tucson, Arizona. IEA staff attended the Secretary of Energy's Advisory Board task force meeting in Washington, D.C. IEA staff attended meetings in Carson City, Nevada, and provided requested information on YMP to government officials and other leaders.

**Forecast:** Initiate PETT negotiating interactions with Nye County. Finalize and implement the Project advertising plan. Develop and implement a new Family Day program at the Las Vegas, Beatty, and Pahrump YMIOs, including hands-on activities and presentations for all ages. Plan and develop a "speak with a scientist" program to be added to YMP public outreach.

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Coordinate a "media day" at the site for work being conducted at the ESF North Portal. Arrange a regular schedule for rural visits by YMP staff, including the annual Nevada Association of Counties and the Nevada League of Cities conferences. Conduct Public Update Meetings and a task force to evaluate their effectiveness and to recommend possible improvements. Conduct at least 10 exhibit showings. Continue to coordinate YMP tours, presentations, educational programs in Nevada schools, and management of the YMIOs. Continue to provide YMIO tours for fifth grade students and Yucca Mountain site tours for secondary school students at least once a week. Host YMP lecture series presentations once a month (six times) during the next reporting period.

Complete a video on the Hydrologic Research Facility (HRF) and a video on the imbibition of water by various types of rocks. Publish two newsletters for IEA public mailing list. Publish educational fliers and five fact sheets. Complete illustrated orientation for the public about YMP radiation protection program.

### **2.1.12 Environmental Audit Program**

In accordance with the requirements of the Environmental Regulatory Compliance Plan (DOE, 1988b), a YMP Environmental Audit program was established during this reporting period. Work efforts included preparation for an Environmental Compliance Audit. Environmental Audit 93A was directed by the YMP Project and Operations Control Division Director and was conducted by the T&MSS Environmental Compliance and Permitting Department during the week of March 8, 1993. Post-audit activities are currently under way. Findings of this audit will be reported in an Environmental Compliance Audit Report.

**Forecast:** Two additional environmental audits are planned over the next six months. The Environmental Compliance Audit Report for Environmental Audit 93A will be completed and published.

### **2.1.13 Annotated Outline**

The MGDS LA AO is a product-oriented management tool that has a key role in YMPO's program management and licensing strategies. Specifically, the LA AO process: (1) verifies the site characterization program, (2) is a vehicle for the implementation of guidance provided by the NRC in their draft regulatory guide "Format and Content for the License Application for the High Level Waste Repository," November 1990; (3) facilitates focused interactions with the NRC, and (4) provides an instrument for the resolution of technical and regulatory issues. The LA AO process is an iterative one which contributes to the development of shared interpretation and understanding of the NRC regulations, and provides important programmatic benefits.

During the reporting period, development of Revisions 2 and 3 of the LA AO continued. Comments from the NRC on Revision 1 were received and responses were prepared for incorporation into Revision 2. Revision 2 concentrates on setting up the

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framework/layout for reporting PA and Performance Confirmation programs. The main focus of Revision 3 is the development of Chapter 3, "The Natural Systems of the Geologic Setting," for distribution to the NRC in November 1993. A key role of the LA AO process is to verify that the site characterization program has plans to acquire the specific information needed in a potential license application, and identify gaps or redundancies in the current program. Development of Chapter 3 will establish a large percentage of these linkages. By linking information needs to the project plans that are currently in place to acquire such information, the LA AO process either validates the site characterization program or initiates a request to change it.

### 2.1.14 Topical Reports

On March 9, 1993, the Erosion Topical Report (DOE, 1993e) was sent to the NRC by OCRWM. This report concludes that evidence of extreme erosion during the Quaternary period is not present at Yucca Mountain. Based upon a comparative evaluation of Yucca Mountain hillslope erosion and stream incision with erosion rates in other analogous geologic and climatic regimes, OCRWM found that extreme erosion has not occurred at Yucca Mountain during the Quaternary.

**Forecast:** During the last half of FY 1993, in conjunction with the issue resolution effort, work will continue on a topical report on seismic hazard assessment methodology.

## 2.2 SITE PROGRAMS

The site characterization effort for the Yucca Mountain site consists of a number of component programs. These programs and a summary of their progress during the reporting period are as follows:

- **Geohydrology** - investigates surface and subsurface hydrology on both site and regional scales, with ground-water flow system characterization and modeling for both the UZ and SZ (SCP Section 8.3.1.2).
- **Geochemistry** - investigates and models rock chemistry and mineralogy, ground-water chemistry, and geochemical behavior of materials along potential radionuclide transport pathways (SCP Section 8.3.1.3).
- **Rock Characteristics** - characterizes and models rock stratigraphic and structural features and distributions within the site area, and integrates geophysical and drilling activities to obtain subsurface stratigraphic and structural data (SCP Section 8.3.1.4).
- **Climate** - analyzes paleoclimate, paleohydrology, and paleoenvironment, and characterizes modern climate, future climate, and future hydrology (SCP Section 8.3.1.5).

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- Erosion - 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 - 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 - 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 - characterizes the site and regional meteorological conditions of the Yucca Mountain vicinity (SCP Section 8.3.1.12).
- Offsite Installations and Operations - 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).
- Surface Characteristics - 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 - 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 - characterizes the potential for flooding and determines location of an adequate water supply for repository construction and operation and preclosure hydrologic conditions in the UZ at Yucca Mountain (SCP Section 8.3.1.16).
- Preclosure Tectonics - 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 Sections 2.2.1 through 2.2.13.

### **2.2.1 Geohydrology (SCP Section 8.3.1.2)**

#### **2.2.1.1 Study 8.3.1.2.1.1 - Characterization of the Meteorology for Regional Hydrology**

Activity 8.3.1.2.1.1.1 - Precipitation and Meteorological Monitoring. Precipitation was above normal at Yucca Mountain during the period; however, no precipitation fell in November. The 18 precipitation events that occurred at Yucca Mountain during the reporting

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period were recorded by the precipitation gauge network and the data were archived. A snow storm in December left 152-203 mm (6-8 in) of snow on the crest of Yucca Mountain and a storm in February left 76-127 mm (3-5 in) of snow. Other precipitation events left lesser amounts of snow. The storms were directed by the polar jet stream that had split into north and south components as it crossed the west coast. The southerly component caused storms to come on shore in California and then cross the Sierra Nevada into southern and central Nevada.

The collection gauge network, consisting of three types of gauges, was expanded to 130 gauges. Some 102-mm (4-in) -diameter plastic gauges were dual mounted with the plastic wedge gauges to compare catches. Some wedge-type collection gauges were replaced with easier-to-read 102-mm gauges. Additionally, National Weather Service standard 203-mm (8-in) -diameter metal gauges were installed at USW UZN-35 in upper WT-2 Wash, near the south end of Midway Valley between Fran Ridge and Bow Ridge, and along the west side of Fortymile Wash about 3.2 km (2 mi) north-northeast of Alice Hill. These gauges filled gaps within the existing collection gauge network.

Preliminary work was done to study a new method of streamlining laboratory procedures for calibrating tipping bucket rain gauges. A peristaltic pump was calibrated to deliver a precise amount of water at preselected flow rates. The advantage of using the pump is that the procedure can be almost totally automated using a computer to control the pump's variable delivery rate and to complete the calibration calculations in a "hands-off" mode.

Automated weather-data acquisition continued via the weather stations and tipping-bucket precipitation gauges. Data were downloaded via radio (installed at all weather stations plus two precipitation gauge sites) and archived. All synoptic, regional, and site data for FY 1992 were collected and reviewed. The compilation of regional precipitation and available evaporation pan data continued. These data were received in report format from the National Climate Data Center via the periodical, Climatological Data, Nevada and California. The FY 1992 regional evaporation pan data set has been completed. A request was submitted to the Western Region Climate Center to obtain historical data for approximately 50 locations in southern Nevada and southern California in a digital format.

Work continued in an attempt to correlate 1991 and 1992 Yucca Mountain and NTS precipitation data with lightning strike data. The goal was to determine if a relationship exists between the number of lightning strikes and precipitation amounts from the same storms. A statistical relationship was attempted using a nearest neighbor technique. Daily weather patterns were monitored and categorized according to five major weather types. National Weather Service charts and maps, received each day, were the source of the data. Satellite data, from the Geostationary Operational Environmental Satellite (GOES), provided additional information on synoptic-scale storm genesis and movement and added in the weather-typing study. GOES data were routinely downloaded and archived. Time-lapse video tape continued to be used to document weather directly affecting Yucca Mountain. A new video surveillance system was installed at the HRF.

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**Forecast:** A report/Technical Data Information Form on synoptic, regional, and site meteorological data will be issued. The collection and analysis of synoptic weather, and regional and site meteorological data will continue. Precipitation measurements will be collected from existing tipping-bucket and collector-type rain gauges. GOES data will be received, archived, and analyzed to determine the origin, movement, and intensity of precipitation events affecting Yucca Mountain.

### 2.2.1.2 Study 8.3.1.2.1.2 - Characterization of Runoff and Streamflow

The NRC submitted two comments and three questions on August 14, 1992, in a Phase II review of the study plan (Revision 0). The USGS submitted responses to these comments and questions to YMPO on Sept. 23, 1992. The OCRWM responded to the NRC on November 5, 1992, stating that a minor revision to the study plan would be made in response to NRC Question 1. The study plan was revised (Revision 1) and the revision approved by OCRWM on December 17, 1992.

Activity 8.3.1.2.1.2.1 - Surface-water Runoff Monitoring. Monitoring activities continued at 11 continuous-recording stream gauges, 13 peak-flow sites, and 22 storage-type precipitation gauges. Reconnaissance was conducted for new gauging sites to be installed on the east face of Yucca Mountain. Three sites were selected and flagged in collaboration with the UZ natural infiltration activity (8.3.1.2.2.1.2) staff. A memorandum was submitted to YMPO requesting the prerequisite environmental and cultural permits. Surveying levels were continued at selected network sites to check staff plate settings and peak-flow indicators against established reference marks.

The draft data report on surface-water and precipitation data collected during water years 1983-85 was submitted to the Reports Section of the Nevada District Office of the USGS for further processing. Compilation of the surface-water and precipitation records for water years 1986-92 continued.

A series of regional, Pacific storms hit the western United States and passed through southern Nevada during the months of December 1992 and January-February 1993. Snow and rainfall activity related to these storms resulted in the highest peaks and volumes of runoff in washes at and about Yucca Mountain since 1984. Runoff was measured and documented by current meter or by indirect methods at most network sites and at numerous miscellaneous sites located within the study area. Water samples were collected from several washes during runoff periods. These samples constitute some of the first samples collected since the 1984 runoff. All samples were submitted to the USGS Central Laboratory in Denver for analyses.

Activity 8.3.1.2.1.2.2 - Transport of Debris by Severe Runoff. No progress during the reporting period; this is an unfunded activity.

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**Forecast:** Monitoring will continue at 11 continuous-recording stream gauges, 13 peak-flow sites, and 22 storage-type precipitation gauges. Three additional continuous-recording gauges will be installed in washes on the eastern slope of Yucca Mountain to support the UZ natural infiltration activity (Activity 8.3.1.2.2.1.2). Other runoff gauges may be installed near Yucca Mountain, either in upper Fortymile Wash to support the Fortymile Wash Recharge Study (Activity 8.3.1.2.1.3.3), or on the Amargosa River to support regional hydrologic studies. Reports documenting historical runoff data in the vicinity of Yucca Mountain for 1983-85 and 1986-91 will be completed.

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

The NRC Phase I review of Study Plan 8.3.1.2.1.3 was completed October 4, 1991, with no comments. The State of Nevada sent 58 comments on Study Plan 8.3.1.2.1.3 to OCRWM on March 16, 1993. On March 29, 1993, the USGS was asked to assess the impact of the State's comments on the planned work.

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 samples were obtained with a modular jack pump from a 457 m (1,500 ft)-deep well in the Amargosa Desert south of Beatty, Nevada. The pump inlet was lowered to a depth of 91 m (500 ft) in a 50.8-mm (2-in) piezometer which was screened at 457 m (1,500 ft). A shallower piezometer, screened at approximately 37 m (120 ft) below land surface in the same borehole was bailed and a hydrochemical sample obtained. Field analyses indicated that the waters from different depths had markedly different chemistries. During the pumping of the deep piezometer, water levels were observed not to change in the shallow piezometer, even though 91 m (500 ft) of drawdown was achieved in the deep piezometer. This observation confirmed the vertical isolation of the two piezometers and is consistent with findings in a similar piezometer nest about 6.4 km (4 mi) to the north.

Depth to water was measured in several wells in the Amargosa Desert using a well sounder to document water-level variation with time.

Activity 8.3.1.2.1.3.3 - Fortymile Wash recharge study. Project staff measured ground-water levels in UE-29a #1, UE-29a #2, and UE-29 UZN #91; took readings from rain wedges at UE-29 UZN #91 and #92; and collected neutron moisture logs from UE-29 UZN #91 and #92. Data collection frequency was increased to document ground-water recharge from winter rainfall/runoff events in Fortymile Wash. Project staff also assisted meteorology personnel (8.3.1.2.1.1.1) in collecting rainfall readings from nonrecording gauges. Project

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staff collected samples from UE-29a #1 and Delirium and Pah Canyon Washes, and conducted field analyses of the samples. Samples were submitted to the USGS National Water Quality Laboratory for analyses.

A paper, "Runoff, Infiltration, and Recharge near Yucca Mountain, NV, 1992" (Savard et al., 1992), was presented at the American Geophysical Union (AGU) fall meeting.

Activity 8.3.1.2.1.3.4 - Evapotranspiration studies. Equipment for a Bowen-ratio station was tested for estimating latent-heat of vaporization (evapotranspiration). Two dew-point hygrometers were tested in a temperature-controlled cell to determine instrument bias over a range of temperatures and humidities.

Forecast: Hydrochemical sampling will continue in deep wells in the Amargosa Desert. 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. Simulations pertaining to the large hydraulic gradient north of Yucca Mountain will continue and a report will be prepared. Further testing of a dew-cell Bowen ratio station will continue, and if successful, the station will be deployed at the north end of Franklin Lake Playa.

### **2.2.1.4 Study 8.3.1.2.1.4 - Regional Hydrologic System Synthesis and Modeling**

The NRC completed their Phase I review of Study Plan 8.3.1.2.1.4 on May 6, 1992. The OCRWM responded to the NRC on July 23, 1992. The State of Nevada sent 18 comments on the study plan to OCRWM on January 22, 1993. The USGS assessed the impact of the State's comments in a letter to YMPO on February 22, 1993. The OCRWM plans to respond to the State's comments in April 1993.

Activity 8.3.1.2.1.4.1 - Conceptualization of Regional Hydrologic Flow Models. Project staff prepared an example of the times needed to clog various pore volumes with  $\text{CaCO}_3$  precipitated from tuff water in the SZ for elevated temperature regimes. The calculation involved running the computer program PHREEQE using the chemistry of water from Well UE-25 J #13 for temperatures between 40 and 100°C to examine which minerals might precipitate. Flow volumes were estimated from a two-dimensional, finite-element model of ground-water flow. The chemistry of water from Well UE-25 J #13 was also used to estimate the volume of precipitate per unit volume of water. The pore volume was varied to cover the potential range in effective-porosity values. This was done to examine the potential effect of the extended-dry concept on ground-water flow in the SZ.

Activity 8.3.1.2.1.4.2 - Subregional Two-Dimensional Areal Hydrologic Modeling. A talk entitled "Preliminary Simulations of Increased Recharge on the Ground-Water Flow System of Yucca Mountain and Vicinity," (Czarnecki) was presented at the Department of Geology and Geography, West Virginia University. An abbreviated version of the talk was presented to the ACNW at NRC headquarters, Bethesda, Maryland. A report entitled



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"Simulated Water-Level Declines Caused by Withdrawals from Wells UE-25 J #13 and UE-25 J #12 Near Yucca Mountain, Nevada," (Czarnecki, 1991) was published.

Computer simulations using a two-dimensional, finite-element model were run to estimate the drawdown effect at nearby wells of pumping one of the C-holes at 0.0126 m<sup>3</sup>/s (200 gpm) for a period of one year.

Activity 8.3.1.2.1.4.3 - Subregional 2-D Cross-Sectional Hydrologic Modeling. No progress during the reporting period; this is an out-year activity.

Activity 8.3.1.2.1.4.4 - Regional three-dimensional hydrologic modeling. No progress during the reporting period; this is an out-year activity.

**Forecast:** New boundary conditions and a new grid will be incorporated into the subregional, two-dimensional ground-water flow model. This model will be used to test various hypotheses about the large hydraulic gradient at the north end of Yucca Mountain. As new information about the gradient becomes available, it will be incorporated into the model. Hydrostratigraphic units and boundary conditions will be selected for the regional flow system. Initial simulations will be made with the three-dimensional regional flow model. The simulations will be conducted to test the hypothesis that ground-water flow in the region is structurally controlled. Regional hydrochemical data will be analyzed to see if it can be used to determine flow paths. Several data sets for the three-dimensional GIS will be completed and released.

### 2.2.1.5 Study 8.3.1.2.2.1 - Characterization of Unsaturated-Zone Infiltration

On September 16, 1992, OCRWM provided the NRC references cited in the study plan that were requested in their Phase I acceptance letter of May 31, 1991. The study plan was revised (Revision 2) by the USGS, submitted to YMPO on February 26, 1993 for review, and was approved March 18, 1993.

Activity 8.3.1.2.2.1.1 - Characterization of hydrologic properties of surficial materials. An experimental surficial sampling project was begun by collecting small grab samples from the surface soils near each neutron hole on a monthly basis. Each month, these bulk samples were processed in the laboratory to measure water potential, gravimetric water content, particle size, and particle density. The grab samples were also separated into two size fractions (less-than and more-than 2 mm [0.08 in]) to determine the coarse fragment content. Due to the large amount of precipitation that occurred during the months of January and February of 1993, standard techniques were adapted that allowed the soil water potential to be measured in the field at a few selected locations. Tensiometers were placed in six locations to determine the in situ soil water potential.

A copy of the site Digital Elevation Map was transferred from EG&G to the USGS for the HRF GIS software. The site elevation data are being used to help develop the surficial maps. Existing geologic, Quaternary, soils, plants, topography, and weather maps were

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collected and are being used in the construction of geohydrology/infiltration maps of the area. A preliminary geomorphic surface map for the area located between Northing 754,750 to 767,500 ft and Easting 559,000 to 569,000 ft was mapped on a scale of 1:6,000. Three major map units were identified; Ridge Crest, Side Slope, and Channel Alluvium. This simplified technique will be used as a baseline until the final mapping method is determined. The preliminary map was transferred to the HRF GIS system using ARC-INFO. Preliminary results show that this technique will be useful; however, further work with the software is needed. Four mapping/sampling transects of selected washes were conducted. In each transect, water content samples were collected at two depths: 0-15 cm (0-5.9 in) and 15-30 cm (5.9-11.8 in). In addition, quick-draw tensiometer readings were obtained at each of the sampling locations. At the same time, a preliminary depth-to-bedrock map was constructed for each wash.

Bulk samples were collected from the exposed alluvial face at neutron access hole UE-25 UZN #85. Bulk samples for each horizon were analyzed for gravimetric water content, water potential, particle density, bulk density, and coarse fragment content. Water release curves, for the < 2 mm size fraction, for each of the major stratigraphic units have been developed. Soil water potential was determined on each of these samples. The geophysical van and equipment to conduct borehole geophysical logging and surveys was used on neutron access hole UE-25 UZN #85. Gamma-gamma logging was performed and the data collected matched well to known borehole conditions.

Activity 8.3.1.2.2.1.2. - Evaluation of Natural Infiltration. Studies were conducted to collect data needed for the small-scale deterministic model. These studies included the neutron hole profile evaluation which is currently awaiting the completion of the neutron log data base. The data base is in PARADOX and includes data for all neutron access boreholes drilled on Yucca Mountain. Included is drilling information, meter information, depth, northing and easting, topographic setting, lithology with depth, and data from the neutron moisture meters (date, time, 10-count, opening and closing counts for each hole, person logging, and counts with depth for every logging date). The data base was checked for errors and includes everything but the final lithologies of the new 24 boreholes, which will be input at a later date once the formal lithologic descriptions are completed. An outline was prepared for a report on the logs from the original 76 neutron boreholes spanning the years from June 1984 to October 1991, when the new holes were begun. Analyses providing information on shallow infiltration processes will be included as well as examples of logs in graphical form and tables of all available information. The actual data will be included in diskette form.

Preliminary modeling exercises included a one-dimensional model developed for neutron hole, USW UZN-7, located in the active drainage channel at Pagany Wash. The model was calibrated against the neutron log profiles collected in 1984 before and after a runoff event which provided obvious infiltration pulses and return of moisture to the atmosphere through evaporation. This model was written using a numerical technique to calculate flow and was expanded to include plant roots as part of the evapotranspiration function. Weather data from the Desert Rock weather station for the past 60 years was used as input to estimate water content profiles during that time. This model will be expanded to

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evaluate its use on other boreholes and will eventually be applied to the small watershed. The result of this study are summarized in a paper entitled "The Influence of Seasonal Climatic Variability on Shallow Infiltration at Yucca Mountain," (Hevesi and Flint, 1993) in the Proceedings of the 1993 International High-Level Radioactive Waste Management (IHLRWM) Conference to be held April 26-30, 1993, in Las Vegas.

The small-scale model is being developed using a watershed consisting of three washes between Highway Ridge and Antler Ridge. Boundaries have been digitized for this watershed along with a preliminary map of surficial material distribution. The meteorology program began work on maps of rainfall amounts and distribution, and the surficial materials activity began the process of providing ground truth for the preliminary map. Properties of alluvium were measured in the field and in the laboratory as a precursor to methods procedures which will be followed by sampling and mapping transects.

Deep borehole infiltration processes were investigated by the development of a one-dimensional model of USW UZN-55. This borehole has detailed measurement of properties and provides good validation of modeling results. The model was extended to a one-dimensional model of UE-25 UZ #16, which was drilled to the water table. Estimated properties of UE-25 UZ #16 from transect samples, and borehole samples from USW UZN-55 and USW GU-3 were input into a model to predict measured saturation profiles yet to be determined. The surface inputs are long-term climate changes prepared using paleoclimatic estimate of warmer/drier and cooler/wetter climate regimes over the last 700,000 years. The study results are summarized in a paper entitled "The Influence of Long Term Climate Change on Net Infiltration at Yucca Mountain, Nevada," (Flint et al., 1993) in the Proceedings of the 1993 IHLRWM Conference.

Following the removal of the drill string in UE-25 UZ #16 a dual-spaced neutron logging tool was used to measure volumetric water content. The tool was calibrated in three tanks designed as a non-changing standard for 152-mm (6-in) boreholes, but the UE-25 UZ #16 borehole is 305-mm (12-in) diameter and uncased and still requires the use of measured volumetric water content from the core to develop a field calibration. The logs, however, showed relative magnitudes of counts and indicated lithologic contacts and highly fractured zones very well. The geometry of the system based on core logs will need to be updated for the UE-25 UZ #16 model. The core samples were requested; some were delivered and will soon be processed to provide the information for a field calibration for the large neutron tool, as well as give a final validation to the UE-25 UZ #16 model.

The mouth of Pagany Wash was used for an evapotranspiration study site. Bowen ratio station data were collected, tensiometers were emplaced, and a detailed time domain reflectometry (TDR) grid will be laid out covering the terrace and channel with 36 automated probes. This study will provide field calibration data for the artificial infiltration project along with providing surface water content changes and heterogeneity for the upper boundary conditions in the small watershed model.

The neutron-access boreholes were logged monthly during this high rainfall season. Six additional boreholes were drilled. Boreholes USW UZN-57, USW UZN-58,

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USW UZN-59, and USW UZN-61 span the wash in upper Abandoned Wash and were spudded into the Topopah caprock, penetrating 100 ft into the Topopah Spring upper lithophysal. USW UZN-35 was drilled in the Ghost Dance fault in the wash just north of Whale Back Ridge and USW UZN-62 was drilled on Yucca Crest south of USW UZ-6 to provide upper Tiva Canyon core in a southern location. Only one more borehole remains to be drilled (in Jackass Flats) to complete the drilling of the 24 new boreholes.

Activity 8.3.1.2.2.1.3 - Evaluation of Artificial Infiltration. A set of three water-storage tanks were each fitted with pressure transducers so that the quantity of water released from the tank over time could accurately be determined. The relative differences between pressure transducer readings and the quantity of water released showed that a head difference of 1 mm may be detected by the pressure transducers. The prototype infiltrometer and water storage tank system was tested in the field at two different locations. The water storage tank systems were also field tested in conjunction with three ring-infiltrometers at neutron hole UE-25 UZN #85.

A prototype ponding/infiltration study was conducted at the UE-25 UZN #85 neutron access borehole. Prior to the application of water, the exposed alluvial profile was measured, described, and sampled. Gravimetric water content, water potential, particle density, bulk density, and coarse fragment content (fragments greater than 2 mm in diameter) were determined for each of the sampled horizons. Three ring-infiltrometers and water-storage tank systems were installed inside the larger outer ring. Multiple sets of TDR probes were installed around the borehole. Suction cup lysimeters and tensiometers were also installed within the large infiltration ring. The infiltration experiment began March 9, 1993, and water was ponded on the site until March 24, 1993. Neutron logs were taken every hour for the first 60 hours and then at selected time intervals, for a total of approximately 350 hours. The neutron logs showed the various stages of the wetting front as the water moved through the stratigraphic units.

A preliminary two-dimensional model that contains nine major stratigraphic units was developed for UE-25 UZN #85. The model was run using data that were collected for each of the nine major units. The infiltration simulations were run under a variety of differing boundary conditions, and for a range of hydraulic conductivities and porosity values.

A soils/unconsolidated sediment laboratory was established in the old Area 25 gas station. Basic equipment (EC meter, pH meter, items for particle size analysis, etc.) were obtained or are on order. The completion of this facility will allow analyses to be performed that were not available in the past.

**Forecast:** Modeling results and actual infiltration results at UE-25 UZN #85 will be compared. The model will be modified to make modeling results conform to the actual field results. Various surficial materials infiltration rates will be characterized using the double ring infiltrometer. A large-scale field calibration of the TDR will be performed. This field test will be designed to take into account field variability, sampling needs, and a desired level of precision. A second ponding/infiltrometer experiment will be conducted at Neutron Hole USW UZN-7.

#### **2.2.1.6 Study 8.3.1.2.2.2 - Water Movement Test**

Revision 1 of the study plan was approved on February 10, 1993 by OCRWM and submitted to the NRC on February 19, 1993.

Activity 8.3.1.2.2.2.1 - Chloride and chlorine-36 measurements of percolation at Yucca Mountain. Chlorine-36 ( $^{36}\text{Cl}$ ) analyses were performed on 40 samples from neutron-access boreholes USW UZN-11, USW UZN-37, USW UZN-53, USW UZN-54 and USW UZN-55; chloride and bromide were analyzed in 500 samples from these holes and from UE-25 UZ #16. Some results of these analyses were summarized at two meetings, the Unsaturated Zone Modelers meeting (January 20-21, 1993) held by the USGS in Las Vegas, and the University of Arizona's Water Resources Workshop VI on Flow and Transport through Unsaturated Fractured Rock in Tucson (January 25-29, 1993). In the presentation entitled "Chlorine-36 in Shallow Boreholes at Yucca Mountain," (J. Fabryka-Martin, 1993) a preliminary interpretation was provided of the  $^{36}\text{Cl}$  data and the possible contamination of surface soils by  $^{36}\text{Cl}$  that was produced by NTS activities between 1950 and 1969 was discussed.

**Forecast:** Collection and analysis of cuttings from deep surface-based UZ and complete collection of samples from the neutron boreholes in the UZ at Yucca Mountain will continue to determine the depth to which bomb-pulse  $^{36}\text{Cl}$  has penetrated, correlating such distribution with lithology and structural features, and to estimate the average residence time of infiltrating water as a function of depth. Surface soil samples, soil profiles, and cuttings from neutron-access boreholes within the controlled area will be collected to determine the pre-bomb meteoric  $^{36}\text{Cl}/\text{Cl}$  ratio, assess the variability in meteoric  $\text{Cl}/\text{Br}$  and  $^{37}\text{Cl}/^{35}\text{Cl}$  ratios, and estimate present-day shallow infiltration rates. A report on FY 1993 progress and available results will be delivered at the end of this activity.

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

Activity 8.3.1.2.2.3.1. - Matrix hydrologic properties testing. Analysis of rock matrix hydrologic properties continued on core samples from the new neutron boreholes and on surface outcrop samples obtained from transects. In addition to the standard suite of physical properties and in situ moisture content measurements, cores from three of the neutron-access boreholes used to calibrate the neutron moisture meters were also dried at  $800^{\circ}\text{C}$  in a high-temperature muffle furnace to remove all free and bound water in the rocks. The calibrated meters will allow neutron moisture measurements from the subject boreholes to be calibrated against total rock water content from the cores. A paper entitled "The Effect of High Temperature on Hydrologic Properties of Volcanic Tuffs," (Nash and Flint, 1992) was published.

Matrix saturated hydraulic conductivity (permeability) measurements were continued on the large number of rock samples collected from surface outcrop transects and traverses on Yucca Mountain. Analyses remain to be completed on samples from the long transect

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through the entire Paintbrush Tuff section on the Prow. An abstract entitled "Porosity and Permeability of Tuffs from the Unsaturated Zone at Yucca Mountain, Nevada," (Soeder and Dishart, 1992) was presented at the annual Geological Society of America (GSA) meeting in Cincinnati, Ohio.

Construction of a second permeameter to measure single-phase water or air permeability on densely-welded tuffs continued. This apparatus will use a precision syringe pump to force water at high pressures through saturated plug samples confined in stainless steel core-holders, and will also be able to measure air permeabilities with the Klinkenberg correction for gas slippage. A Decagon CX-2 chilled-mirror psychrometer was used to measure water potentials as low as -300 MPa on the dry rocks and soils from Yucca Mountain. Experiments were performed to determine the effect of rock fragment size on the measurement of water activity with this psychrometer and the results were presented in a published abstract entitled "Effect of Rock Fragment Size on Laboratory Determination of Water Potential," (Nash et al., 1992) at the 1992 Soil Science Society of America annual meeting. Also, a fairly rapid method for determining a full moisture retention curve on homogeneous rock or soil samples was developed by using representative sample splitting. The various subsamples were allowed to air dry for increasingly longer time periods during the course of the testing, resulting in a set of measurements of water potential across a wide range of saturation values, thus providing a water retention curve. A presentation entitled "Rapid Determination of Moisture Retention Curves Using a Chilled-Mirror Psychrometer," (Flint et al., 1992) was presented at the AGU Winter Meeting.

A study was conducted to evaluate the effects of high temperatures on core samples from the Calico Hills zeolitized unit and the Topopah Spring Member potential repository horizon. Samples from each rock unit were dried at 60°C (45 percent relative humidity in an RH oven) and 105, 200, 300, and 400°C in a conventional oven.

Activity 8.3.1.2.2.3.2 - Site vertical borehole studies. Borehole UE-25 UZ #16 was completed in March. The borehole was started in May, 1992, dry-drilled and cored to a total depth of 514 m (1,686 ft). Water was first encountered at a depth of approximately 491 m (1,612 ft) in the Prow Pass Member of the Crater Flat tuff. Core recovered from depths between 489-490 m (1,605-1,609 ft) was visually "dry". Between 491 and 494 m (1,610 and 1,620 ft) several horizontal partings (bedding planes) were encountered and water flowed to the borehole. Water samples were collected from this interval. Core recovered from 494-498 m (1,620-1,635 ft) also appeared visually "dry," and all water draining from higher in the section was lost. After drilling to depths between 498 and 503 m (1,635 and 1,650 ft), water again flowed into the borehole and rose to a depth below land surface of 489 m (1,605 ft) (stabilizing between 489 and 490 m). Core analysis of saturation and water potential are being conducted to resolve whether the first water encountered in UE-25 UZ #16 was perched water or merely drainage from fractures in a saturated matrix of very low permeability.

Further progress was made on testing and evaluating a gas sampling system for use in the Borehole Instrumentation and Monitoring Programs to recover nearly vapor-saturated rock gases without condensing water vapor in the sampling tubes. This process will also be used

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to independently verify in situ psychrometric measurements. Tests were conducted to establish how precisely vapor pressures of downhole formation gases could be determined from surface measurements of dew point temperature of source gas that is mixed with a dry carrier gas introduced at the ground surface. Additional tests will be run to establish absolute accuracies and system control requirements needed to support pumping and sampling from up to 16 downhole instrument stations simultaneously. HRF borehole monitoring continued throughout the period. Sensors in these boreholes have been operating since October 1991 (17 months). Primary sensors have over 2,500 duty cycles each.

Two talks entitled "Advances in Psychrometer Technology," and "Results of Monitoring UZ Flood Flow Potentials at the HRF Boreholes" (Rousseau), were presented at the 4th Vadose Zone Technology Exchange Workshop hosted by the NRC at the University of Arizona in Tucson.

Five presentations were made to YMPO summarizing Vertical Seismic Profiling (VSP) and Crosshole Imaging research work conducted by the USGS and Colorado School of Mines to resolve issues attendant to the use of grout in UE-25 UZ #16 to couple the geophones to the earth. Also at issue, was a review and assessment of the value of the VSP and crosshole imaging program at UE-25 UZ #16 (VSP-2) and UZ borehole cluster sites. Agreement on both issues was reached; the VSP program will proceed as outlined in the study plan. Seven research reports by investigators from the Colorado School of Mines relating to this activity were delivered to YMPO.

A reorganization of the Integrated Data Acquisition System (IDAS) software development program was initiated. Reorganization resulted in converting IDAS from a DEC PDP 11/73 hardware supported system to a PC-based DAS system. Much of the software used to operate sensors in the HRF boreholes has already been modified to handle the larger data sets associated with instrumenting deep UZ boreholes. This reorganization and conversion will have no impact on overall project schedules.

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

**Forecast:** Geophysical logging of UE-25 UZ #16 is scheduled for May 1993; air-permeability testing is scheduled from June - September; geophone instrumentation in October, and the first VSP field reconnaissance survey in November. UE-25 UZ #14 drilling is scheduled to start early in April, and will be dry drilled and cored to the water table. Drilling time (one shift) is estimated at nine months. Final plans for instrumenting UE-25 UZ #16 will be developed during the next six months. Plans include preparing a technical procedure for stemming and grouting in-place a string of 96, three-component geophones. A fully operational PC-based DAS should be ready to field by October 1, 1993.

A criteria letter will be submitted to YMPO requesting contractor support to instrument four existing shallow UZ boreholes at three sites on Yucca Mountain (USW UZ-7, UE-25 UZ #4 and UE-25 UZ #5, and USW UZ-13). Work on preparing these sites for instrumentation could possibly begin before the end of FY 1993. Instrument shelters to support these sites

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have been procured; delivery is expected in October 1993. Sensor calibrations will begin in June 1993. It is anticipated that these shallow UZ boreholes could be instrumented by January 1994. Work will continue on the gas sampling system, development of the PC-based DAS to replace IDAS, and the monitoring of the HRF boreholes.

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

The Study Plan, 8.3.1.2.2.4 (Activities 4, 5, 7, and 8), for this study was revised (Revision 1) to reflect the current design of the ESF and transmitted to the NRC on January 21, 1993. The NRC accepted the study plan, with no comments, in a Phase I review completed March 5, 1993.

Activity 8.3.1.2.2.4.1 - Intact-fracture test in the Exploratory Studies Facility. Sketches for a low-pressure vessel to test single-fracture rock cores and for the Linear Variable Differential Transformer mounts were completed. These sketches were sent out for cost estimates and a machine shop was chosen to fabricate these items for this vessel. The machine work is still in progress. The "north test pit" (test pit #1) at Fran Ridge, Yucca Mountain, Nevada was inspected and could be used as a possible sampling site for single fracture core samples.

Staff supported prototype testing of the Percolation Test in the Exploratory Studies Facility (8.3.1.2.2.4.2a) including the following: probed all the large block boreholes with a videoscope and videotaped the moisture travel within the boreholes; replaced some thermocouple psychrometers (TCP) with pressure transducer tensiometers in the block boreholes; documented day-to-day events concerning the block and data collection; prepared sample 13B for additional tests; set-up a computer logging station for an imbibition test including sample preparation; and TCP calibrations.

Work on the moiré projection method for fracture profile characterization continued. The high-resolution imaging equipment was installed and software evaluation was begun. Two technical papers concerning the moiré projection technique for fracture topography have received OCRWM approval, "Implementation and Use of an Automated Projection Moiré Experimental Set-Up," (Cardenas-Garcia et al.) and "Projection Moiré as a Tool for the Automated Determinations of Surface Topography," (Cardenas-Garcia et al.). A third technical paper has completed internal USGS technical review, "3D Reconstruction of Objects Using Stereo Imaging," (Cardenas-Garcia et al.). A paper describing the use of fast-Fourier transforms for the fracture topography technique is in preparation.

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 that was started October 1991 was terminated January 1993. The block dimensions were 54.3 cm long x 47.5 cm wide x 80.6 cm high. Eighteen TCPs were installed in the block to track the water front. Following two initial slugs of water, a continuous water supply was maintained along the top block surface to maintain a constant and positive water pressure. This water was



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tagged with boron to differentiate it from the two initial slugs. The initial applied pressure for the continuous supply was +10 cm of water. It was increased to +12, then to +14 cm of water. The initial water flow rate was between 100 and 150 cm<sup>3</sup>/day; it fluctuated between 0 and 100 cm<sup>3</sup>/day during the final period, decreasing to zero when the test ended. The TCPs indicated a continuous increase in water potential. During the final stage, five psychrometers were replaced with tensiometers since the water potential increased above the detectable limit of psychrometers. The fracture network appeared to be interconnected when it was tested with air prior to starting the ponding test, and accordingly, water flow should not have stopped under positive pressure. The mineralogy of the fracture coating indicated that less than one percent is composed of swelling clays.

A paper entitled "Laboratory Study of Water Infiltration into a Block of Welded Tuff," (Thamir et al., 1993) was published in the Proceedings of the 1993 IHLRWM Conference.

Activity 8.3.1.2.2.4.3 - Bulk permeability tests in the Exploratory Studies Facility.  
Work continued on the study plan for bulk permeability testing.

Activity 8.3.1.2.2.4.4 - Radial borehole tests in the Exploratory Studies Facility.  
Requirements of the downhole line-packer system for use in the air-permeability testing were defined. The system will operate in 96.5-mm (3.8-in) -diameter holes up to 45.7 m (150 ft) in length, and isolate a minimum of 15 test intervals. Test intervals will be connected to the surface with Teflon tubing to allow gas sampling and pressure monitoring. This system will be easy to operate and will meet the requirements of several ESF studies.

The TCPs used at the Apache Leap Tuff Site prototype testing showed that the air in these volcanic tuff boreholes was saturated. The TCPs showed some response due to the injection of dry air downhole; however, none of the test intervals were dried sufficiently to allow the TCPs to measure relative humidity. Statistical analysis of the permeability results suggests some correlation between injection rates and calculated permeabilities for the injection zone, and no correlation between injection rates and calculated permeabilities for crosshole monitoring zones. Constant-rate transient tests, and allowing the tests to run until steady state is achieved, provided estimates of permeability based on transient testing, and identification of boundary influences that would adversely impact steady state analysis.

Activity 8.3.1.2.2.4.5 - Excavation effects test in the Exploratory Studies Facility. The study plan including this activity was revised and transmitted to YMPO.

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 SCPB. 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. A technical procedure for sampling, testing, and monitoring perched-water zones in the ESF was written. Borehole packer-instrumentation systems were studied for possible use in perched-water testing in the ESF.

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Activity 8.3.1.2.2.4.8 - Hydrochemistry tests in the Exploratory Studies Facility. The study plan including this activity was revised and transmitted to YMPO.

**Forecast:** The accelerated schedule for starting ESF construction requires that preparations for certain construction-phase tests progress quickly. As part of the coordinated sampling plan, personnel will be trained to collect data and samples in accordance with USGS technical procedures for these activities.

Monitoring for perched water will commence as soon as access to the ramp opening is available. 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 late this FY. Equipment to support the excavation effects test has been identified, but has not been procured because this test will not be conducted until FY 1994.

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 SCPB. 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.

### **2.2.1.9 Study 8.3.1.2.2.5 - Diffusion tests in the Exploratory Studies Facility**

The NRC accepted the study plan, with no comments, in a Phase I review letter dated January 19, 1993.

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

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

Study Plan 8.3.1.2.2.6 received NRC acceptance in a Phase I review on October 7, 1991. Sixteen comments on the study plan were received from the State of Nevada on April 27, 1992. The OCRWM responded to the State of Nevada's comments on July 27, 1992, and the study plan is currently being revised in response to the State's comments.

Activity 8.3.1.2.2.6.1 - Gaseous-phase circulation study. Gas-flow data were collected from Borehole USW UZ-6s, tabulated, and analyzed for utilization in the three-dimensional gas-flow and transport model. Project scientists conducted a shut-in pressure response at Borehole USW UZ-6s. Preliminary analysis of the data collected in conjunction with the shut-in pressure response test at USW UZ-6s began. Temperature profiles were measured in Borehole USW UZ-6s. A shut-in pressure test was conducted at borehole USW UZ-6 in the

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annulus space and in the open borehole. These boreholes will be used during convergent-flow tracer tests. A tracer-gas position paper was prepared, reviewed, revised, and distributed to appropriate YMP personnel. The Bromo-Chloro-Difluoro-Methane concentration profile for determining dilution factors was completed at Borehole USW UZ-6s. Gas sampling for gas chromatograph analysis and for  $^{14}\text{C}$  analysis was conducted in Boreholes USW UZ-6 and UZ-6s, and in selected neutron-access boreholes.

**Forecast:** Gas-flow data will be collected from Boreholes USW UZ-6 and UZ-6s. Convergent and divergent flow tests will be conducted. Gas-flow and gas-sample testing may be conducted in additional UZ boreholes at the discretion of the PI.

### 2.2.1.11 Study 8.3.1.2.2.7- Hydrochemical Characterization of the Unsaturated Zone.

The NRC accepted Study Plan 8.3.1.2.2.7, Revision 0, on May 1, 1992. The State of Nevada provided 27 comments on the study plan on December 22, 1992. The USGS assessed the impact of the State of Nevada's comments on January 21, 1993 and YMPO responded to the State's comments in a letter dated February 18, 1993. Revision 1 of the study plan was submitted to YMPO for review on November 24, 1992. The USGS received YMPO's comments on the revision on February 8, 1993, and the Principal Investigator's (PI) revision was approved March 31, 1993.

Activity 8.3.1.2.2.7.1 - Gaseous-phase chemical investigations. The annual gas sampling at borehole USW UZ-1 was conducted in January 1993. Chemical data obtained are consistent with previously determined chemical compositions. A paper entitled "Carbon-Isotopic Data From Test Hole USW UZ-1, Yucca Mountain," (Yang et al., 1993) was approved by the USGS and OCRWM for publication in the Proceedings of the 1993 IHLRWM Conference. Carbon-14 diffusion modeling indicated that diffusion is the primary gas movement process below 50 m in USW UZ-1. The top 50 m does not fit  $^{14}\text{C}$  diffusion modeling due to complicating factors introduced by surface disturbance and vegetation inputs.

The packer system to be used at UE-25 UZ #16 was completed. The system was shipped to NTS and will be assembled as it is installed in UE-25 UZ #16.

Batch-type experiments were conducted to test the sorption and desorption of sulfur hexafluoride ( $\text{SF}_6$ ) and carbon dioxide ( $\text{CO}_2$ ) tracer gases on crushed tuffs of the Tiva Canyon and Yucca Mountain members of the Paintbrush Tuff, bedded tuff of approximately 10 percent (by weight) moisture content, and the Topopah Spring Member of the Paintbrush Tuff. Carbon dioxide gas absorption and desorption characteristics on crushed gypsum cement to be used for borehole stemming materials were also investigated. Staff presented core analysis data at the NRC sponsored Workshop VI, "Flow and Transport Through Unsaturated Fractured Rock" at Tucson, Arizona in January 1993. This workshop was an important avenue in comparing data from both NRC sponsored work at Apache Leap, Arizona, and YMP for the possible recharge and fluid flow mechanism.

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Activity 8.3.1.2.2.7.2 - Aqueous-phase chemical investigations. Two abstracts entitled "Preliminary Isotopic Data on Unsaturated-Zone Flows at Yucca Mountain, Nevada," (Yang, 1992) and "Preliminary Results of Pore-Water Extraction from Unsaturated Tuff by Compression," (Peters et al., 1992) were published in EOS and presented at the Fall 1992 AGU meeting. A paper entitled "Effects of Core Sealing Methods on the Preservation of Pore Water," (Striffler and Peters, 1993) is in the Proceedings of the 1993 IHLRWM Conference. A draft report entitled "Pore-Water Extraction from Unsaturated Tuff by Triaxial and One-Dimensional Compression Methods, Nevada Test Site," (Mower et al.) was revised after technical review and has been submitted for further USGS processing.

Four additional reports or journal papers are in draft form. Topics include: (1) the method of tritium ( $^3\text{H}$ ) and  $^{14}\text{C}$  measurements in water using a liquid scintillation counter; (2) the effects of pressure versus chemistry during pore-water extraction; (3) the development of the one-dimensional compression test for pore-water extraction from tuff; and (4) the studies conducted in G-tunnel associated with the optimal rubble test and the lab studies associated with the dry coring tests.

All the core samples from UE-25 UZ #16 above 213-m (700-ft) depth were transported from the SMF to the USGS laboratories in Denver, Colorado. Five UE-25 UZ #16 core samples (one partially welded, having 31 percent saturation, and four welded tuffs, having 77 to 93 percent saturation) were compressed by one-dimensional compression. Pore water was obtained from the partially welded core only. Five pore-water compression samples from UE-25 UZ #16 core were analyzed in the gas chromatograph for  $\text{CO}_2$  and  $\text{SF}_6$ . All USW UZN-55 core samples were compressed by the one-dimensional compression method. Many of the welded tuffs with very low moisture content failed to yield pore water; however, vacuum distillation was successful in extracting residual water. The Orion microelectrodes were calibrated for analyses of dissolved  $\text{CO}_2$ , chloride, potassium, and oxidation-reduction potential. These electrodes will be used to determine pore-water chemistry changes after water has been removed by compression as a function of time and storage and also as a function of pressure effects during compression.

Water samples from the zone where liquid water was first encountered at UE-25 UZ #16 borehole were collected and analyzed for specific conductivity, pH, and alkalinity on site. Samples were also preserved for other chemical and isotopic analyses.

Geochemical modeling of data on pore-water chemistry versus pressure is in progress. A second high-pressure one-dimensional compression cell has been constructed. It will be used in rotation with the original cell to streamline the pore-water compression process.

**Forecast:** Core samples from UZ boreholes will be compressed and distilled for pore-water extraction. Extracted water will be analyzed for cations, anions, and isotopic content. Papers entitled "Effects of Core Sealing Methods on the Preservation of Pore Water," (Striffler and Peters, 1993) and "Carbon Isotopic Data from Test Hole USW UZ-1, Yucca Mountain, Nevada," (Yang et al., 1993) will be presented at the 1993 IHLRWM Conference and published in the Proceedings. Papers on the following subjects will be completed: (1) the method of  $^3\text{H}$  and  $^{14}\text{C}$  measurements in water using a liquid scintillation counter;

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(2) a data report for the pore water extraction tests; and (3) a journal paper on the development of the one-dimensional compression test for pore-water extraction. Geochemical modeling of pore-water chemistry versus pressure data will continue. Gas sampling from UE-25 UZ #16 using straddle-packer system will be conducted. Tracer-injection monitoring during drilling of UE-25 UZ #14 and North and South Ramp geotechnical boreholes will start in early April 1993.

### 2.2.1.12 Study 8.3.1.2.2.8 - Fluid Flow in Unsaturated, Fractured Rock

The NRC accepted the study plan in a Phase I review letter dated January 28, 1993, with two comments and a request for a reference cited in the study plan. The USGS responded to the NRC comments and request in a letter to YMPO dated March 4, 1993. An OCRWM response letter to these comments is in preparation.

Study Plan 8.3.1.2.2.8 was revised per YMPO review comments and was approved by OCRWM August 12, 1992. Revision 0 was submitted to the NRC on September 1, 1992, and the NRC Phase I review was completed January 28, 1993. Revision 1 has been prepared and was submitted to YMPO on November 24, 1992. The USGS is responding to YMPO comments at this time.

Activity 8.3.1.2.2.8.1 - Development of conceptual and numerical models of fluid flow in unsaturated, fractured rock. Two models that calculate rates of dry-out and condensation generation are being compared by USGS and LBL scientists. One model, the equivalent continuum model (ECM), assumes the numerical simulations of repository dry-out due to thermal loads generated by radioactive decay of nuclear waste results in negligible error when simulating the movement of water and vapor in unsaturated fractured rock. However, because the ECM does not consider the time required for water to move from the middle of a matrix block to a fracture face (where it is vaporized), both the rate of dry-out and the rate of condensate generation may be overestimated by the ECM. The other model, the double porosity model, considers transient fracture-matrix processes. An initial thermal load of 114 kW/a was examined with the double-porosity model. Temperature, gas pressure, and saturation profiles, calculated at 100 and 500 years with the double-porosity model, were indistinguishable from those calculated at the same times with the ECM. The dual porosity simulations therefore supported the continued use of the ECM for thermal loading calculations utilizing matrix permeabilities and fracture spacings considered by the study.

Data on fracture orientation, dip, frequency, density, orientation and flow rates in differential stress regimes, and fracture characterization at different scales were being compiled. This information will be used as input to fracture network models.

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-25a #4, a #5, a #6, and a #7 located in or near Drillhole Wash. Preliminary results show that core from Topopah Spring partially welded rock has an average calculated fracture

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porosity that is high but not unreasonable considering the wash is thought to be fault controlled.

A paper entitled "Accuracy and Efficiency of a New Dual Porosity Simulator for Flow in Unsaturated, Fractured Rock Masses," (Zimmerman et al.) was accepted for publication in the journal Radioactive Waste Management and the Nuclear Fuel Cycle (Special Issue on Yucca Mountain). The paper describes the modified version of the TOUGH code that performs transient simulations of unsaturated flow without the use of the quasi-steady-state equivalent porous medium approximation. A more accurate fracture/matrix coupling term was incorporated into the dual-porosity model, and was tested on the problem of vertical infiltration into an unsaturated, fractured formation. The simulation results compared well with asymptotic analytical solutions that can be derived for this problem.

A paper entitled "An Inverse Procedure for Estimating the Unsaturated Hydraulic Conductivities of Volcanic Tuffs," (Zimmerman et al., 1993) was published in the Proceedings of the 1993 IHLRWM Conference. The paper describes a new procedure for estimating hydraulic conductivity from laboratory measurements of water retention curves and sorptivities, thus potentially eliminating the need for time consuming and difficult conductivity measurements.

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 is an out-year activity.

**Forecast:** The collected data from the large-block prototype percolation experiment will be simulated with numerical models to evaluate the predictability of water and solute movement in variably saturated fractured tuff. Scoping and bounding calculations will be made, as required, to assist laboratory and field investigators in the design and interpretation of surface-based and ESF tests. Laboratory experiments on imbibition into variably saturated, fractured, and unfractured cores will be simulated as part of the model validation part of this study. An existing finite-element, fracture-network model will be adapted to simulate flow and transport for unsaturated conditions. Numerical experiments will be performed to examine the variability in matrix potential and the possible concentration of flow in networks of fractures at fluxes less than the flux at full saturation. A report will be completed on the determination of capillary pressure curves for Yucca Mountain tuffs based on inversion of linear sorptivity-saturation data.

### 2.2.1.13 Study 8.3.1.2.2.9 - Site Unsaturated-Zone Modeling and Synthesis

Study Plan 8.3.1.2.2.9 was revised extensively in YMPO's review to supply additional detail concerning numerical codes and modeling strategy to be employed by the study. The study plan was resubmitted to YMPO on December 10, 1992.

Activity 8.3.1.2.2.9.1 - Conceptualization of the unsaturated-zone hydrogeologic system. Porosity, gravimetric water content, bulk-density and water potential data from previously

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published reports entitled "Geohydrologic Data from Test Holes UE-25UZ#4 and UE-25UZ#5, Yucca Mountain Area, Nye County, Nevada," (Loskot and Hammermeister, 1992); "Geohydrologic Data from Test Hole USW UZ-7, Yucca Mountain Area, Nye County, Nevada," (Kume and Hammermeister, 1990); and "Geohydrologic Data from Drill-Bit Cuttings and Rotary Cores from Test Hole USW UZ-13, Yucca Mountain Area, Nye County Nevada," (Kume and Hammermeister, 1991) were used to construct saturation versus depth profiles for four unsaturated-zone boreholes: UE-25 UZ #4, UE-25 UZ #5, USW UZ-7 and USW UZ-13. These holes penetrated the upper part of the UZ, including those stratigraphic units informally referred to as the Paintbrush nonwelded (PTn) hydrogeologic unit, and terminated within the upper part of the Topopah Spring welded (TSw) hydrogeologic unit. The saturation profiles within the PTn unit exhibited considerable vertical and lateral variability that could be explained only by considering the local microstratigraphy of the units. The saturation profiles were used to create estimated water flux profiles. This was done by first deriving correlations between porosity, saturated hydraulic conductivity and parameters for the unsaturated hydraulic functions of van Genuchten, based on the data contained in Peters et al. (1984). Then, using porosity as the predictor variable, estimates of water potential were made at each of the four UZ boreholes for each depth at which porosity and saturation values were available and compared with measured water potential values in order to further provide further calibration of the previously derived correlations. Estimates of effective hydraulic conductivity were then determined at the same depths using the van Genuchten functions. These were used in conjunction with both measured and estimated water potential data to produce more or less continuous profiles of flux in each of the four boreholes. Although subject to considerable uncertainty, major trends and discontinuities in the flux profiles suggested that lateral flow may be occurring above and within horizons deposited by air-fall processes. Furthermore, the data indicate that significant infiltration has occurred beneath the washes in the recent past, probably through near-surface fractures in the densely welded Tiva Canyon unit. The observation that flow within and above the PTn unit is neither one-dimensional nor steady questions the validity of models that depict near-surface flow processes in that manner. Analyses were also made of the internal consistency of the data collected from the various sources; systematic errors in certain data were indicated.

Activity 8.3.1.2.2.9.2 - Selection, development, and testing of hydrologic-modeling computer codes. The decoupling of the numerical code TOUGH was completed. The decoupled code can solve problems that involve moisture flow only, resulting in large savings in computer time and allowing solution of larger problems. The decoupled TOUGH code is being tested and a report will be prepared on the testing activity.

Activity 8.3.1.2.2.9.3 - Simulation of the natural hydrogeologic system. Meetings were held between USGS and LBL scientists to discuss recent data acquired from laboratory and field activities. These data included porosities, permeabilities and characteristics curves for the different rocks at Yucca Mountain, and were incorporated into the three-dimensional site-scale model. Various two-dimensional cross sections from the site-scale model were simulated using different assumptions regarding infiltration rates and fault properties.

A paper entitled "Studies of the Role of Fault Zones on Fluid Flow Using the Site-Scale Model of Yucca Mountain," (Wittwer et al., 1993) was prepared for presentation at the

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1993 IHLRWM Conference. A paper entitled "Development of a Three-Dimensional Site-Scale Model for the Unsaturated Zone at Yucca Mountain, Nevada," (Wittwer et al.) was revised according to reviewers' comments. The paper will be published in a special Yucca Mountain issue of Radioactive Waste and the Nuclear Fuel Cycle.

Structural and material properties data continued to be incorporated into the site model as they become available. The computational mesh for the site two- and three-dimensional models will continue to be refined if additional data or sensitivity analysis indicate this is necessary.

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

**Forecast:** A two-dimensional cross-sectional numerical model will be created to examine potential for lateral flow within the non- and partially welded rocks of the PTn unit at Yucca Mountain. The model will most likely assume that focused recharge occurs within the alluvial channels. A representative cross section will be assumed, based on the stratigraphy at boreholes UE-25 UZ #4 and UE-25 UZ #5. Testing of the decoupled TOUGH hydrologic-simulator code will be completed and a report describing performance of the code prepared. Development of the preliminary three-dimensional, site-scale, moisture-flow model using the TOUGH code will continue. New geologic and hydrologic data will be incorporated into the model as they become available. Reports describing the initial construction of the model and the effects of the model grid on calculated moisture distribution will be prepared. Data on spatial and temporal distribution of infiltration at Yucca Mountain will be incorporated into the model, and the model's sensitivity to infiltration will be tested.

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

On September 14, 1992, OCRWM responded to a variety of concerns expressed in NRC's December 6, 1991, Phase 1 acceptance letter for Study Plan 8.3.1.2.3.1 (.1-6). Study Plan Section 8.3.1.2.3.1.7 was approved. Revision 1 of the study plan was submitted to YMPO for review on March 31, 1992.

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

Activity 8.3.1.2.3.1.2 - Site potentiometric-level evaluation. Monitoring of water levels in the SZ at Yucca Mountain continued. Monthly water-level measurements were made in 20 wells. Hourly water-level data were collected from 18 zones in 12 wells and continuous data were obtained in three zones in two wells. All hourly water-level data are now being collected in real time using data-collection platforms. This allows for monitoring of the



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network at any time, via computers and modems, to check on possible water-level excursions or problems with the data recording equipment. Thirty-three transducer calibrations were performed and a 792-m (2,600-ft) steel tape was calibrated. Evaluation of the 1990-91 water-level data continued. The 1992 water-level data evaluation began. Water levels essentially remained stable during the reporting period.

Three zones in two wells were monitored continuously to detect water-level fluctuations caused by earthquakes and underground nuclear testing. Aftershocks from major earthquakes that struck California and Nevada in June 1992 occurred sporadically during this reporting period and minor associated water-level fluctuations were recorded. Analysis of water-level fluctuations related to the June earthquakes were documented in a report entitled "Earthquake-Induced Water-Level Fluctuations at Yucca Mountain, Nevada, June, 1992," (O'Brien), which was approved for publication by the USGS. Maximum water-level fluctuations of 0.9 m and maximum fluid-pressure fluctuations of 2.2 m were estimated for the June 28, 7.5-magnitude Landers, California earthquake. On the following day, June 29, 1992, a 5.6-magnitude earthquake occurred at Little Skull Mountain, Nevada, resulting in an estimated maximum water-level fluctuation of 0.4 m and an estimated fluid-pressure fluctuation of 1.1 m. Water-level responses to the earthquakes were observed in several wells but most were of very short duration (1-2 hours). Only two wells showed any persistent change in water level. The maximum long-term water-level change of 0.5 m occurred in Well UE-25p #1, which is the only well that monitors the deep carbonate aquifer beneath Yucca Mountain; however, water levels in that well have slowly been recovering since the earthquake.

Three reports entitled "Precision and Accuracy of Manual Water-Level Measurements Taken in the Yucca Mountain Area, Nye County, Nevada, 1988-90," (Boucher), "Water Levels in Continuously Monitored Wells in the Yucca Mountain Area, Nevada, 1989," (Luckey et al.), and "Hydrologic Responses to Earthquakes, June 28-29, 1992, at Yucca Mountain, Nevada" (O'Brien and Tucci) 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. Work continued on the draft report entitled "Intraborehole Flow & Stress Test," (Geldon). The report will include analyses of past C-hole complex test data using manual graphical matching techniques.

Activity 8.3.1.2.3.1.4 - Multiple-well interference testing. Work continued with expanding the two 3-zone packer systems to three 5-zone packer strings. This included ordering all the packers, pressure transducers, thermistors, multiple-conductor cables, water-proof electric connectors, high pressure hydraulic hose for packer inflation, and other components needed to do the work. Eighteen packers were ordered and were under construction. A team from USGS and U.S. Bureau of Reclamation (USBR) staff supervised the testing of these packers prior to shipment to Denver.

The two 3-zone packer strings, which had been constructed in FY 1992, were shipped to a prototype site in California, placed in two 91 m (300 ft) deep wells, and tested for

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electrical signal continuity between a data logger at the surface and downhole transducers. Problems were identified with the electric signal continuity in one of the strings.

Activity 8.3.1.2.3.1.5 - Testing of the C-hole sites with conservative tracers. Several meetings were held between the activity staff and the contractor supplying the down-hole tracer injection system. Discussions centered around the design "cracking pressure" of a downhole valve that will serve to hold the column of tracer (to be injected into a particular zone) in place, until the top of the tracer column is pressurized by nitrogen gas. All the components of this down-hole tracer injection system were delivered to the USGS.

USGS scientists used the software package FracMan to develop a three-dimensional fracture-network model for the C-holes. The model will be used for designing (and eventually for analyzing the results of) the multiple-well conservative tracer tests to be conducted at the C-holes. A porous-medium-equivalent model of the C-holes was also investigated for the same purpose.

**Forecast:** Hourly water-level monitoring will continue in 18 zones of 12 wells. Continuous data to monitor the effects of earthquakes and other short-term stresses will be collected in four zones of two wells. Monthly measurements will be made in about 20 wells. As new wells are drilled, the water level will be measured whenever possible. The data report on the 1990-91 water levels will be completed and the report on the 1992 water levels will be nearing completion.

Hydraulic testing at the C-well complex is scheduled to begin in mid summer (1993). The initial tests will be short-term (1-3 days) and will include a final shake-down of equipment and techniques. Pressure changes as a result of pumping will be monitored in three to five zones in each of the three C-wells. Water levels also will be monitored in other nearby wells when longer tests (up to 30 days) are conducted. Hydraulic tests will continue for approximately one year before tracer tests begin. Planning will begin for the first of several new water-table wells, USW WT-23. Planning also will begin for the Solitario Canyon fault study test well USW H-7 if it is moved ahead in the drilling schedule so that it will be drilled in 1994.

Activity 8.3.1.2.3.1.6 - Well testing with conservative tracers throughout the site. No progress during the reporting period; this is 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 staff began preparing a paper on this characterization work.

A new technique for measuring microsphere concentration was developed and was being tested. Microspheres were successfully counted using a flow cytometer in samples of UE-25 J #13 water spiked with 1- $\mu$ m polystyrene microspheres. Spheres with different

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fluorescent dyes were also measured in higher concentration solutions containing natural colloidal material.

Data collection was completed on methods for measuring aperture profiles of laboratory-sized fracture specimens, and a paper describing this research entitled "Aperture Characteristics, Saturated Fluid Flow, and Tracer Transport Calculations for a Natural Fracture" (Reimus et al., 1993) was prepared and approved by YMPO. The authors used surface-profile data taken with a noncontact laser profilometer to determine the aperture distribution within a natural fracture.

Two papers were prepared for the Journal of Radioactive Waste Management—Special Issue on the Yucca Mountain Project. "The Use of Selectivity Coefficients to Estimate Modified Langmuir Isotherm Parameters as a Function of Experimental Conditions" (Polzer et al.) derived expressions for thermodynamic selectivity and discussed coefficients that can be used to interpret sorption experiments involving ion exchange reactions. "A Strategy for Validating a Conceptual Model for Radionuclide Migration in the Saturated Zone Beneath Yucca Mountain" (Robinson) presented calculations showing that a series of field tests can be performed to validate or refute the matrix diffusion model for transport in the SZ. Both papers are in the YMPO review process.

A Los Alamos report entitled "FEHMN 1.0: Finite Element Heat and Mass Transfer Code, Rev 1" (Zyvoloski et al., 1992) was published. It summarized the computer code FEHMN, a finite-element heat and mass transfer code in three dimensions. The code simulates saturated or unsaturated flow, solute transport, and a variety of constitutive relationships for permeability, porosity, and capillary pressure.

The computer code SORBEQ was certified. This code, which is modified to include nonlinear equilibrium sorption, solves the one-dimensional convective-dispersion equation. It will be used to model the lithium column experiments.

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

**Forecast:** Los Alamos will design the C-Wells experiments, choose the well, and determine the flow rates of circulation. Using previous modeling results, the test duration, injection amount, concentration and duration of tracer injection, and sampling frequency will be set. A report on preliminary modeling of the C-Wells reactive tracer experiment with FRACNET and FEHMN will be delivered at the end of this activity. Completed laboratory experiments using lithium as a tracer to develop understanding and parameter values for field experiments and laboratory transport experiments in columns of crushed tuff will be included in the report.

### **2.2.1.15 Study 8.3.1.2.3.2 - Characterization of the Saturated-Zone Hydrochemistry.**

The study plan was accepted, with no comments, by the NRC in a Phase I review letter January 4, 1993.

Activity 8.3.1.2.3.2.1 - Assessment of saturated-zone hydrochemical data availability and needs. Data from several sources were quality checked, formatted, and combined with previously entered data to yield a general data base containing more than 4,600 analyses. Site identities were established or verified for all records. This data base was edited to delete simple duplicates, to combine site records that did not contain identical data entries, and to resolve data and location discrepancies. This yielded a subset of about 3,700 records. All records in this set were then sorted according to their balance status; "balanced", "not balanced" or "not enough information to balance". It was found that 2,204 records had cation-ion balance differences of 10 percent or less. Selected statistical analyses were performed on major cations and anions for the "balanced" data set using SAS software. These analyses included basic statistics, histograms, and X-Y plots for raw data, standardized data, and log transformed data. Methods of standardization and log transformation were useful because the raw data values have a very large range ( $10^{-4}$  to  $10^{+4}$  mg/L) and are not normally distributed. Correlations between parameters were evident from a correlation analysis and log-log plots.

Preliminary spatial analysis was performed on the "balanced" data set. Contours of concentrations of major cations and anions appear to correlate with regional geologic and structural features. Coverages have been created in ARC for later analysis and plotting. Lithologic data were retrieved from ARC and combined with the lithologic information in the edited data base. The records were then sorted by lithology and basic statistics for major cations and anions within each lithologic group were calculated using SAS and examined graphically using LOTUS. Preliminary Piper-diagram plots of major cations and anions have been made. In addition, data for twenty-three minor elements have been plotted and contoured for the regional area.

Activity 8.3.1.2.3.2.2 - Hydrochemical characterization of water in the upper part of the saturated zone. Plans were made for collecting ground-water samples and field-data collection both for activities at UE-25 UZ #16, and for planned/potential efforts at USW G-2 and selected water-table holes. Sample and data collection at UE-25 UZ #16 were successful. Input was provided in preparation of criteria letters for work at USW G-2 and the water-table holes.

Extended discussions were held with a Swedish contractor to the Swedish Nuclear Fuel Supply Co. regarding data and sample collection methods planned for use in the YMP. Discussions focused on methods used in the Swedish program for the collection of ground-water samples for colloidal particles. Discussions were also held with a Swiss National Cooperative Society for the Storage of Radioactive Wastes (NAGRA) investigator who has worked extensively in this field. Recommendations from these scientists largely will be incorporated in any work performed by the USGS regarding ground-water colloid quantification and description.

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The PI participated in a YMP geochemistry integration team workshop to identify post emplacement geochemical aspects of geochemical/hydrological processes that likely will occur as a result of the perturbation of the thermal and geohydrologic regimes at and in the vicinity of the potential repository block. Distinct physical regimes attendant to the scenarios described by the simulations were identified, and experimental investigations and data needs requisite to an understanding of the geochemical processes likely to be operative in those regimes were proposed and discussed.

Review was begun of a large set of hydrochemical data for analog recharge sites from the Analog Recharge Studies (Activity 8.3.1.5.2.1.4).

Activity 8.3.1.2.3.2.3 - Regional hydrochemical tests and analyses. Sampling plans for springs in the Death Valley National Monument were finalized with National Park Service staff members at the Monument and in Fort Collins, Colorado, and with investigators at the Center for Environmental Studies, University of Nevada, Reno (CES), and Los Alamos. Accelerator mass spectrometric determinations of  $^{14}\text{C}$  concentrations will be determined by Woods Hole. It was agreed that CES investigators would accompany USGS and Los Alamos investigators to collect additional samples for lanthanide element analyses. Samples and field data were collected at several sites.

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

**Forecast:** Assessment of existing hydrochemical data will be completed and new data will be collected throughout the region. Preparations will be made to conduct detailed hydrochemical characterization at and in the vicinity of Yucca Mountain. This will include equipment design, evaluation, and purchases, as well as methods development. Plans will be further developed to purge existing wells at Yucca Mountain in preparation for sampling.

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

Study Plan 8.3.1.2.3.3 was revised per YMPO comments on Revision 0, was approved by OCRWM on January 14, 1993, and sent to the NRC January 28, 1993.

Activity 8.3.1.2.3.3.1 - Conceptualization of saturated-zone flow models within the boundaries of the accessible environment. A report entitled "Revised Potentiometric-Surface Map, Yucca Mountain and Vicinity, Nevada," (Ervin et al.) has received USGS approval and OCRWM approval for publication. The report describes the revised potentiometric map of mainly 1988 average water levels for the vicinity of Yucca Mountain (scale 1:24,000) and details time-trend analysis, water-level adjustments for temperature and density effects of the deep wells, and a conceptual model of the flow system at Yucca Mountain. A paper entitled "Updated Potentiometric-Surface Map for Yucca Mountain and Vicinity, Nevada," (Ervin et al., 1993) summarizing this report is in the Proceedings of the 1993 IHLRWM Conference.

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Activity 8.3.1.2.3.3.2 - Development of fracture network model. Several modifications and improvements were made to the fracture flow and transport code TRINET. A version of TRINET was ported to run on a supercomputer to increase the speed and to allow for model applications with larger meshes. LBL staff completed a report entitled "Techniques for Evaluating the Effects of Borehole Bias on Fracture Orientation Distributions Derived from Boreholes," (Martel and Peterson), and the report is awaiting publication. Visual/graphical methods of estimating fracture density in boreholes were developed to examine correlation between changes in fracture characteristics (density, strike, and dip) from C-hole complex of wells.

In addition, a report on the inversion of pressure-transient tests, "Simulated Annealing," (Peterson) was drafted and is in review at LBL. The report discusses accuracy and resolution of an LBL designed numerical-inversion technique for cross-hole tracer tests in fractured rocks. Also, a forward modeling technique was developed to incorporate two-dimensional covariance structure of lattice bonds into a model and to evaluate estimates of flow parameters using cross-validation methods. The regular square-lattice model was used for statistical representation of fluid flow in fracture networks. An article entitled "Using the Bootstrap and the Jackknife with Spatially Dependent Hydrological Data," (Maulden et al., 1992) was presented at the Fall 1992 AGU meeting in San Francisco. The article discusses theory and application of model cross-validation.

Activity investigators have completed fracture mapping in the Bullfrog Member of the Crater Flat Tuff at Raven Canyon and east of Little Skull Mountain, Nevada by performing additional fracture-line surveys and accurately locating the mapping sites. The fracture data, strike, dip, azimuth, dimensions, expression, shape, roughness and mineralogy are being entered into a data base in preparation for a USGS report.

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 is an out-year activity.

**Forecast:** Work planned in the second half of FY 1993 includes continued refinement of the numerical fracture-network model that will be used to interpret results of hydraulic tests at the C-hole complex. A report containing data on fracture networks in the Bullfrog Member of the Crater Flat Tuff will be prepared. The data will be used to constrain the numerical fracture-network model. The TRINET users's manual will be completed and published as an LBL report. In addition, LBL will use TRINET to test the spatially correlated model. The results of the C-hole hydraulic tests also will be examined by 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.

## **2.2.2 Geochemistry (SCP Section 8.3.1.3)**

### **2.2.2.1 Study 8.3.1.3.1.1 - Ground-Water Chemistry Model**

The study plan was returned to Los Alamos in May 1992 from YMPO; review comments are being addressed.

A test matrix, which will support the testing of radionuclide solubility and radionuclide sorption on Yucca Mountain tuffs, was established for modeling the "most-active ground water" at Yucca Mountain. Version 7 of the LLNL geochemical code EQ3/6 was received and installed on Sun platform.

**Forecast:** Using the EQ3/6 code, Los Alamos will study the stability and elucidate the parameters controlling or influencing the oxidation-reduction potential and the hydrogen ion concentration potential (pH) of Yucca Mountain ground water and provide these bounds to the Sorption and Solubility studies. This activity is a predecessor to the conceptual ground water modeling activity. A report is due at the end of this activity and will be incorporated in the milestone on Np in Study 8.3.1.3.6.1.

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

The State of Nevada sent 12 comments on the study plan to YMPO on December 23, 1992. Los Alamos assessed the impact of these comments on the planned work on January 29, 1993, and responded to the State's comments on February 24, 1993. Los Alamos began preparation of Revision 1 of the study plan in January 1993.

Activity 8.3.1.3.2.1.1. - Petrologic stratigraphy of the Topopah Spring Member. There was no progress in this activity during the reporting period because efforts have been deferred until samples become available from new drill core and from the ESF. New drill core from UE-25 UZ #16 was examined and samples were requested.

Activity 8.3.1.3.2.1.2. - Mineral distributions between the host rock and the accessible environment. Data were collected and summarized on chemical, mineralogical, and petrographic studies by Los Alamos (Broxton et al.); mechanical properties studies by SNL (Rautman), and hydrologic properties studies by the USGS (Flint). A report describing this work, "Geologic Evaluation of Six Nonwelded Tuff Sites in the Vicinity of Yucca Mountain, Nevada for a Surface-Based Test Facility for the Yucca Mountain Project," (Broxton) was submitted for YMPO approval. The report summarizes data for six locations at which a shallow mined facility might be developed for field tests of rocks analogous to the tuffaceous beds of Calico Hills beneath Yucca Mountain.

Collection of quantitative x-ray diffraction (XRD) data on mineral distributions and their likely modes of interaction with waste (cation exchange, surface complexation, or co-precipitation) was completed. A report describing this work, "Mineralogy as a Factor in

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Radioactive Waste Transport Through Altered Pyroclastic Rocks at Yucca Mountain, Nevada" (Vaniman et al.), was approved by YMPO and is being reviewed for publication in the Geological Society of America Bulletin.

Data collection was completed on a chemical and petrographic study of 12 calcite samples from USW G-2 and USW GU-3/G-3 at Yucca Mountain. A report on this work entitled "Calcite Deposits in Drill Cores USW G-2 and USW GU-3/G-3 at Yucca Mountain, Nevada" (D. Vaniman) was approved by YMPO. This report described studies of fracture calcites, including samples from localities above and below the water table. Trace-element data collected by instrumental neutron activation analysis were used to draw distinctions between drill cores and between calcites above or below the water table.

Data collection was completed on calcite chemistry in samples from drill cores USW G-1, USW G-2, USW GU-3/G-3, and USW G-4. A paper describing this work entitled "Calcite Deposits in Fractures at Yucca Mountain, Nevada" (Vaniman, 1993) was written, approved by YMPO, and is in the Proceedings of the 1993 IHLRWM Conference. This paper summarizes the calcite chemistry in samples from drill cores USW G-1, USW G-2, USW GU-3/G-3, and USW G-4.

Data collection was completed, and a general paper describing this work entitled "The Importance of Zeolites in the Potential High-Level Radioactive Waste Repository at Yucca Mountain, Nevada" (Bish et al.) is being prepared for the Zeolite '93 conference in Boise, Idaho. The abstract of this paper was approved by YMPO. This paper considers the importance of zeolites in both retardation of waste migration and in determination of water compositions.

Staff studied samples of shallow calcite and opal from UE-25 UZ #16; samples from the first 427 m (1,400 ft) of core were requested. Staff began to study samples from portal excavations at the ESF starter-tunnel site. Field work to characterize the fibrous minerals in dust samples near the UE-25 UZ #16 drill site began.

Staff prepared an invited paper entitled "Applications of Advanced X-ray Powder Diffractions Methods to Natural Zeolites" (Bish) for the International Congress on Applied Mineralogy (Perth, Australia, May 30-June 4, 1993). It was submitted to YMPO for approval. This paper describes the use of full-pattern Rietveld methods to address problems in zeolitic characterization, structural refinement, detection in trace amounts, and stability relative to the temperature and activity of water.

Activity 8.3.1.3.2.1.3. - Fracture mineralogy. A revised version of "Fracture-Lining Manganese Oxide Minerals in Silicic Tuff, Yucca Mountain, Nevada" (Carlos et al.) was accepted for publication in Chemical Geology. This paper summarizes a large quantity of data on Mn-oxide mineralogy, chemistry, and distributions at Yucca Mountain.

Two papers were being prepared for the Zeolite '93 conference in Boise, Idaho. They are entitled "Distribution and Chemistry of Fracture-Lining Zeolites, Yucca Mountain, Nevada" (Carlos et al.) and "Equilibrium Modeling of the Formation of Zeolites in Fractures



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at Yucca Mountain, Nevada" (Chipera et al.). These papers describe the complex variety of zeolites that occur within fractures of the devitrified tuffs at Yucca Mountain and examine the possible reactions that may lead to their deposition. The abstracts of these papers were approved by YMPO.

The first 1,400 ft of UE-25 UZ #16 were examined and samples of fractures containing silica, calcite, clay, zeolites, and manganese oxide minerals were received for analysis.

**Forecast:** Los Alamos will characterize the mineralogy of airborne dust in the vicinity of drilling operations and at the SMF using XRD, Transmission Electron Microscope (TEM), and Scanning Electron Microscope (SEM). Los Alamos will identify trace minerals and characterize those that have significantly greater sorption potential than bulk rock. Core from the surface-based testing program will be used to determine the mineralogy of units above and below the potential repository horizon. A report on the mineralogy of Borehole UE-25 UZ #16 will be delivered nine months after the final sample is received. The reports on the distribution of fracture-lining minerals in drill core from Yucca Mountain (Paintbrush Tuff) and characterization of minerals in fractures from UE-25 UZ #16 core will be initiated, and three reports on mineral characterization at Yucca Mountain will be published. A presentation will be made on zeolites in fractures at Yucca Mountain at the Zeolite '93 conference at Boise, Idaho. Another presentation at the same conference will discuss the overall importance of zeolites at Yucca Mountain. Los Alamos will continue to examine the mineralogy and chemistry of calcite in fractures at Yucca Mountain to determine the origin of calcite-depositing fluids and to identify paleo-transport pathways for these fluids. The status of current findings will be presented at the 1993 IHLRWM Conference. Work will begin on samples collected from excavations related to the ESF Starter Tunnel.

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

Activity 8.3.1.3.2.2.1 - History of mineralogic and geochemical alteration of Yucca Mountain. Preparation was under way for studies of alteration in the ESF North Ramp Starter Tunnel. Documents detailing plans and support requirements for sampling in the tunnel were prepared.

Data collection on the application of the K/Ar dating method to clinoptilolite was completed, and an abstract entitled "K/Ar Dating of Clinoptilolites: Methods and Preliminary Results" (Woldegabriel et al.) describing this work was approved by YMPO and submitted to the Zeolite '93 conference. A full paper is being prepared.

A study evaluating the use of K/Ar geochronology in determining the alteration history of the zeolitized portions of Miocene tuffs at Yucca Mountain was completed. A report on this work, "Preliminary Assessment of Clinoptilolite K/Ar Results From Yucca Mountain, Nevada, USA: A Potential High-Level Radioactive Waste Repository Site" (Woldegabriel et al.) was prepared and submitted to YMPO for approval. This paper discusses the dating of

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K-rich zeolites, which may provide useful information for assessing the zeolitization and zeolite-ground-water interactions at Yucca Mountain.

Staff determined the chlorine, nitrogen, phosphorous, sulfur, and oxalate contents of ashed plant roots from the vicinity of Trench 14 and from pinon-juniper woodlands using ion chromatography. These data, along with Instrumental Neutron Activation Analysis data on trace-element contents of the roots, will help characterize the chemical contents of the plant materials and their contribution to pedogenesis and soil-water composition.

Data collection was completed on several outcrop sites at Yucca Mountain and Busted Butte that have figured in the controversy about recent surface discharge of water from depth, and a talk on this subject entitled "Surface-Discharging Hydrothermal Systems at Yucca Mountain -- Examining the Evidence" (Levy, 1992b) was presented at the Materials Research Society Symposium on the Scientific Basis for Nuclear Waste Management (November 30 - December 4, 1992). Levy concluded that the observed alteration probably resulted from hydrothermal processes active more than 12 million years ago. A full paper on this subject was prepared, approved by YMPO, and accepted for publication in the conference proceedings.

A paper entitled "Natural Gels in the Yucca Mountain Area, Nevada, USA" (Levy, 1992a) was published. The paper discusses gels (colloidal aggregates), which were associated with past diagenetic and hydrothermal alteration of volcanic glass, in the Yucca Mountain area. The two major conclusions were (1) principal gel products in both environments were heulandite-clinoptilolite and silica, and (2) gels recently collected in Rainier Mesa tunnels were smectite-water mixtures.

Activity 8.3.1.3.2.2.2 - Smectite, zeolite, manganese minerals, glass dehydration, and transformation. The first phase of long-term steam-heating experiments was under way. Powdered samples of Yucca Mountain material including devitrified tuff, vitric nonwelded tuff, vitrophyre, smectite-rich altered tuff, and zeolitic altered nonwelded tuff were tested. The starting materials also included Na-bentonite, Ca-smectite, opal-CT, and two standard clinoptilolites. All samples were being run at a 2:1 water-rock ratio at 100 and 200°C. They will be examined for mineralogic changes on a periodic basis.

Data collection was completed on the effects of heating on zeolite crystal lattice dimensions and a paper describing this work entitled "Thermal Behavior of Natural Zeolites" (Bish) was prepared and approved by YMPO. A full paper is being prepared and will be presented at the Zeolite '93 conference and published in the proceedings.

A paper, "Dehydration and Rehydration of a Tuff Vitrophyre" (Vaniman et al.) was approved by YMPO and accepted for publication in the Journal of Geophysical Research. The authors described the loss of water and fluorine of vitrophyre samples from the Topopah Spring Member following several years of dry heating at 50 to 200°C, and the rehydration of these samples after heating.

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**Forecast:** Los Alamos will begin analysis of core from Boreholes UE-25 JF #3 and UE-25 UZ #16 and also begin analysis of samples from the North Ramp Starter Tunnel, for faults and breccia zones, transport-related features, and natural gels. Study of surface and subsurface samples to identify past preferential ground-water pathways will be continued. Radiometric dating of secondary minerals and determine feasibility of their use as indicators of alteration age and paleohydrology will be completed. A paper will be presented at the Zeolite '93 conference summarizing the results of the studies. Staff will continue short-term steam-heating experiments on pure minerals to determine dehydration/rehydration behavior and volume changes and long-term steam-heating experiments to determine the stability of clinoptilolite, smectite, hematite, devitrified, vitric, and zeolitic tuffs, vitrophyre, and opal-CT. These data will be used to predict the chemical and mineralogical effects on tuffs in the vicinity of the heated repository under different thermal loading scenarios.

### **2.2.2.4 Study 8.3.1.3.3.1 - Natural Analog of Hydrothermal Systems in Tuff**

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

### **2.2.2.5 Study 8.3.1.3.3.2 - Kinetics and Thermodynamics of Mineral Evolution**

The draft study plan is being reevaluated for necessary revisions.

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

### **2.2.2.6 Study 8.3.1.3.3.3 - Conceptual Model of Mineral Evolution**

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

### **2.2.2.7 Study 8.3.1.3.4.1 - Batch Sorption Studies**

A new 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 in October 1992. Review comments on the study plan were returned to Los Alamos in February 1993, and are being incorporated.

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Activity 8.3.1.3.4.1.1 - Batch sorption measurements as a function of solid phase composition. Data collection was completed on the effects of sample grinding and pre-conditioning of water on sorption. A paper entitled "Dependence of Radionuclide Sorption on Sample Grinding, Surface Area, and Water Composition" (Rogers and Meijer, 1993) describing this work was prepared, approved by YMPO, and is in the Proceedings of the 1993 IHLRWM Conference.

Data collection was completed on the dependence of sorption coefficients on sample grinding and sieving, and a talk on this work entitled "Sorption Characteristics of Yucca Mountain Tuffs as a Function of Particle Size" (Rogers et al., 1992) was presented by K. Kung at the November 1992 Materials Research Society Symposium on the Scientific Basis for Nuclear Waste Management XVI. The abstract of this talk was approved by YMPO. The authors reported on their specific grinding and dry sieving procedures that preserved sample bulk. When these procedures were followed, they found that the sorption distribution coefficients were insensitive to particle size for samples between 75  $\mu\text{m}$  and 2 mm in diameter.

Data collection was completed on the role that minerals in tuffs from Yucca Mountain play in Np retardation. A paper describing these batch sorption experiments, which used magnetically separated fractions of crushed tuff from USW G-4-1530 in a  $^{237}\text{Np}$  solution prepared with ground water from Well UE-25 J #13 was prepared for the Proceedings of the 1993 IHLRWM Conference. The paper is entitled "Neptunium Retardation with Tuffs and Groundwaters from Yucca Mountain" (Triay et al., 1993a).

Data collection was completed on the effect of organic coatings on cadmium sorption onto minerals in Yucca Mountain tuffs. The results of these experiments were summarized in an abstract entitled "The Effect of Organic Coatings on Radionuclide Sorption" (Kung and Triay), which was in the YMPO review process. When approved, this abstract will be submitted to Migration '93; a full paper will be submitted for publication in the conference proceedings.

Activity 8.3.1.3.4.1.2 - Sorption as a function of sorbing element concentrations (isotherms). Staff began experiments to evaluate Np sorption onto tuffs from USW G-4-275 and USW G-4-1530 and onto the following pure minerals: calcite, hematite, montmorillonite, clinoptilolite, and quartz, as a function of  $^{237}\text{Np}$  concentration ( $10^{-6}$  and  $10^{-7}$  M) and temperature (25, 60, and 90°C). All particles were in the size range of 75–500  $\mu\text{m}$ .

Activity 8.3.1.3.4.1.3 - Sorption as a function of ground-water composition. Staff began experiments to study sorption of Np onto the tuffs and pure minerals (given in Section 8.3.1.3.4.1.2) as a function of ground water (UE-25 J #13 and UE-25p #1) and temperature (25, 60, and 90°C).

Activity 8.3.1.3.4.1.4 - Sorption on particulates and colloids. To help define future YMP experiments to test radionuclide sorption onto colloids, staff hosted C. Degueldre of the Paul Scherrer Institute, Switzerland, who discussed colloid research at the NAGRA.

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

**Forecast:** Los Alamos will report on batch sorption experiments using whole-rock material from drill cores and from the ESF to resolve analytical artifacts and uncertainties. A report on the effects of water/rock ratios on sorption coefficients will be published. Focusing on key radionuclides, such as Np and Pu, and specific ground-water compositions, Los Alamos will continue experiments to determine the dependence of  $K_d$  values on radionuclide concentration in solution. Los Alamos continues to use whole rock from drill cores, and ESF samples have been requested. Scoping experiments at higher temperatures to determine the effect of temperature on sorption continue. A report summarizing results of sorption experiments at higher temperatures will be delivered at the end of this activity. Using various solution compositions and all of the important radionuclides, Los Alamos will continue batch sorption experiments on pure mineral separates found in Yucca Mountain tuffs, and the data will be interpreted in terms of whole rock  $K_d$ . Np sorption experiments on feldspar to obtain surface complexation constants and try to predict Np sorption onto tuffs with high feldspar content in UE-25 J #13 water will be continued. A report on Np sorption onto feldspars will be delivered on June 30, 1993.

### 2.2.2.8 Study 8.3.1.3.4.2 - Biological Sorption and Transport

The study plan was approved by YMPO on November 25, 1992. The NRC accepted the study plan, with no comments (but with a request for references cited in the study plan), in a Phase I review completed March 25, 1993.

The principal investigator was on a sabbatical leave at the University of California, Berkeley studying microbially enhanced mineral dissolution, primarily of hematite. Growth curves of micro-organisms supplied with various types of synthetic hematite as an iron source were compared to growth curves of microorganisms in media void of iron. It is expected that the results of these studies will provide information on the ability of microorganisms to make metal oxides more soluble, a key process with explicit application to Yucca Mountain.

Data collection was completed on siderophore and plutonium complexation and a talk entitled "The Role of Siderophores in the Transport of Radionuclides" (Hersman et al., 1992) was presented at the Materials Research Society Symposium on the Scientific Basis for Nuclear Waste Management (November 30 - December 4, 1992). The abstract was published in the conference program. A full paper with the same title (which received YMPO approval under the title "Preliminary Evidence of Siderophore and Plutonium Complexation") was submitted for publication in the conference proceedings.

**Forecast:** Continue sabbatical research on microbially enhanced mineral dissolution. Produce two detailed procedures for the quality program.

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### 2.2.2.9 Study 8.3.1.3.4.3 - Development of Sorption Models

Staff studied sorption reactions on mineral surfaces using atomic force microscopy (AFM). Atomic resolution scans of the goethite (010) cleavage plane were interpreted using known structural and crystallographic properties. Depth resolution was very good, approximately 0.3-0.4 nm, which is the depth of one unit cell.

Data collection (using the surface complexation approach) was completed on modeling of Np adsorption on silica, albite, gibbsite, and kaolinite. A report describing these results is being prepared.

Staff continued modeling of uranium adsorption on goethite and hematite and on monomineralic surfaces.

**Forecast:** Los Alamos will model sorption experiments on rocks and minerals representing the proposed repository block and predict sorption coefficients for key radionuclides under water-rock conditions not included within, but bounded by, the experimental program. Use of the AFM to examine surfaces of goethite and hematite for possible experiments to study sorption of radionuclides on individual minerals and to determine the possible influence of existing surface coatings will continue. A report on AFM analyses of hematite and goethite will be delivered at the end of this activity.

### 2.2.2.10 Study 8.3.1.3.5.1 - Dissolved Species Concentration Limits

Revision 0 of the study plan was submitted to YMPO for verification of comment resolution on October 9, 1992.

Activity 8.3.1.3.5.1.1 - Solubility measurements. Staff continued to determine the solubility of Np, Pu, and Am in UE-25p #1 water at 60°C and pH 6, 7, and 8.5 under undersaturation conditions; these data were compared with previously obtained oversaturation data. Np speciation studies at pH 7 and 8.5 were completed. The solid phases from the Pu and Am oversaturation experiments were characterized using XRD, and similar characterizations of solids from undersaturation experiments were under way.

The following four detailed technical procedures were submitted for approval: "X-ray Powder Diffraction by the Debye-Scherrer Method" (LANL-LBL-DP-03, R1), "Operating and Calibrating a Low-Energy Gamma-Ray Counting System" (LANL-LBL-DP-02, R1), "Operating and Calibrating the Mettler H6T Analytical Balance" (LANL-LBL-DP-14, R0) and "Concentration Determination of Soluble Radionuclides from Data Provided by a Low-Energy Gamma-Ray Counting System" (LANL-LBL-DP-01, R0).

Interim data collection was completed on the solubility of Np, Pu, and Am, and a paper entitled "Radionuclide Solubility and Speciation Studies for the Yucca Mountain Site Characterization Project" (Nitsche et al., 1993) is in the Proceedings of the 1993 IHLRWM Conference. This paper was approved by YMPO. The authors summarize interim results on

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the solubility and speciation of Np, Pu, and Am in UE-25 J #13 and UE-25p #1 waters at 25, 60, and 90°C and pH 6, 7, and 8.5.

Data on solubility of Np, Pu, and Am in UE-25 J #13 water from oversaturation was summarized, and a paper entitled "Measured Solubilities and Speciation of Neptunium, Plutonium, and Americium in a Typical Groundwater (J-13) from the Yucca Mountain Region" (Nitsche et al.) was completed, approved by YMPO, and was in press as a Los Alamos report. 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.

Activity 8.3.1.3.5.1.2 - Speciation measurements. Using Nuclear Magnetic Resonance (NMR), staff conducted experiments on oxygen-17 and obtained structural information about carbon-13 carbonate complexes of uranyl and neptunyl in solution. Using photoacoustic spectroscopy, staff focused on the search for pentavalent and hexavalent Pu species in equilibrated carbonate solutions of extremely dilute tetravalent Pu. New solutions, using pure tetravalent or hexavalent Pu as starting material, were prepared and the wavelength range of ~40 to 83 nm was examined.

Staff began electronic spectroscopy experiments (absorption and Photo Acoustic Spectroscopy [PAS]) to study the speciation of Np(V) in carbonate solutions. The initial studies were at pH 8.4 to 13. Interim data collection was completed on the speciation of Pu(IV) in carbonate media, and D. Morris presented a talk at the Materials Research Society Symposium on the Scientific Basis for Nuclear Waste Management (November 30 - December 4, 1992) on this work entitled "Speciation of Pu(IV) in Carbonate Media," (Tait et al., 1992). The abstract of this talk was published in the conference program. This paper discussed recent results on the speciation of Pu(IV) in carbonate solutions as a function of solution pH, carbonate concentration, plutonium concentration, and temperature.

Data collection was completed on the design and testing phase of Los Alamos' PAS system, and a paper entitled "Evaluation of Alternative Detection Schemes for Actinide Speciation Using Photoacoustic Spectroscopy" (Tait et al.) was prepared and submitted for YMPO approval. The authors introduced a new PAS detection scheme, and compared it to existing approaches.

Data collection was completed on the speciation of Pu in extremely dilute solutions, and staff members are preparing a paper on this work entitled "Plutonium(IV) Carbonate Speciation Changes" (Tait et al.) for journal publication.

Data collection on the determination of the molecular structure and ligand exchange mechanisms for hexavalent Pu in aqueous carbonate solutions was completed, and a paper describing this work entitled "Carbon-13 NMR Characterization of Plutonyl(VI) Aqueous Carbonate Complexes" (Clark et al.) is being prepared.

A paper reviewing the rationale behind this study's multifaceted spectroscopic approach to characterizing actinide speciation entitled "Actinide (IV) and Actinide (VI) Carbonate

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Speciation Studies by PAS and NMR Spectroscopies" (Clark) was completed and submitted for YMPO review. This paper includes specific examples using NMR and PAS spectroscopy.

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

**Forecast:** Los Alamos will complete solubility measurements for Np, Pu, and Am at three pH values and three temperatures at undersaturated conditions and prepare a report comparing the results of solubility experiments at oversaturation and undersaturation conditions. The photothermal spectroscopy system for radionuclide speciation studies at extreme dilution, including integration of all detection methods (photoacoustic, thermal lensing, thermal deflection) will be used. Studies of Pu(IV) carbonate speciation at concentrations of less than  $10^{-6}$  M using PAS will be completed and a report will be prepared at the end of the activity. Los Alamos will begin PAS and conventional electronic absorption spectroscopy studies of Np(V) speciation in carbonate media. Staff will collaborate with Dynamic Transport and Sorption Tasks to study speciation of Np(V) in solutions following batch and column sorption experiments. Speciation of Pu in UE-25 J #13 water with samples supplied from Solubility task will be examined. Speciation of Np, Pu, and Am in synthetic Yucca Mountain ground water using spectroscopic techniques and determine speciation of other solubility-limited radionuclides by PAS, PDS, LIF where applicable will be determined. Other, higher-concentration, species studies using visible ultraviolet and near-infrared and NMR spectroscopies will be conducted. Staff will begin  $^{13}\text{C}$  and  $^{17}\text{O}$  NMR studies of the speciation of Np(V) and Pu(IV) in carbonate media in the concentration range from  $10^{-2}$  to  $10^{-6}$  M. A report will be delivered on the NMR studies at the end of this activity.

### 2.2.2.11 Study 8.3.1.3.5.2 - Colloid Behavior

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

**Forecast:** No activity is planned for FY 1993.

### 2.2.2.12 Study 8.3.1.3.6.1 - Dynamic Transport Column Experiments

The study plan was revised by Los Alamos in response to YMPO review comments. It was returned to YMPO in March 1993.

Activity 8.3.1.3.6.1.1 - Crushed tuff column experiments. Staff completed data collection on retardation of Np by minerals in Yucca Mountain tuffs as a function of ground-water chemistry. A talk describing this work entitled "Transport of Neptunium through Yucca Mountain Tuffs" (Triay et al., 1992) was presented by I. Triay at the Materials Research Society Symposium on the Scientific Basis for Nuclear Waste Management (November 30 - December 4, 1992). The abstract was published in the conference program. 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



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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. A full paper was prepared, approved by YMPO, and submitted for publication in the conference proceedings.

Activity 8.3.1.3.6.1.2 - Mass transfer kinetics. Column experiments to determine the rate of Np sorption onto tuffs were completed. The results will be reported in a paper entitled "Neptunium Retardation with Tuffs and Groundwaters from Yucca Mountain, " (Triay et al., 1993a), which was approved by YMPO and is in the Proceedings of the 1993 IHLRWM Conference.

Activity 8.3.1.3.6.1.3 - Unsaturated tuff columns. Staff determined the hydrologic parameters of solid-tuff columns that will be used to study the Np transport.

Activity 8.3.1.3.6.1.4 - Fractured tuff columns. Staff began radionuclide migration studies through fractured-tuff samples from Borehole USW G-1. A column of fractured tuff was confined in a vessel and placed in a constant-temperature enclosure ( $25 \pm 0.2^\circ\text{C}$ ), and a constant flow (0.3 mL/h) of UE-25 J #13 water through it was established. Staff prepared to determine the hydrological parameters of the fractured-tuff column.

Activity 8.3.1.3.6.1.5 - Filtration. Staff organized the Colloid Workshop, which will be held May 3-5, 1993, and will evaluate whether colloids will significantly increase radionuclide release to the accessible environment at Yucca Mountain. The following six sessions were planned: Colloid Transport Calculations, Evidence of Colloids from Sampling Studies, Evidence of Colloid Transport at the Field Scale, Potential Sources of Colloids at Yucca Mountain, Laboratory and Field Experiments Relevant to Yucca Mountain, and Future Direction of Colloid Studies in the YMP.

**Forecast:** Using columns of fractured Yucca Mountain tuff, Los Alamos will study the transport of radionuclides using transverse matrix diffusion and channeled flow in fractures. Staff will conduct column experiments using crushed tuff and mineral separates, and intact tuff to verify the results of batch sorption measurements under flowing conditions; the water velocity will be varied to study kinetic effects. A talk will be presented at the 1993 IHLRWM Conference and a report entitled "Diffusion of Sorbing and Non-Sorbing Radionuclides in Tuff" (Triay et al., 1993b) published in the conference proceedings. A Colloid Workshop will be organized and conducted and a report produced on the workshop at the end of this activity. Following the workshop, we will submit a proposed YMP colloid strategy for YMPO review. Staff will conduct experiments on the formation and stability of colloidal material and present a summary report on Np transport in tuff collating data from the Sorption, Solubility, Speciation, and Diffusion tasks at the end of this activity.

### 2.2.2.13 Study 8.3.1.3.6.2 - Diffusion

The study plan was revised by Los Alamos in response to YMPO review comments, and returned to YMPO in November 1992.

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### Activity 8.3.1.3.6.2.1 - Uptake of radionuclides on rock beakers in a saturated system.

Staff began a study of the kinetics Np sorption. Wafers of intact tuff from USW G-4 and USW G-4 (at depths of 82.3 m [270 ft] and 467 m [1,532 ft], respectively) were placed in contact with solutions made from Np and water from UE-25 J #13 or UE-25p #1. To determine the uptake of Np by the wafer, aliquots were removed from the solution as a function of time.

Activity 8.3.1.3.6.2.2 - Diffusion through a saturated tuff slab. Data collection on diffusion of sorbing and non-sorbing radionuclides in saturated tuff was completed, and a paper summarizing this work entitled "Diffusion of Sorbing and Non-Sorbing Radionuclides" (Triay et al., 1993b) was prepared, approved by YMPO, and is in the Proceedings of the 1993 IHLRWM Conference.

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

**Forecast:** Los Alamos will design and conduct experiments to study the diffusion behavior of specific radionuclides (simple cations, anions, and actinides) under saturated and unsaturated conditions using intact tuff. Staff will support the Sorption and Dynamic Transport task. A presentation on results of ongoing experiments will be given at the 1993 IHLRWM Conference, and a paper will be published in the conference proceedings.

## 2.2.2.14 Study 8.3.1.3.7.1 - Retardation Sensitivity Analysis

The NRC accepted the study plan, with no comments, in a Phase I review completed January 19, 1993.

Activity 8.3.1.3.7.1.1 - Analysis of physical/chemical processes affecting transport. Using percolation theory, staff was developing a relative permeability model of the flow of gas and liquid through fractures.

Activity 8.3.1.3.7.1.2 - Geochemical/geophysical model of Yucca Mountain and integrated geochemical transport calculations. Using data from SNL and USGS, staff generated three-dimensional grids of Yucca Mountain. These grids will be inputted into the large-scale integrated transport calculations that will be performed using the computer code FEHM.

The TRACRN documentation (Milestone 3052) was completed, and TRACRN was certified for probationary release; GZSOLVE, a multi-use component of this code, must be completed for TRACRN to be fully certified. Completion of GZSOLVE was being delayed because of programmatic requests by LLNL to model the "extended dry" concepts.

Activity 8.3.1.3.7.1.3 - Transport models and related support. Dual permeability models, capable of representing flow in both fractures and matrix material, were completed for air-water systems for both flow and transport, and work was under way to improve the

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efficiency of the solution process. The air-water-heat system with dual permeability, which will have immediate application to thermal repository calculations, was also completed. This capability is being applied in PA to model the LLNL "extended dry" concepts.

Staff used an unstructured-mesh construction tool to improve the mesh generation capability of FEHM. This tool allows the three-dimensional grid of Yucca Mountain to more realistically capture the hydrologic units.

**Forecast:** To support PA assumptions for transport models, Los Alamos will study processes that affect transport of radionuclides at Yucca Mountain. Staff will continue to investigate the various assumptions using a fundamental model that excludes the equilibrium assumption and simulate effects that fracture flow and fracture/matrix interactions have on transport through Yucca Mountain tuffs. Conditions will be investigated under which transport in fractures is significant and these conditions will be modeled. Staff will compare the dual porosity/permeability model to the effective continuum model for parameters from the Calico Hills. Development of a geophysical/geochemical model that is based on laboratory and field experiments, field observations, and sensitivity studies important to transport at Yucca Mountain will be continued. Staff will begin testing the minimum  $K_d$  approach using available hydrologic data and various conceptual models of flow and transport at Yucca Mountain, and a three-dimensional mesh of Yucca Mountain for FEHM. Staff will simulate transport using dual porosity/permeability on the same grid as previous effective continuum simulations have been conducted. A report will be prepared on the results of the three-dimensional integrated-transport simulation.

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

A Los Alamos report entitled "A Summary and Discussion of Hydrologic Data from the Calico Hills Nonwelded Hydrogeologic Unit at Yucca Mountain, Nevada" (Loeven, 1993) was published. This report summarized hydrologic data available in 1989 for the Calico Hills nonwelded unit at Yucca Mountain, Nevada, including hydraulic conductivity, porosity, pore-size distribution and parameters from fitting pressure-saturation data. Sample statistics for some of the properties were presented for the vitric, devitrified, and zeolitic tuffs. Issues related to the design of field experiments for radionuclide transport in the Calico Hills were also discussed.

Activity 8.3.1.3.7.2.1 - Intermediate-scale experiments. No progress during the reporting period; this is 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 is an unfunded activity.

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

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

### **2.2.2.16 Study 8.3.1.3.8.1 - Gaseous Radionuclide Transport Calculations and Measurements**

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

**Forecast:** No activity is planned for FY 1993.

### **2.2.3 Rock Characteristics (SCP Section 8.3.1.4)**

#### **2.2.3.1 Activity 8.3.1.4.1.1 - Development of an Integrated Drilling Program**

To ensure that YMP scientific and technical requirements are being met by the drilling program, an effort is under way to evaluate and prioritize currently planned boreholes. Two drilling prioritization planning meetings were conducted with project participant PIs to identify opportunities for borehole consolidation. Considerations included scientific testing needs which establish borehole sizes needed and the extent of core required from borehole construction. Drilling experience was used to determine support resource capabilities in developing a prioritized drilling schedule.

**Forecast:** The preliminary integrated drilling program is being reviewed with respect to overall additional programmatic requirements identified in the site investigations long-range plan (in preparation). Participants will review the preliminary drilling prioritization to ensure technical needs are met by the sequencing and consolidation of boreholes. The annual plan for FY 1994 will identify the rationale for selection of specific boreholes to be drilled in FY 1994 based on the results of the drilling prioritization effort and integration with the site investigations long-range plan.

#### **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. During the past year, 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

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- advance planning, scheduling, budgeting, and sequencing of geophysical tests
- 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 (GIT) was established within the YMPO Regulatory and Site Evaluation Division as part of the Geophysics Integration Initiative. The GIT will oversee the geophysical testing program and ensure implementation of the integration initiative. The GIT consists of highly trained geoscientists from YMP contractor and participant organizations and is chaired by a member of the Regulatory and Site Evaluation Division.

**Forecast:** The GIT will be assisted in the integration activities by the CRWMS M&O. The CRWMS M&O has been requested to develop catalogs and folios of past and proposed geophysical activities and to cooperate with the GIT in geophysics integration functions. The requested information will serve as a basis for future analysis and planning of the geophysics testing program.

### **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**

The NRC accepted the study plan in a Phase I review dated December 14, 1992, with three comments and a request for references cited in the study plan. The OCRWM responded to the NRC's comments on March 22, 1993.

Activity 8.3.1.4.2.1.1 - Surface and subsurface stratigraphic studies of the host rock and surrounding units. Geologic cross sections depicting the North Ramp, South Ramp, and main Topopah-level drift alignments of the ESF were completed. The 1:6,000-scale geologic cross sections contain all major geologic formations as well as stratigraphic subdivisions of the Topopah Spring Member of the Paintbrush Tuff and mapped subdivisions of the Tiva Canyon Member of the Paintbrush Tuff. These cross sections, along with location maps and a

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description of the stratigraphic units, were delivered to YMPO and project design engineers. Preparation of the cross section for publication has begun.

A presentation of progress toward an integrated computer-interactive lithostratigraphic synthesis of surface and subsurface information was given to YMPO. This demonstration included an overview of all software tested, addressed the advantages and disadvantages of each, presented a synopsis of the data compiled from a digitized data base, and reviewed the technical problems involved in such an effort.

The basic geologic data in the developed digitized data base used for input into a computer-based lithostratigraphic synthesis included original cross sections and borehole and map data. Data also included secondary cross sections and "virtual drillholes", incorporating lithologically significant subdivisions of the Topopah Spring Member of the Paintbrush Tuff and mapped subdivisions of the Tiva Canyon Member of the Paintbrush Tuff, several faults in the northern part of the proposed repository site area, and most of the faults in the southern and central part of the area. Preliminary multiple stacked cross sections using the subsurface data were compared with Scott and Bonk (1984) surface geologic mapping to determine if they were consistent with known data and were geologically sound. The construction of volume components of each lithologic unit (defined by bounding faults and using the previously entered sections as guides) continued.

A manuscript entitled "Development of 3-D Lithostratigraphic and Confidence Models at Yucca Mountain, Nevada," (Buesch et al., 1993) is in the Proceedings of the 1993 IHLRWM Conference.

A preliminary core log from UE-25 UZ #16 was developed on schedule to total depth of 1,686.2 ft. Textural variations in the tuffaceous rocks of Calico Hills suggest the rocks formed from two or three pyroclastic flow deposits. Partial and preliminary core logs for ten Unsaturated Zone Neutron Holes were described from core samples archived in Lexan (plastic) tubes. The logs focused on the interval in the Paintbrush Tuff near the base of the Tiva Canyon Member. A standardized method of compiling structure logs of core was established including parameters and how these parameters will be represented. The final format of the structure log will be used on all coreholes.

A list proposing consistent stratigraphic names of lithologic units for YMP and a summary correlation chart of lithologic, hydrologic, and thermal-mechanical units was submitted for USGS review.

A report entitled "Isotopic and Trace Element Variability in Altered and Unaltered Tuffs at Yucca Mountain, Nevada," (Peterman et al., 1993) is in the Proceedings of the 1993 IHLRWM Conference.

Some of the samples from UE-25 JF #3 have been leached and measured for unspiked Nd ratios. Results were compared with a similar suite of samples that have never seen present day water-table saturation. Results are being evaluated for their implications on stratigraphic variability as well as secondary mobility in the saturated environment.

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### Activity 8.3.1.4.2.1.2 - Surface-based geophysical surveys.

The evaluation of the seismic reflection survey contract continued. Best and final bids were received; the technical committee and staff continued evaluation. Due to the extended bid process, the gravity and magnetic investigations in Yucca Wash and along the seismic profile remained in the planning stage. Staff continued development of responses to concerns for planning and safety, security, and operational issues for the seismic reflection work. Responses to Air Force concerns over acquisition of seismic reflection surveys and use of land in northern Yucca Wash were provided to YMPO. Off-road shot locations for the seismic reflection survey were staked and adjusted locations were clarified for DOE/NTS staff in preparation for pre-activity surveys. Adjustments were made to locations near environmental study plots. Maps for seismic field investigations were submitted to YMPO showing locations of existing staked shothole locations including Global Positioning System satellite-derived shothole coordinates.

In the gravity/magnetism investigations, computer programs were written to evaluate digital terrain maps that cover essentially all the conterminous U.S. Programs to distinguish between land and water below sea level, list elevations on terrain maps as a validation method, and to create artificial maps for testing were completed. Thirty-eight software products to be used by this activity to reduce and interpret field data for YMP were submitted for Software QA processing. Both gravity and magnetic profiles of Midway Valley were reduced. A paper entitled "Geophysical Investigations of Concealed Faults Near Yucca Mountain, Southwest Nevada," (Ponce, 1993) is in the Proceedings of the 1993 IHLRWM Conference.

The following additional reports are in the Proceedings of the 1993 IHLRWM Conference: "Structure of Crater Flat and Yucca Mountain, Southeastern Nevada, as Inferred From Gravity Data" (Oliver and Fox, 1993); "Seismic Reflection Profiling: Essential Geophysical Data for Yucca Mountain, Nevada" (Hunter et al., 1993); and "Geophysical Investigations of Buried Volcanic Centers Near Yucca Mountain, Nevada" (Langenheim et al., 1993).

The following have been released as USGS Open-File Reports: "Status of Aeromagnetic Survey Coverage of Yucca Mountain and Vicinity to a Radius of About 140 Kilometers, Southwestern Nevada and Southeastern California" (Sikora et al., 1993); and "Gravity and Magnetic Data of Fortymile Wash, Nevada Test Site, Nevada," (Ponce et al., 1992).

A report entitled "Magnetic Investigations of Buried Volcanic Centers Near Yucca Mountain, Southwest Nevada," (Langenheim et al.) has been approved for publication and will be published in the Water Resources Investigations Report and Technical Journal of Geological Research.

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The following paper was published in the Geological Society of America Bulletin in January 1993: "Seismic Reflection Profiling Across Tertiary Extensional Structures in the Eastern Amargosa Desert, Southern Nevada, Basin and Range Province, United States," (Brocher et al., 1993) .

A paper entitled "Gravity and Magnetic Anomalies in the Vicinity of Yucca Mountain and Their Geologic Implications," (Ponce and Oliver) was submitted for publication in the Geophysical Research Letters series.

A poster and extended abstract entitled "Characterizing Yucca Mountain, Nevada, by Geophysical Methods," (Oliver and Mooney, 1992), was presented at the AGU Meeting in December 1992. The poster consisted of new regional gravity and merged aeromagnetic maps of the Yucca Mountain area, seismic refraction profiles through Yucca Mountain, and lists of advantages and unresolved issues relating to storage of radioactive waste in Yucca Mountain.

Work continued on the proposed USGS Bulletin entitled "Status of Regional Geophysical Studies at Yucca Mountain and Vicinity, Nevada and California," (Oliver et al.).

Activity 8.3.1.4.2.1.3 - Borehole geophysical surveys. A report entitled "Assessment of Geophysical Logs from Borehole USW G-2, With Recommendations for Future Logging at Yucca Mountain, Nevada," (Nelson and Schimschal, 1992) was published.

Technical procedures "Magnetic Susceptibility of Borehole Logging Operations" (GPP-15) and "Magnetometer Borehole Logging Operations" (GPP-17) were written and issued.

Density algorithms were re-examined as part of the on-going development of the porosity-saturation technique. Preliminary results indicated that in situ porosity and water saturation can be obtained through geophysical methods. A meeting to establish suites of logs to be acquired in future boreholes was held November 13, 1992, and was attended by several investigatory groups reliant on well logs. Results from analysis of USW G-2 well logs were presented which indicated how the logs can be used to obtain porosity and saturation in the UZ. A list of logs for future use was agreed upon by the PIs in attendance.

Staff attended presentations demonstrating the RAAX borehole video tool in November 1992. The tool records digital video images of the wellbore, which can be manipulated and rotated in playback mode to simulate either core or wellbore images. Strike and dip of planar features can be determined interactively. The system operates in air or in clear water.

A first-pass computation was presented on the geochemical logs acquired in USW G-2. Discussions were held regarding the few problems with parameters used in the mineralogic computation. Due to the lack of geochemical data in borehole USW G-2, the mineralogy from XRD was used to guide the computations.



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The maintenance and expansion of the existing data base continued; large-format plots of the log and core data from the 40 deep boreholes in and around Yucca Mountain were submitted for technical review.

Many hours were spent on ensuring that geophysical tools and equipment were in quality working order. The magnetometer tool was inspected and rewired in an effort to cure an erratic dropout from the gyro. The gyro package was damaged by water during a previous logging trip and needed replacement in order to acquire directional information. The portable field magnetometer was sent out for calibration; it will be used to reference the 3-component borehole magnetometer. During checkout of the magnetic susceptibility tool, a broken potentiometer was located and replaced. Checks on the gain steps, linearity, and radial and vertical characteristics of the tool were completed.

A paper entitled "Estimation of Water-Filled and Air-Filled Porosity in the Unsaturated Zone, Yucca Mountain, Nevada," (Nelson, 1993) is in the Proceedings of the 1993 IHLRWM Conference.

A paper entitled "Geological and Mineralogical Controls on Physical Properties of Tuff at Yucca Mountain," (Nelson) was submitted to The Log Analyst for publication.

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; these are unfunded activities.

**Forecast:** In the next six months, numerous preliminary reports will be submitted. The synthesis of the borehole data report will describe standardized lithologic and stratigraphic logging methods. This final logging format will be used on all coreholes, including site characterization and engineering holes. A list proposing stratigraphic names of lithologic units for YMP and a summary correlation chart of lithologic, hydrologic, and thermal-mechanical units will be completed. The report on evaluation of stratigraphic modeling of the central block will present a computer-based lithostratigraphic volume modeling process. Another preliminary report will describe an analysis of isotopic data from available borehole materials. This report will develop a working hypotheses addressing issues such as spatial variability within units and subunits and will compare relationships between water-rock interaction, degree of fluid imbibition, and past water table fluctuations.

Field survey work for the seismic test line across Crater Flat and Yucca Mountain will be carried out and interpretation of seismic data will be under way. With seismic work under way, gravity and magnetic studies in support can also be carried out.

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

In the OCRWM transmittal letter for Revision 2 to the study plan the relationship between the revision and NRC's open items from the SCA (Comment 36 and Question 5)

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

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

Detailed field work and investigations into the depositional environments represented in upper Paintbrush Canyon continued on schedule, including discussions regarding the nature and extent of Quaternary deposits in upper Paintbrush Canyon. Details of field mapping of the northeast corner of the site area, interpretation of aerial photographs, locations of field photographs, and the largest unconformities were transferred to a 1:4,000 scale base map.

Work progressed in the mapping and measuring of stratigraphic sections in the Calico Hills unit exposed in Fortymile Wash near Comb Peak. Several other locations were identified for possible future measured sections.

Preparation of maps, cross sections, and illustrations for a summary report and presentation at the 1993 GSA Cordilleran and Rocky Mountain Section meeting in Reno, Nevada, were completed. The abstract entitled "Intraformational Deformation in the Tuffs and Lavas of Calico Hills Exposed near Yucca Mountain, Nevada," (Buesch and Dickerson) which summarizes some of the stratigraphic and structural relations in the upper Paintbrush Canyon area, was accepted for presentation by the Society.

Mapping of northern Crater Flat, on the western side of Yucca Mountain, progressed on schedule. An abstract entitled "Tectonic Framework of Crater Flat Basin, Adjacent to Yucca Mountain, Nevada: a Preliminary Report," (Fridrich, 1992), was presented at the annual GSA National Meeting in Cincinnati, Ohio, in October 1992. Field trips in Crater Flat were attended by members of the Rock Characteristics and Tectonics studies; this ongoing mapping effort is contributing to both programs. The field trip participants observed volcanic rocks exposed in Crater Flat and adjacent structural domains as a demonstration of stratigraphic and tectonic relationships in the rocks west of Yucca Mountain.

Chemical analyses of 22 Crater Flat volcanic rock samples were completed. Rock chemistry (energy-dispersive X-ray fluorescence technique) was used to check field correlations. Initial results indicated that some rock units frequently difficult to distinguish in hand specimen were notably different in trace-element abundances including elements that are virtually immobile during weak hydrothermal alteration.

Technical review began of a draft report entitled "Preliminary Map of the Pahute Mesa 30 by 60 Minute Quadrangle, Nevada," (Minor et al.) of the USGS Weapons Containment Group. Staff was asked to do this review, in part, to ensure that mapping being done for YMP in Crater Flat is well integrated with current ongoing mapping efforts in areas immediately to the north on the NTS, Nellis Bombing Range, and adjacent areas.

Staff continued detailed field mapping along the trace of the Ghost Dance fault in Split Wash and Live Yucca Ridge. Mapping will continue for several months. Meetings of the ACNW and the NWTRB were attended in Las Vegas to discuss the preliminary results of detailed mapping along the Ghost Dance fault. Grid points were set, eighteen areas were

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located, and six were mapped at a scale of 1:240. Increased geologic complexities and unusual inclement weather conditions during November, December, and January decreased productivity but to date, 24 areas in Split Wash have been mapped and over 300 fractures have been recorded in this area. Additional efforts focused on these outcrops included sample collection for petrographic analysis and trace element geochemistry. Processing began of thin sections of samples from the Tiva Canyon Member of the Paintbrush Tuff. A one-day field trip with presented current mapping work completed on the Ghost Dance fault and compared zonal features in the Tiva Canyon Member exposed in Drill Hole Wash and on Antler Ridge.

Discussions of quantitative and semiquantitative methods to characterize lithologic contacts in the Tiva Canyon Member of the Paintbrush Tuff continued in response to requests for clarification of the field distinction of these contacts.

A report entitled "Structural Character of the Ghost Dance Fault, Yucca Mountain, Nevada," (Spengler et al., 1993) is in the Proceedings of the 1993 IHLRWM Conference.

Samples of the Topopah Spring high-silica rhyolite in USW G-4 have been evaluated for trace element and isotopic data. These data show that the "isotope stratigraphy" in the high-silica rhyolite previously observed in samples from UE-25a #1 is an illusion imposed by alteration of the unit. Work is continuing on both sample suites to better understand the isotope geochemistry in terms of element mobility and the role of fluids in this mobility.

Forty samples from a stratigraphic sequence of Tiva Canyon tuffs in the vicinity of the Ghost Dance fault mapping effort, have been prepared and analyzed for trace element geochemical analysis. Interpretation of the resulting geochemical data into a working chemical-stratigraphic model of potential use in confirming detailed mapping efforts was initiated. The systematic variation in these elements clearly provides independent evidence corroborating the subtle physical and mineralogical features presently being used to map fault-related offsets of lithostratigraphic subunits. A first-order geochemical break, analogous to that observed in the Topopah Spring Member, occurs between the high-silica rhyolite and the quartz latite caprock. This feature, which can be resolved within approximately one meter, will be of primary significance as a geochemical marker in future studies requiring independent evidence of stratigraphic position.

Activity 8.3.1.4.2.2.2 - Surface-fracture network studies. The compilation of the report for the Tiva Canyon data area was postponed slightly due to reassignment of priorities in support of ESF activity; the final report, based on previously acquired data, is expected to be finished in April 1993. A detailed fracture map of the UE-25 NRG #1 pavement will be part of the Tiva Canyon report. The report will include the completed UE-25 NRG #1 core-fracture and pavement-fracture data acquisition. These data will be used in Starter Tunnel construction and were used for support of Surface Facilities Exploration Program (8.3.1.14.2.1) and Soil and Rock Properties of Potential Locations of Surface Facilities (8.3.1.14.2.2) activities. Three preliminary drawings summarizing existing Tiva Canyon Member fracture data were prepared and submitted for informal review. These and other technical drawings will be incorporated into the final report.

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The mapping and analysis of the Fran Ridge Exploratory Site Facility pits area has begun. Pavement 2001 was opened for data collection in November. It is approximately 1,300 m<sup>2</sup> (14,000 sq ft), overlies UE-25h #1, and encompasses two testpits. The Fran Ridge Pavement 2001 was examined in December for any possible washovers due to heavy rains occurring at NTS. No damage or washover of the cleared pavement was evident. Two areas of data collection were completed.

Survey data were acquired in January for completion of the clearing of Pavement 2001. These data provided the topographic base map required and will be used in subsequent mapping of the pavement. Work to incorporate these data into the Pavement 2001 mapping has begun. Drawings to accommodate the survey data were created. Preliminary/draft graphics showing the extent of mapping were submitted in February.

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

Activity 8.3.1.4.2.2.4 - Geologic mapping of the Exploratory Studies Facility. Activity staff hosted meetings to re-examine the techniques and approaches for use in underground geologic mapping. Budget constraints and changes in the ESF construction schedule required extensive planning. Topics of discussion included the viability of photogrammetry as a mapping technique in TBM excavation, consolidating underground sampling to be done by the mapping teams, changes to the existing study plan and criteria letters, and training of personnel for the mapping effort. The most feasible mapping scheme, given budget and scheduling realities, was to map photogrammetrically the Starter Tunnel and the first 200 ft of the tunnel borehole machine ramp in a test of the photogrammetric technique. Conventional mapping will also be conducted.

Planning meetings were held to discuss the basics of a consolidated sampling program for the Starter Tunnel of the ESF. The purpose of the consolidated program is to minimize the number of personnel required underground and to maximize the results of regular underground schedules. There was discussion of which samples might be taken by the underground mapping team and which samples must be taken by individual PIs.

Geologic mapping of the North Ramp Portal for the ESF was completed in March. This involved excavation and clearing of the pavement surrounding the "box cut." A plan-view map of the exposed geology was finished. Four traceline surveys were completed in the first lift, and six traceline surveys were completed in the second lift of the portal cut. The portal cut was excavated in the upper lithophysal subunit of the Tiva Canyon Member of the Paintbrush Tuff.

Activity 8.3.1.4.2.2.5 - Seismic tomography/vertical seismic profiling. The major effort during the first quarter focused on preparation for the VSP field work. Equipment was lab tested to ensure proper operation and calibration. Computer codes needed to gather input from field work were validated. These interpretational codes present tomographic images in two and three dimensions and will be used for finalizing the design of the VSP work in support of the proposed seismic reflection line. Modeling work began, using the computer

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codes, and work began to complete documentation and improve stability of the inversion routines. Software modifications were made to allow longer records and to record lower frequency content. The display software was modified to allow more flexibility in recovering the in-field results. The data acquisition software was modified to incorporate multi-offset, multi-level recording.

Meetings were held regarding input to YMPO on the expected results of the VSP in UE-25 UZ #16 and interfacing work in the North Ramp Geologic (NRG) holes with the upcoming VSP work. It was concluded that if the work can be done on a "non-interference" basis by both LBL and the others involved with the NRG holes, a VSP will be carried out in USW NRG-6 to examine the utility of check-shot data for tunnel design criteria. Work began on the summary report describing conclusions and recommendations.

**Forecast:** Efforts in the next six months will focus on sample collection for petrographic analysis of the Tiva Canyon Member of the Paintbrush Tuff. Thin sections of samples will be examined for petrographic differences within the sub-units exposed along the Ghost Dance fault. Additional petrographic work is expected in support of geochemical characterization of fault-filling materials. Mapping will continue along the trace of the Ghost Dance fault, and plans will be developed for a roadcut exposing the trace of the fault.

Further mapping in the northeast quadrant above Yucca Wash will be carried out, with emphasis on the rhyolites of the Calico Hills and associated rocks. Investigations into the eruptive geometry of these units will continue. Surface-fracture network studies will continue at the Fran Ridge Pavement 2001. Compilation of North Portal mapping will result in interpretation and data submittal. Mapping of the launch chamber excavation will proceed, with early emphasis on planning, training of additional staff, and refining of procedures.

### 2.2.3.5 Study 8.3.1.4.2.3 - Three-Dimensional Geologic Model

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

**Forecast:** No activity is planned for FY 1993.

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

The study plan was approved by OCRWM December 8, 1992. It was sent to the NRC on January 11, 1993.

**Activity 8.3.1.4.3.1.1 - Systematic drilling program.** SNL staff have participated in a number of project-level exercises directed toward reassessing the overall drilling program: revising the proposed schedule and sequence of boreholes; bringing stated requirements of each program up to date based on current thinking; eliminating duplicative boreholes wherever possible; and ensuring that the revised drilling program meets the requirements of

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the ESF design team. The workshops also addressed the relationship between the ESF and SBT. An important general conclusion from these two efforts is that the expanded ESF workings cannot be considered a substitute for borehole information. As a result of these workshops, several boreholes in similar locations tentatively have been combined, and some boreholes of the Geostatistical/Systematic Drilling Program (SD) may be relocated better to serve design needs. A revised schedule that incorporates these changes is being prepared by the CRWMS M&O. Although the impact of such schedule revisions cannot be predicted in detail, increased emphasis is being placed on completing all prerequisites for beginning quality-affecting activities. Several technical procedures have been drafted and are in review. Revision of the project-level QARD (DOE, 1992b) necessitated changes to several SNL QA implementing procedures, which has delayed finalizing the actual technical procedures. Additional project-level planning exercises involving the SD focused on developing a uniform geophysical logging program for all drilling programs and on the potential for new down-hole video technology to provide sufficiently detailed information that core requirements might be reduced for the description of geologic information.

Scoping activities during the reporting period, directed toward refining preliminary estimates of spatial continuity patterns of the hydrologic properties in tuff, focused primarily on the evaluation and reporting of previously conducted work. This effort is a collaborative undertaking by SNL and the USGS. Minor additional sampling and field checking was required to resolve specific technical questions. A summary paper, "Influence of Deterministic Geologic Trends on Spatial Variability of Hydrologic Properties in Volcanic Tuff" (Rautman et al., 1993), was written, approved, and is in the Proceedings of the 1993 IHLRWM Conference. An important result from this recent work in Solitario Canyon is that hydrologic properties may be more accurately described in some settings by the concept of "stratigraphic elevation," or proportional location of the sample within a unit.

Laboratory measurement of bulk properties from a limited, natural-analog outcrop-sampling study in the Quaternary Bandelier Tuff near Los Alamos, New Mexico, has been completed. The Bandelier Tuff consists of well-exposed nonwelded ash-flow and air-fall units that may be analogous to portions of the vitric tuffaceous beds of Calico Hills that are only poorly exposed in the vicinity of Yucca Mountain. Sampling was difficult and took longer than planned because of the poorly consolidated nature of these vitric materials. Spatial analysis of the data has been deferred due to higher priorities placed on preparations for the SD.

The commercial gas permeameter identified for field testing did not prove suitable for its intended use. Accordingly, investigators working under Subactivity 1.6.2.1.1 have produced a design for an in-house-developed unit and are constructing the device. The portable permeameter will be tested in the field when completed.

The rock properties laboratory at SNL, designed to support continued outcrop scoping studies, the SD, and activities in the SNL unsaturated flow and transport laboratory (Section 2.2.11), is operational. Technical procedures are being finalized to conduct quality-affecting activities of the SD. These documents have been delayed by changes to SNL QA implementing procedures necessitated by revisions to the project-level QARD.

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**Forecast:** The forecast in PR 7 was based on the assumption that drilling of hole USW SD-1 would commence early in FY 1993. This assumption proved incorrect due to other project priorities and the continuing drilling of hole UE-25 UZ #16. Consequently, funding of this study was significantly reduced. The following revised forecast for the next six months reflects the actual level of funds allocated thus far in FY 1993.

The study plan for this activity should complete the NRC review during the next six months. A minor revision to the study plan will be prepared to revise proposed borehole locations and correct the text for now-canceled SCP activities (i.e., the Exploratory "Shaft"). In other activities, emphasis will be placed on completing all prerequisites for beginning the SD. Scoping activities will focus on evaluating and documenting the work already accomplished. Several data reports will be prepared in cooperation with USGS investigators. The 1993 IHLRWM Conference paper (Rautman et al., 1993) will be rewritten for outside publication in peer reviewed media.

Commencement and completion of actual drilling activities under the SD cannot be predicted because of dependence upon other project drilling programs. The intent of this study is to provide data from approximately one-half the SD for use in the ACD PA exercises (Milestone 1220) and the remainder of the data for use in LA Design PA calculations (Milestone 1160). The need for information from within the potential repository area for ESF design may also work to accelerate the drilling of some holes for the SD. Specifically, the ramp hole drilling program (Section 2.2.10), as currently formulated, will not provide the information required for design of the ESF ramps to the CHL, whereas the SD specifically targets the tuffs of Calico Hills for both design and PA purposes. Therefore, the project drilling schedule may be changed to start the first SD hole during FY 1993. If this rescheduling occurs, it is assumed that additional funding to support those activities will be made available.

### 2.2.3.7 Study 8.3.1.4.3.2 - Three-Dimensional Rock Characteristics Models

The modeling work developed by this study provides the primary mechanism for producing geostatistically based physical property distributions (using data from the site characterization program) into PA models. Work to date focuses on development of geostatistical modeling tools and testing these tools by applying them to ongoing (preliminary) PA modeling efforts. Out-year activities will focus on applying these modeling tools to site data from the SD and other site characterization activities. A high priority has been assigned to preparation of the study plan for this activity in the past. Preparation of the study plan for the three-dimensional rock characteristics models study is scheduled for FY 1993. Modifications to the OCRWM-NRC agreement specifying the requirements for study plans, however, were not approved as early in the FY as anticipated. Following formal notice of approval and receipt of the new agreement on March 22, 1993, SNL QA implementing procedures must be revised. The study plan will be subsequently prepared in light of the new agreement.

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Activity 8.3.1.4.3.2.1 - Development of three-dimensional models of rock characteristics at the repository site. The Geostatistical Software Library and User's Guide (GSLIB), an integrated collection of advanced geostatistical algorithms and implementing FORTRAN subroutines developed by the Stanford (University) Center for Reservoir Forecasting (SCRF) with partial funding by YMP, has been published and released by Oxford University Press (Deutsch and Journal, 1992).

The contract with SCRF continues to provide a vital mechanism for technical interchange between SNL YMP staff and the academic geostatistics community. The cause for some anomalously short correlation structures in geostatistical simulations of Yucca Mountain was identified and SCRF researchers are developing a more sophisticated search strategy for conditioning data in an effort to alleviate this problem, which apparently is common in other sparse data situations. Additional interchange has sparked the potential for developing a very powerful technique for incorporating soft data, such as the microstratigraphic unit-dependent hydrologic properties identified through the outcrop sampling studies described in previous reports under Section 2.2.3.6. The suggested technique consists of modifying the simple kriging mean (which represents the "expected value") when computing the conditional probability density function as part of the simulation. Extracting unit-specific expected values (perhaps from geometric models such as those being developed by SCP Activity 8.3.1.4.2.3.1, Three-dimensional geologic model) is a more theoretically rigorous method for incorporating these soft data than arbitrarily incorporating a number of pseudo-boreholes to constrain the algorithm. Implementation of this methodology will not be simple and it is unclear how best to provide the resources for this task.

A major software upgrade of the LYNX Geotechnical Modeling System (GMS) was received from LYNX Geosystems during February 1993. The new release, which has been anticipated for some time under the continuing program-development and beta-test contract with LYNX, will convert the existing archaic user interface of the GMS to the current X-Windows standard for UNIX workstations. Development of modeling capabilities using the LYNX GMS has been limited by FY 1993 funding constraints. SNL staff continued to interact with LYNX personnel at a low level to guide development of capabilities.

The adaptive grid algorithm reported last period has been implemented and applied successfully to the stochastic simulations of the N54/N55 cross section of the medial Paintbrush Tuff sequence. This adaptive grid mechanism provides a computationally efficient method of scaling-up hydrologic properties measured on one scale (core samples) for use at a much larger scale (a numerical flow/transport model). The issues of upscaling hydrologic properties is only beginning to be addressed within the YMP. Both the underlying geostatistical simulations and the adaptive grid algorithm are described in a paper, "Recent Developments in Stochastic Modeling and Upscaling of Hydrologic Properties in Tuff" (Rautman and Robey, 1993), in the Proceedings of the 1993 IHLRWM Conference.

Additional GSLIB (Deutsch and Journal, 1992) subroutines have been utilized on the stochastic simulations of the N54/N55 cross section and other data to map directly the probability of obtaining various material property values. Such probability maps are another means of viewing the information provided by a set of simulations (rather than attempting to



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view and make sense of a large number of individual simulations simultaneously). The visualization technique has particular value when applied to the distribution of contaminants or to the search for fast transport paths through a geologic medium. The utility of the method in Yucca Mountain PA calculations will be explored.

A major new geostatistical simulation effort began early in the reporting period to support PA exercises for FY 1993. These simulations use indicator techniques to code major lithologies in boreholes into a few basic categories (e.g., welded versus nonwelded). A description of spatial continuity for this indicator data has been derived by digitizing published cross sections of Yucca Mountain (Scott and Bonk, 1984) and matching the polygonal outlines of the various units to discrete data by imposing a gridded sampling pattern. Standard variogram analysis of the resultant point information has allowed development of a geologically reasonable continuity model that quantitatively incorporates the easterly dip of the stratigraphic units and other features. A number of stochastic simulations have already been produced to debug and test the technique and preliminary spatial models. The simulations are large (approximately six million nodes each) and truly three-dimensional. Although the results thus far are definitely preliminary, the simulations produce reasonable representations of the inferred geology of Yucca Mountain. Dipping units and layered stratigraphy are replicated in the models, although there are still a number of apparent artifacts and anomalous regions that do not fit well with the standard conceptual model of Yucca Mountain; these discrepancies are being investigated. However, one tentative conclusion is that the conceptual model of Yucca Mountain as "simply" interlayered welded and nonwelded intervals is inadequate in the deeper units (Crater Flat Tuff). The final simulations will be used to investigate the effects of uncertainty in the location of stratigraphic contacts between boreholes on measures of site performance. Several one-dimensional columns will be extracted from the models and appropriate hydrologic properties assigned to the welded and nonwelded intervals. Because the relative thicknesses of the different lithologies will vary stochastically among simulations, the computed ground-water travel times (and similar measures) likely will vary as well. Two-dimensional cross sections will also be extracted from the models to investigate the sensitivity of performance results to slight reversals of dip that might cause ponding and local saturation of ground water. This effort appears to be the first attempt within YMP to evaluate quantitatively the uncertainty in basic stratigraphy using stochastic methods.

**Forecast:** The forecast in PR 7 was based on anticipated funding levels that exceeded actual allocations. The following revised forecast for the next six months reflects the actual level of funding allocated in FY 1993.

A new-format study plan will be prepared and submitted for OCRWM review in light of requirements in the new OCRWM-NRC Level of Detail Agreement and Review Process for Study Plans. Currently this milestone is set in December 1993. The new study plan format may allow the document to be completed ahead of schedule and the comment resolution process may be well advanced. The upgraded LYNX GMS package will be installed. Development of LYNX models will begin as soon as appropriate staff can be assigned to the effort. Geostatistical models of portions of Yucca Mountain will continue to be developed and refined to support the ongoing TSPA exercises. Exactly how these models

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and their development will be documented as part of the TSPA is not yet defined. A basic description of the models and their underpinnings will almost certainly form a chapter or appendix in the TSPA report. Planning is under way for a more integrated user interface to many of the more useful GSLIB subroutines. New staff resources are being assigned to this effort, which may be cooperative with interested non-YMP programs within SNL.

### **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**

A draft of Study Plan 8.3.1.5.1.1 has been completed and is currently being revised internally following review by USGS personnel.

Activity 8.3.1.5.1.1.1 - Synoptic characterization of regional climate. Precipitation samples associated with several storms in October and December 1992 have been analyzed for Sr isotopic compositions.

Forecast: In the last half of FY 1993, the study plan will be submitted for YMPO review. In addition, precipitation data will continue to be obtained and analyzed from the regional network. This ongoing monitoring activity generates data when precipitation has been collected. Later synthesis and analyses support broader objectives of the climate and geohydrology programs.

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

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

Activity 8.3.1.5.1.2.2 - Analysis of the stratigraphy-sedimentology of marsh, lacustrine, and playa deposits. A spreadsheet was created showing the physical and chemical properties and the ostracode species found live from 244 lake, wetland, spring, and stream sites in the western United States. These modern data were used to establish a best match for both a sub-assemblage of the fossil ostracode species which lived primarily in springs and seeps and another best match for the entire assemblage which included both lacustrine and spring taxa. The spring-only taxa matched Matthews Spring near the Ruby Mountains, Nevada. Matthews Spring is a spring seep complex having a primary discharge at 14.8°C and is located in an area with a mean annual air temperature of about 9°C. The total ostracode assemblage matched a spring pond complex in southeastern Colorado. That site is in an area with a mean annual precipitation of about 341 mm, which is roughly 200 percent higher than present precipitation at the Corn Creek Spring fossil site. Both the mean annual temperature and precipitation reported are likely to be conservative values. Even higher matches are probable for more northerly sites closer to the modern average position of the polar jet. Future reconstructions from larger baseline data sets could result in colder or warmer mean annual temperature estimates and will probably result in wetter precipitation estimates.

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Three-dimensional graphs were created to show the distribution of common modern ostracodes relative to the percentage of total dissolved calcium plus total carbonate (a proxy for precipitation), water temperature, and total dissolved solids (a proxy for evaporation). The graphs illustrate the different distributions of various ostracode species that were common in the Yucca Mountain area in the past or are common there today. These graphs, with cores and other stratigraphic data, can show the path of environmental change that occurred at a given site. They may also serve as an alternate graphical means of reconstructing past environments. The graphs were presented at the November meeting of the Nuclear Energy Agency's (France) Organization for Economic Cooperation and Development Workshop on Paleohydrogeological Methods and their Application for Radioactive Waste Disposal, and at the November 1992 NRC meeting in Bethesda, Maryland.

Ostracode taxa were identified from a sediment sample taken with a Monterey Mammoth skeleton found near modern day Corn Creek Spring. The estimated age of the mammoth and ostracode site in the Las Vegas Valley Marsh deposits is about 15ka.

About 320 sediment samples obtained from the University of Arizona were prepared for ostracode extraction and analysis. The sample set was obtained from marsh and spring deposits in ten Great Basin valleys near Yucca Mountain. The sample set will serve as a guide to select core sites and to take additional outcrop samples from these deposits. Two of the samples, from Corn Creek Spring, contain taxa new to the region and may have lived in an alluvial aquifer, possibly associated with stream flow. Ostracodes and related fossils were extracted from samples collected in the western Indian Springs Valley marsh deposits. Initial results from these samples and those from the same section collected by the University of Arizona suggest runoff and ground-water discharge varies substantially over short spatial and temporal distances.

A major field trip was conducted to a dozen field sites in southern Nevada. The trip was arranged both to collect fossil and chemical sedimentary material and to identify sites for future coring. Material from the cores will provide the paleontological and isotopic basis for reconstructing past regional climate and hydrology from the late Pleistocene and Holocene. Potential coring sites were selected in the Las Vegas, Indian Spring, Cactus Spring, Ash Meadows, and Pahrump Valleys. Seventy-four samples collected from 12 sites were prepared for ostracode analysis. The units described contain fossil and isotopic evidence that suggests elevated levels of past discharge from the sediments during the late Pleistocene and early Holocene. Participants on the field trip included participants from YMPO, USGS, University of Arizona, University of Nevada, Reno (UNR), and Desert Research Institute (DRI).

Above normal rainfall in the Southern Great Basin delayed a trip to collect cores during the late winter. The wet conditions made it impossible to reach most dry lakes and playas. The major coring activity originally scheduled to begin in February 1993 was tentatively rescheduled to begin in April 1993.

Staff from the Isotope and Geochemistry Support Group spent several days in the field examining late Pleistocene paludal deposits in the Yucca Mountain vicinity. Carbonate-rich samples were collected from several sections in Pahrump Valley that have been well-dated by

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$^{14}\text{C}$  techniques. These samples will provide an empirical test of the fundamental assumptions used in the  $^{234}\text{U}$ - $^{230}\text{Th}$  disequilibrium technique. Concordance between several independent radiometric clocks is one means of validating the methods used to date marsh and spring discharge carbonates throughout the Yucca Mountain region.

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

**Forecast:** Cores from about 12 lake, playa, and marsh deposits throughout southern Great Basin will be collected by DRI. The USGS will subsample the cores to provide dates for the deposits. These studies are closely integrated with those from the Terrestrial Paleoecology activities.

### 2.2.4.3 Study 8.3.1.5.1.3 - Climatic Implications of Terrestrial Paleoecology

Activity 8.3.1.5.1.3.1 - Analysis of pack rat middens. In late January, the USGS and DRI participated in a field trip to southern Nevada. A number of pack rat middens, plus mammoth, horse, camel, and smaller rodent fossils were found in the Pahrump, Amargosa, and Las Vegas Valleys. These fossils will be used to help reconstruct the climatic and environmental history of southern Nevada.

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

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

**Forecast:** During the last half of FY 1993, these studies will proceed, using both paleontologic and isotopic records, to identify climate change in southern Nevada. They will be closely integrated with the Lake, Playa, and Marsh Deposits activities. A meeting will be held with participants in this study and other climate and paleoclimate studies to evaluate progress and to 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 is a out-year activity.

Activity 8.3.1.5.1.4.2 - Surficial deposits mapping of the Yucca Mountain area. A preliminary stratigraphy of surficial deposits map for the Yucca Mountain area was developed

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on the basis of previous studies of surficial deposits at Yucca Mountain and elsewhere in the southwest. The stratigraphy was developed from photo interpretation and fieldwork. Initial drafts of map sheets that cover the northernmost portion of the specified map area were completed. Samples were collected of alluvial, eolian, and colluvial deposits, and intercalated ash marker beds from Midway Valley and Yucca Wash. Analysis of these samples will help constrain the paleoenvironmental history of Yucca Mountain.

Investigation of the geochronology of surficial deposits focused on collection and preparation of carbonate-rich samples from buried soils at several trenches in Midway Valley and outcrop sites in Fortymile Wash. Trench MWV-T5 was resampled to obtain dateable material from the older soils (older subunits of Q3 and upper portions of Q2) near the floor of the trench. These samples will provide additional stratigraphic framework for samples collected previously from the upper platy carbonate horizon of Q3. In addition, rhisoliths and pedogenic carbonate horizons were sampled across a section of buried Q2 and Q3 soils in Trench MWV-T7. These units should provide further geo-chronological constraints for the older colluvial units. Rhisoliths from a distinct eolian deposit on the east side of Fortymile Wash were also sampled for U-Th disequilibrium dating. This horizon underlies the Fortymile Wash high terrace and, if dateable, should place a lower age limit on initiation of active fluviation from the upper reaches of the Fortymile drainage basin. In addition to carbonate dating by U-Th disequilibrium, two samples of distinct, ashy units from Yucca Wash were prepared for tephrochronological investigations. These units consist predominantly of felsic volcanic glass shards exhibiting clay-rich coatings on individual particles. The outer layers were removed by dilute hydrofluoric acid leaching and the remaining glass will be analyzed for trace element contents and Sr isotopic compositions. Results will be used for geochemical correlation with known Plio-Pleistocene eruptions throughout the western United States.

Activity 8.3.1.5.1.4.3 - Eolian history of the Yucca Mountain region. A report entitled "Lead Isotopic Composition of Paleozoic and Late Proterozoic Marine Carbonate Rocks in the Vicinity of Yucca Mountain, Nevada," (Zartman and Kwak, 1993) was completed and is in the Proceedings of the 1993 IHLRWM Conference.

A new suite of playa samples was selected for geochemical and Sr isotopic analysis. Samples include silty playa deposits from Cottonball Basin, Silver, Lucerne, Frenchy, Mud, Silurian, Soda, and Cronese Lakes, Peter's Playa, Sand Spring, Alkali Flat, Lida Junction, and Stone Cabin, Pahump, Coal, Railroad, Ralston, and Big Smokey Valleys. Samples have been analyzed for Rb and Sr by x-ray fluorescence. In addition to playa cores, eolian components from sixteen Av soil horizon samples in Crater Flat were isolated by particle size analysis. The silt- and clay-sized fractions were analyzed by x-ray fluorescence in preparation for further isotopic analysis to further characterize the source of eolian components in pedogenic samples from the Yucca Mountain region.

**Forecast:** In the last half of FY 1993, mapping of the northern third of the area will be completed, and mapping of the center and southern third will continue. Participants in the study will meet to formally compare results from mapping work and isotopic analyses to determine if additional field work or analysis needs to be conducted.

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### 2.2.4.5 Study 8.3.1.5.1.5 - Paleoclimate-Paleoenvironmental Synthesis

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

**Forecast:** No activity is planned for FY 1993.

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

Limited activity has been conducted to evaluate YMPO review comments on the draft study plan for SCP Study 8.3.1.5.1.6 and to address QA concerns arising from an October 1992 QA audit of a contract between SNL and the National Center for Atmospheric Research.

SNL was directed on March 11, 1993, to prepare a transition plan for restructuring work efforts associated with SCP Study 8.3.1.5.1.6 in the expectation that responsibility for all efforts associated with this study will be moved to SNL during FY 1993. This plan is expected to include the transition of global and empirical modeling work currently performed by PNL. The currently planned approach to this study and anticipated schedules will be evaluated and revised if necessary.

**Activity 8.3.1.5.1.6.1 - Global climate modeling.** No progress during the reporting period; this activity is being transitioned from PNL to SNL.

**Forecast:** This transition will be completed by the end of FY 1993.

**Activity 8.3.1.5.1.6.2 - Regional climate modeling.** A paper entitled "Simulation of the Arid Climate of the Southern Great Basin Using a Regional Climate Model" was published (Giorgi et al., 1992) summarizing some of the results of the regional climate model phase 1 validation analysis.

**Activity 8.3.1.5.1.6.3 - Linked global-regional climate modeling.** This is identified as an out-year activity. However, the feasibility of linking (or nesting) regional and global climate numerical models has been adequately demonstrated and accepted by the scientific community.

**Activity 8.3.1.5.1.6.4 - Empirical climate modeling.** No progress during the reporting period; this is an out-year study.

**Forecast:** The forecast in PR 7 was based on anticipated funding levels that exceeded actual allocations. A revised forecast for the next 12 months that assumes the same level of funding allocated in FY 1993 cannot be accurately specified until completion of the planning activity. It is expected that current FY 1993 funding will permit (1) the preparation and issuance of a transition plan to consolidate all Study 8.3.1.5.1.6 activities at SNL, (2) revision and resubmittal of a draft study plan for review and comment resolution, and (3) response to

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QA concerns and resolution of any open deficiencies. A readiness review also is planned and will be performed before modeling activity is resumed.

### 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 the NRC on December 24, 1992.

Activity 8.3.1.5.2.1.1 - Regional Paleoflood Evaluation. Activity staff continued to prepare Landsat spectral images, aerial photographs, and digital elevation models, needed for geomorphometric analysis of paleoflood features in the Yucca Mountain region. Data sets were prepared to evaluate the physical parameters and the modern-day, precipitation-runoff conditions of the Fortymile Wash and Amargosa River drainage basins. Preliminary precipitation, evaporation, and area measurement maps of the Amargosa River and Fortymile Wash drainage basins were completed.

Field inspections were conducted at the lower Mojave River, upper and lower Amargosa River, and lower Fortymile Wash drainages following the heavy rains in January and February. Moderate to heavy runoff resulted in shallow lakes filling otherwise dry playa lake basins. Detailed investigations were conducted at Silver Lake and Death Valley to determine the surface area, volume, and source of water which contributed to the formation of lakes in these basins. Evaluation of these hydrologic data will enable the development of a region-wide model relating magnitudes and frequencies of streamflow events to past changes in climate.

Activity 8.3.1.5.2.1.2 - Quaternary unsaturated zone hydrochemical analysis. Activity 8.3.1.5.2.1.2 has been deleted and its scope of work moved to Study Plan 8.3.1.2.2.7. A change request to the SCPB, Revision 9, to accomplish Activity 8.3.1.5.2.1.2 under the scope of work for Study Plan 8.3.1.2.2.7 was approved by the YMPO CCB and is reflected in Revision 2 of the study plan.

Activity 8.3.1.5.2.1.3 - Evaluation of past discharge areas. A report entitled "Ground-Water Recharge Estimates Using a Geomorphic-Distributed Parameter Simulation Model Approach, Amargosa River Basin, Nevada and California" (Osterkamp et al.), has received a USGS internal technical review.

Vegetation mapping has progressed by producing preliminary vegetation density and land use maps. Work has continued on vegetation analysis in the Amargosa Desert where GIS methods were also used to develop initial vegetation maps.

Plots of hydrochemical data and flow paths were developed to help with hypothesis testing of the ground-water flow system. The flow line hypothesis was used to plan water and faunal collecting trips. Water samples and modern ostracode faunal samples were collected from three springs in the Lake Mead and Moapa areas and a flowing well near Ash Meadows that were sampled previously. Additional springs were sampled in the Bullfrog

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Hills, Death Valley National Monument, and near Tecopa, California. A well was also sampled for water chemistry in California Valley.

A draft report entitled "Characterizing the Distribution of Pedogenic Carbonates Using a Geographic Information System and a Carbonate Accumulation Program, Amargosa Desert, Nevada," (Faunt et al.) has gone to USGS technical review. The results of this study will be compared with results from vegetation and soil chemistry studies to determine origins of surficial deposits.

Activity 8.3.1.5.2.1.4 - Analog recharge studies. One field trip was conducted to the East Stewart and Kawich Creek study sites. Two snow course surveys in Kawich basin showed above average water content while the water content calculated from the snow survey in Stewart Basin was average for that time of year. The above average snowpack in Kawich basin increases the chance of runoff for Kawich Creek this spring.

The report of 1985-91 data for the East Stewart and Kawich Creek sites was submitted for technical review. Data tables for the 1992 report were developed. Hydrologic data for the 1992 water year were added to the water data management file to update watershed model applications using the precipitation-runoff modeling system (PRMS). The continued testing of PRMS focused on the model's optimization and sensitivity capabilities to investigate various configurations of parameter estimates relating to snowpack energy and water balance computations and to develop error propagation estimates of mean squared runoff prediction error resulting from parameter uncertainty. Two important sets of parameters in this regard are; (1) transmission coefficients, and (2) monthly scaling parameters of the potential evapotranspiration (PET) algorithm. Transmission coefficients quantify the effect of forest canopy cover density on shortwave radiation reaching snowpack surfaces. The PET scaling parameters quantify the varying effects of temperature and humidity relations on computed evapotranspiration on a monthly basis.

An existing computer implementation of the chloride-ion balance approach to estimate effective moisture was modified to make it more applicable to the Nevada analog recharge sites as regards (1) the availability of data on vegetation density (canopy cover density as opposed to basal area measurements) and (2) the method used for computing precipitation as a function of elevation. Vegetation transect data and color infra-red aerial photographs were used to develop canopy cover density estimates for the major woodland vegetation types for both Stewart and Kawich Creek watersheds. These data, along with a topographic delineation of the watersheds in terms of slope and aspect, were used to characterize the cell configurations required for the application of the chloride-ion balance method. Results of the chloride-ion balance method are inconsistent. Estimates of effective moisture are too low for Stewart Creek and too high for Kawich Creek as judged by comparison with observed streamflow.

Long-term meteorological data collection at all three levels on the tower at Organ Pipe Cactus National Monument continued uninterrupted for the whole period. The DECODES program required to download the data was written and the data were transferred to the national USGS data base. All of the figures and data sets and most of the text needed for the FY 1991-1992 long-term meteorological monitoring data report were generated. The October



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and January bulk atmospheric precipitation collections were completed. The National Park Service archaeologist approved all sites of future ground-disturbing project activities: 5 v-notch weirs with stilling ponds and stilling wells, two atmospheric bulk precipitation collectors, and four tipping-bucket rain gauges.

In support of this activity, the New Mexico Institute of Mining and Technology completed the following work: (1) 87 rock, soil, and caliche samples prepared for total Cl measurement; (2) 66 samples measured for total Cl using the Teflon cell method; (3) 139 samples measured for total Cl using the ion chromatograph; (4) 97 samples measured for total Cl using an ion selective electrode; (5) 14 samples were measured for gravimetric water content and fines fraction; (6) 18  $^{36}\text{Cl}$  dates were run; (7) 36 whole rock analyses were performed; (8) 31 B and Gd analyses were performed; (9) 42 stable isotope  $^{18}\text{O}$ ,  $^{13}\text{C}$ ,  $^2\text{H}$  (deuterium) measurements were made; (10) 29 boulder, soil, and caliche samples were collected; and (11) the stone content of 24 samples was measured.

Activity 8.3.1.5.2.1.5 - Studies of calcite and opaline silica vein studies. Installation and testing of the new Finnigan MAT 252 mass spectrometer demonstrated that the instrument was capable of analysis of routine-sized samples of carbon dioxide but its performance on small samples was disappointing. The upgrade of the existing MAT 251 is designed to provide results with small sample capability but it has been plagued with mechanical problems to date.

Cathodoluminescence microscopy demonstrated the widespread existence of growth banding in calcites from the UZ. If a suitable means of dating these growth bands can be developed, it will provide the basis for reconstruction of the paleoclimate history of the fluids percolating into the UZ from the surface. This in turn will permit fine-tuning of models predicting the possible effects of future climate changes on the UZ hydrology.

A study was started of the geochemistry of carbon dioxide and water in the soil zone and what processes, such as evaporation and soil respiration, might produce significant changes in the isotopic compositions of the waters and dissolved carbonate that ultimately percolate from the soil horizon into the UZ. Initial laboratory experiments have demonstrated the feasibility of collecting soil gas samples in the field and determining the  $\sigma^{13}\text{C}$  and  $\sigma^{18}\text{O}$  values of the carbon dioxide. A two-week sampling trip successfully installed permanent soil-gas sampling probe arrays at Fran Ridge, Exile Hill, Fortymile Wash, Pagany Wash, the southern flank of Rainier Mesa, and at the U.S. Ecology low-level waste disposal site near Beatty. Several hundred samples of soil, soil gases, and soil carbonate were collected during this trip.

Papers entitled "Lead Isotopic Composition of Paleozoic and Late Proterozoic Carbonate Rocks in the Vicinity of Yucca Mountain, Nevada," (Zartman and Kwak, 1993), and "Strontium Isotopic Evidence for a Higher Water Table at Yucca Mountain," (Marshall et al., 1993) are in the Proceedings of the 1993 IHLRWM Conference.

The  $\sigma^{13}\text{C}$  and  $\sigma^{18}\text{O}$  values of 250 to 300 samples of calcite from drill core, soil calcrete, and spring deposits were determined.

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**Forecast:** Geomorphic investigations of late-Quaternary fluvial landforms and a regional evaluation of the climatic and hydrologic conditions that were responsible for large-magnitude regional floods will be summarized in a report. A field trip is planned to collect surficial chemistry samples from playas and springs at Nellis Bombing Range and to field check the vegetation maps. Additional field trips will be planned to help define the flow system. Vegetation mapping of the area underlain by the Death Valley flow system will be field checked and completed, and initial estimates of recharge will be made based in part on the maps. Data on water chemistry, microorganisms and discharge will be collected along flow lines from wells, springs and playas in the Yucca Mountain area. These data will be used to estimate source and quantity of discharge from the flow system during the geologic past with emphasis on the past 40,000 years.

Analysis of data from two analogs to the Yucca Mountain recharge area under full glaciation in central Nevada will be completed and the final report of the study will be nearing completion. Meteorological, hydrologic, and soil data will continue to be collected in an monsoonal analog area in southern Arizona.

Isotopic studies of calcite from drill core samples including those from UE-25 UZ #16 will be completed and a journal article summarizing the data and its implications for past hydrology of Yucca Mountain will be started. Monitoring of permanent soil gas probe sites and installation of a permanent site on the top of Rainier Mesa will continue as well a preparation of a progress report for this activity. Configuration of a network of precipitation collection sites at the NTS and in the southern Great Basin in support of 8.3.1.5.1.1 and determination of the  $\sigma^2\text{H}$  and  $\sigma^{18}\text{O}$  values of precipitation samples collected to this date will continue. Fluid inclusion studies will continue of calcite sampled from the UZs of Boreholes USW G-2, USW GU-3/G-3, and USW G-4; and from UE-25 UZ #16, UE-25 A #4, 5, and 7. Preparation will continue for procedures on the extraction and analysis of  $\text{H}^2/\text{H}$  and O isotopic ratios from water and for the extraction of water from soil samples.

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

Study plan 8.3.1.5.2.2 was sent to the NRC on December 24, 1992.

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 is an unfunded activity. The name for this activity was changed in SCP Revision 9.

Activity 8.3.1.5.2.2.2 - Analysis of future unsaturated-zone hydrology due to climate changes. A change request for the SCPB was submitted to YMPO proposing the elimination of this activity and transferring its scope of work to Activity 8.3.1.2.2.9.5 (Site unsaturated-zone integration and synthesis). This change is recorded in SCPB, Revision 9.

Activity 8.3.1.5.2.2.3 - Evaluation of possible future changes of the climate and regional geologic framework on the regional saturated zone hydrology. The name of this

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activity was changed in SCPB, Revision 9, and an additional objective was added, "3) Evaluate possible regional tectonic and thermal events that may produce prolonged or transient effects on the regional water level."

Faults and horizons necessary to define the three-dimensional geologic model were identified. Cross-section modeling software code was used to attribute both faults and horizons on the cross sections and surface geologic maps. The horizon data were plotted in three dimensions for examination and to find problems in the data before gridding. Data for the tops of horizons from wells in the area were also gathered. Geologic analysis software (Intergraph) is being examined for extracting the x, y, and z coordinates defining the hydrogeologic units and faults from the cross sections and geologic map files.

A complete structural analysis of the regional study area was conducted in an attempt to evaluate the effects of stress regimes on ground-water fracture flow. A report entitled "Hydrogeologic Characterization of Structural Discontinuities of Death Valley Region, Nevada and California" (Faunt), describing the results of this study is in internal USGS technical review. New statistical techniques and seismic data were added to the work. Map products from the study include mapped faults and orientations, structural zones, regional principal stresses, and potential regional flow paths. Flow paths hypotheses are undergoing continual testing with regional three-dimensional geologic model and potentiometric surface maps.

A number of papers/abstracts were prepared or published for presentation at technical meetings. These include: "Development of Three-Dimensional Hydrogeologic Framework Model for the Death Valley Region, Southern Nevada-California, USA" (Faunt et al., 1992); for Hydro GIS '93 International Conference, April 19-22, 1993, Vienna Austria; "Geoscientific Information Systems and 3D Hydrogeologic Models for the Yucca Mountain Area, Southern Nevada-California, USA" (Faunt et al.) for Waste Management '93 at Tucson; and "Characterizing the Hydrogeologic Framework of the Death Valley Region, Southern Nevada and California" (Faunt et al., 1993) for the 1993 IHLRWM Conference.

A paper describing the development of the surface hydrogeologic units for the area entitled "Hydrogeologic Map of the Death Valley Region" (Faunt and D'Agnesse) is in internal USGS technical review.

Regional vegetation mapping was conducted. Vegetation density maps and land cover maps were produced and compared with existing maps. Field trip(s) were scheduled to field check resulting map classes.

Techniques used to estimate recharge and discharge parameters were developed. Work included developing an average annual precipitation map of model area based on Quiring's regression. A Maxey/Eakin "first approximation" of recharge for regional model was constructed and compared with estimates made for previous models.

Preparation of a regional potentiometric surface map began. Surface geology and three-dimensional cross sections were analyzed to determine where lithology and structure

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impede regional ground-water flow. Interbasinal flux boundaries were delineated. Diffuse discharge and phreatophyte areas were mapped. Spring data (locations, discharge, and temperature) were plotted and well locations with depth to water data were incorporated. Preliminary regional water table maps were developed representing the potentiometric surface as both continuous and discontinuous. The maps are being revised to include water table depressions at discharge areas.

Transmissivity and hydraulic conductivity data sets for the three-dimensional model were gathered from published information. Methods on distributing hydraulic conductivity were reviewed including random analysis, Bayesian methods, stochastic conditional simulation and deterministic methods.

Water chemistry information for the regional area from existing USGS files and reports was compiled. A draft report entitled "Hydrochemical Data in Death Valley Region," (Perfect et al.) is being written. Chemical balances for the data base and some preliminary statistical analyses were begun. The data were also transferred into ARC/INFO for some spatial analyses.

**Forecast:** The regional hydrogeologic framework model should be completed within the next six months. The first runs of a multilayered regional ground-water flow model (MODFLOW) should be begun. Statistical analysis of the hydrochemical data should be completed within the next six months.

### **2.2.5 Erosion (SCP Section 8.3.1.6)**

In the fall of 1992, the USGS provided several text revisions for the technical chapters in the Erosion Topical Report (DOE, 1993e). In January and February, staff provided input for the comment resolution of extensive YMPO review comments. In February, the staff worked with YMP counsel to revise several sections of the technical evaluation and to add suggested new text to the final draft of the topical report. The final topical report was issued by OCRWM on March 9, 1993, to the NRC, State of Nevada, and other affected parties.

A study related to the long-term erosion rate work of Coe et al. (1993) is in YMPO review. The study used photogrammetric methods to calculate the volume of material eroded from relict colluvial boulder deposits from a 1984 precipitation event at Jake Ridge near Yucca Mountain. The photogrammetric calculation of these volumes, in combination with rock varnish dates on the surface of the deposits, have confirmed the amount of hillslope degradation and the long-term erosion rates calculated by Harrington and Whitney (1991) and reported in the Erosion Topical Report (DOE, 1993e).

**Forecast:** Further work on Study Plan 8.3.1.6.1.1 is deferred until the NRC has responded to the Erosion Topical Report (DOE, 1993e). The USGS anticipates the need to participate in comment response for State of Nevada and NRC reviews of the topical report.

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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 YMPO responded to 13 comments and one question from NRC's Phase II technical review of the study plan on March 9, 1993. Minor revisions were made to the study plan in response to the NRC's comments, and it was submitted to YMPO in February 1993, approved by YMPO, and submitted to the NRC in March 1993. Minor editorial changes were made to the SCPB, Revision 9, for consistency with the study plan.

Activity 8.3.1.8.1.1.1 - Location and timing of volcanic events. No progress during the reporting period; this is an unfunded activity.

Activity 8.3.1.8.1.1.2 - Evaluation of the structural controls of basaltic volcanic activity. A statistics program was used to calculate the distribution centroids of the older post-caldera and younger post-caldera basalts. Three-dimensional, distance-weighted least-squares analysis was completed for the volume-location attributes of the Pliocene and Quaternary basalt centers of the Crater Flat volcanic zone. The disruption ratio was revised using multiple alternative structural models of the distribution of Pliocene and Quaternary volcanic events.

Activity 8.3.1.8.1.1.3 - Presence of magma bodies in the vicinity of the site. A contract with a consultant to investigate for the presence of magma bodies in the Yucca Mountain region was being processed.

Activity 8.3.1.8.1.1.4 - Probability calculations and assessment. Using repose intervals, homogeneous Poisson event counts, and magma output rates through time, staff revised values for the probability of magmatic disruption of the repository.

**Forecast:** Los Alamos will establish the recurrence rate of volcanic events (E1), using an approach similar to that used for establishing E2. Using data from field geologic studies and tectonics programs, the probability that a future volcanic event would directly intersect the potential repository or the controlled area surrounding it (E2) will be modeled. A draft Los Alamos technical report will be delivered at the end of this activity. Staff will revise the technical report following input received at a technical exchange with the NRC on June 9, 1993.

#### **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 OCRWM in October 1992. Review comments, which were returned in January 1993 for comment resolution, are being addressed.

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Activity 8.3.1.8.1.2.1 - Eruptive effects. Field work at the Paiute Ridge intrusion site continued to focus on defining the dimensions of hydrothermal zones of affected areas adjacent to dikes and sills.

Activity 8.3.1.8.1.2.2 - Subsurface effects of magmatic activity. The three-dimensional grid used to model intrusion effects from emplacement of basalt dikes and sills in the Yucca Mountain region was refined and expanded.

Activity 8.3.1.8.1.2.3 - Magma system dynamics. Staff reviewed historical data on melt segregation, magma ascent, and magma storage in the mantle and shallow crust. Revision 9 of the SCPB added this activity to the scope of work intended for the study.

**Forecast:** Los Alamos will determine and attempt to bound E3, the probability that a magmatic disruption of the repository will result in dispersal of radioactive waste exceeding the regulatory requirements for licensing; if the probability of waste being released is  $> 0.1R$ , staff will model the eruption. The potential subsurface effects of magma intrusion into the repository or waste isolation system will also be studied.

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

Study Plan 8.3.1.8.2.1 was approved by OCRWM and sent to the NRC on December 23, 1992.

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

**Forecast:** This study will be combined with Study 8.3.1.8.3.2 in a future change request to the SCPB.

### **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**

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

**Forecast:** This study will be combined with Study 8.3.1.8.3.2 in a future change request to the SCPB.

### **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 final edit has been completed on a manuscript entitled "Hydrologic Analysis of the Saturated-Zone Ground-Water System Under Yucca Mountain, Nevada," (Fridrich et al.). This paper analyzes the

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large hydraulic gradient under northern Yucca Mountain and proposes two alternative models for its cause.

Scoping has begun on a combined study plan entitled "Evaluations of Changes in the Engineered and Natural Barrier Systems Resulting From Tectonic Processes and Events," that covers the scope of Studies 8.3.1.8.2.1, 8.3.1.8.3.1, 8.3.1.8.3.3, and 8.3.1.8.4.1 of the SCPB. Because the combined study collates and synthesizes data from numerous other studies, a major part of the effort and focus consisted of compiling a list of all the interfaces with the other studies and verifying that all of the information needed for the study is being generated.

**Forecast:** Work on the combined study plan package will continue for the remainder of FY 1993. The study plan is expected to be submitted to YMPO early in FY 1994.

### **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 is an out-year study.

**Forecast:** This study will be combined with Study 8.3.1.8.3.2 in a future change request to the SCPB.

### **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 is an out-year study.

**Forecast:** This study will be combined with Study 8.3.1.8.3.2 in a future change request to the SCPB.

### **2.2.6.8 Study 8.3.1.8.5.1 - Characterization of Volcanic Features**

A minor revision to the study plan was incorporated in March 1993, and sent to the NRC on March 24, 1993.

Activity 8.3.1.8.5.1.1 - Volcanism drillholes. No activity during the reporting period. Funding for this activity begins with initiation of the regional drilling program.

Activity 8.3.1.8.5.1.2 - Geochronology studies. At the Lathrop Wells volcanic center, four large trenches were excavated and staff began field studies to investigate the stratigraphic relationship of the lava flow and pyroclastic surge volcanic units. Statistical analyses of the conventional K-Ar and  $^{40}\text{Ar}/^{39}\text{Ar}$  data sets were completed, and a report describing the level of contamination and the correlation between the percentage of radiogenic Ar and age was being prepared. Paleomagnetic sampling of the lava-flow units and measurement of field

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magnetic directions of oriented clasts from dissected scoria deposits were completed. Samples were collected from three sites for thermoluminescence age estimates and from four new sites for cosmogenic He age determinations. Consistent cosmogenic He ages were obtained from five separate samples sites for the Ql<sub>5</sub> lava unit. Additional cosmogenic ages were obtained for a surface scoria sample collected near the summit of the main cone and a large intact bomb projecting above the cone slope near the summit. A sample of welded spatter from the Qs<sub>2b</sub> unit was analyzed for a cosmogenic helium age.

The <sup>232</sup>U/<sup>232</sup>Th isotopic analysis was completed for a sample from the Ql<sub>4a</sub> lava of the Lathrop Wells center and a lava flow from the Little Black Peak center.

A talk entitled "Surface Exposure Ages and Noble Gas Components of Volcanic Units at Lathrop Wells Volcanic Center, Nevada," (Poeths and Crowe, 1992) was presented at the Fall Meeting of the AGU in October 1992. The abstract was approved by YMPO and published in the conference program. The authors determined the cosmogenic He surface exposure ages of four eruptive units at Lathrop Wells volcanic center and discussed the implications of those ages.

Activity 8.3.1.8.5.1.3 - Field geologic studies. Revised mapping of the Qs<sub>6</sub>/Ql<sub>6</sub> volcanic units at the Lathrop Wells volcanic center was completed.

The geology of the Lathrop Wells volcanic center was revised based on studies in trenches at the north side of the center. The stratigraphic relations in tephra units in two new soil pits were described, and the field relations of a southern conduit complex in the area of active quarrying was determined.

Field sites were surveyed at the Hidden Cone, Little Cone, Red Cone and Black Cone in preparation for trenching studies.

Activity 8.3.1.8.5.1.4 - Geochemistry of scoria sequences. Sr, Nd, and Pb isotopic data were obtained for basalt samples from Black Cone, Hidden Cone, and Little Black Peak Cone.

Samples for petrology studies were collected at newly recognized lava units at the Lathrop Wells volcanic center.

Activity 8.3.1.8.5.1.5 - Geochemical cycles of basaltic volcanic fields. Volume and geochemical patterns of post-Miocene basaltic volcanism in the Great Basin and its marginal areas were evaluated.

**Forecast:** Los Alamos will perform petrological and isotopic studies (and analysis of Sr, Nd, and Pb) on the basalt of Sleeping Butte and the 1 Ma and 3.7 Ma basalt of Crater Flat. Staff will model basalt petrogenesis, which will be used to test assumptions used in probability calculations. A report will be delivered at the end of this activity. Evolutionary cycles of basaltic volcanic fields will be evaluated. Staff will continue studies of the Cima, Lunar, San Francisco Peak, and Springerville volcanic fields and begin studies of Saline



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Valley, the Big Pine area, and selected volcanic fields in southern Arizona and southern New Mexico. Geochronology studies on samples from Lathrop Wells will be performed. Final assessments of the U-Th disequilibrium, cosmogenic He, and thermoluminescence methods for establishing the ages of Late Pleistocene and Holocene volcanic centers will be made. The  $^{39}\text{Ar}/^{40}\text{Ar}$  method to determine the ages of the various basalts in the vicinity of Yucca Mountain will be used. Geologic mapping of Buckboard Mesa basalt, and final geologic maps of the Lathrop Wells, Sleeping Butte, and basalt units of Crater Flat will be completed. Field studies will be conducted in the Cima and Lunar Crater volcanic fields. A map will be delivered at the end of this activity. Staff anticipates a comment response effort following receipt of NRC and State of Nevada comments on the draft Los Alamos status report on volcanism hazard studies.

### 2.2.6.9 Study 8.3.1.8.5.2 - Characterization of Igneous Intrusive Features

The YMPO review of Study Plan 8.3.1.8.5.2 has been completed and comments are being addressed.

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

Activity 8.3.1.8.5.2.2 - Chemical and physical changes around dikes. Revision 10 of the SCPB deleted this activity and transferred its scope of work to Study 8.3.1.8.1.2, where data on the nature and extent of physical changes that may occur in the surrounding tuffs as a result of the intrusion of dikes or sills will be performed.

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. The data from temperature logs obtained in September 1992, from holes at Yucca Mountain was processed and examined. No thermal effects attributable to the June 29, 1992 Little Skull Mountain earthquake were observed. Some improvements were noted in the continued efforts to improve medium term (1-2 hr) temperature stability of temperature calibration baths. Tests were continued of the high-temperature thermal conductivity apparatus. A comparison with the conventional room-temperature apparatus using samples of pure minerals yielded results well within specifications. Research has begun on the issue of shielding the apparatus against high-pressure failure of the pressure vessel.

**Forecast:** The laboratory dedicated for thermal studies at Yucca Mountain will be maintained for the remainder of FY 1993. A complete revamping of the temperature-calibration facility and preliminary tests of high-temperature thermal-conductivity apparatus will be completed. All laboratory equipment will be kept calibrated and in ready state. Emphasis will be placed on resolving QA software issues so that temperature logs can be measured and samples collected for thermal conductivity experiments by the end of the FY.

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### **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 is an out-year activity.

Forecast: No activity is planned for FY 1993.

### **2.2.7 Human Interference (SCP Section 8.3.1.9)**

One of the Programmatic Highlights during this reporting period (Section 1.4) was the signing into law of the Energy Policy Act of 1992. Section 801 of this Act directs the EPA to consult the NAS on whether institutional controls would prevent human intrusion from breaching the repository's engineered and natural barriers. Changes may come about in these activities based on this direction.

#### **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 is an out-year activity.

Forecast: No activity is planned for FY 1993.

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 is an out-year activity.

Forecast: No activity is planned for FY 1993.

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

The NRC accepted the study plan in a Phase I review letter dated March 16, 1993, with no comments. The OCRWM supplied documentation to the NRC to resolve SCA Comment 53 and Questions 14 and 15 in a letter dated February 5, 1993. These open items pertained to the natural resource assessment study.

Activity 8.3.1.9.2.1.1 - Geochemical assessment of Yucca Mountain in relation to the potential for mineralization. A geochemical study was initiated to assess the utility of determining changes in Pb and Sr isotopic compositions of limestones during mineralization. Host carbonate rocks have relatively well-defined primary compositions which can be altered

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by overwhelming or replacing the indigenous Sr and Pb with additional Sr and Pb introduced by the hydrothermal fluids. Samples of Paleozoic limestones and dolomites from mineralized areas in Bare Mountain were collected for use in this pilot portion of the study; however, if this hypothesis is substantiated, Pb and Sr isotopes will be of immense value in assessing potential mineralization.

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

The YMPO received 25 comments from the State of Nevada on the study plan on December 24, 1992. The evaluation of possible impact of these comments on the planned work began on January 8, 1993. A response to the State's comments is pending.

Activity 8.3.1.9.2.2.1 - Projected trends in local and regional ground-water development, and estimated withdrawal rates in southern Nevada, proximal to Yucca Mountain. No progress during the reporting period; 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 is an out-year study.

Forecast: No activity is planned for FY 1993.

### **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 is an out-year study.

Forecast: No activity is planned for FY 1993.

## **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 is an out-year study.

Forecast: No activity is planned for FY 1993.

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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 is an out-year study.

**Forecast:** No activity is planned for FY 1993.

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

**Activity 8.3.1.12.2.1.1 - Site meteorological monitoring program.** Meteorological monitoring continued at eight sites. The monitoring is focused on acquiring atmospheric dispersion information, that is, measurements of air flow and diffusion, but includes other meteorological monitoring for general environmental characterization that could be used for other purposes. Past data processing was continued in preparation for an upcoming six-year report. The ninth site (site 9), which is similar to the other three new installations, is located at Gate-510 along the southern border of the NTS near the community of Amargosa Valley.

Meteorological data from five calendar quarters were reported to the State of Nevada to fulfill monitoring conditions associated with Air Quality Permit No. 2693. Particulate matter data are also reported to the State in the required reports.

**Activity 8.3.1.12.2.1.2 - Data summary for input to dose assessments.** No progress during the reporting period: this is an out-year activity.

**Forecast:** The data collection program is planned to continue throughout FY 1993 and FY 1994. The Study Plan 8.3.1.12.2.1, Revision 1, will be submitted for final processing in April of 1993. The data required to maintain the State of Nevada air quality permit will continue to be collected and reported. Equipment upgrades at the first five sites will continue so that measurement capability is improved.

### **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**

This investigation in the SCP was written with no distinct studies or activities. Instead of a study plan, a Scientific Investigation Implementation Package, which is a planning document used for investigations, was written to plan work for this investigation. The package was submitted to YMPO in March. Portions of the data compilation and field study tasks in this investigation began during this period.

**Forecast:** Preliminary analysis of the existing regional and local data compiled as part of the meteorological data (Activity 8.3.1.12.2.1.1) for the six-year summary report will be initiated in FY 1993. New measuring equipment procedures will be developed and personnel trained on the operation of this equipment during the next six months. The National Oceanic

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and Atmospheric Administration Atmospheric Turbulence and Diffusion Division from Oak Ridge, Tennessee will be scheduled for field measurement activities in October 1993.

### **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 is an out-year study.

**Forecast:** No activity is planned for FY 1993.

### **2.2.9 Offsite Installations and Operations (SCP Section 8.3.1.13)**

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

**Forecast:** No activity is planned for FY 1993.

### **2.2.10 Surface and Subsurface Access Characteristics (SCP Section 8.3.1.14)**

#### **2.2.10.1 Study 8.3.1.14.2.1 - Exploration Program**

In December 1992, this work was transferred from the USBR to the USGS and SNL. The USGS assumed responsibilities for the Soil and Rock Investigations with specific focus on North Ramp drilling plans, logging of available new core from USW NRG-6 and UE-25 NRG #2, sample handling, and arrangement for analytical lab support for these investigations. Reconstructed cross sections along the ramp alignments were completed. Numerous meetings were held to discuss the transfer of the Soil and Rock study, specifically procedures for sample acquisition, requirements of structure logs, and timing of deliverable milestones. Much effort went to closing out USBR responsibilities to this activity. As of March 1993, this activity will be conducted by SNL. The USGS has continued to review drilling program plans for North Ramp boreholes; in particular, USGS produced interpretations of geology encountered in the UE-25 NRG #2 borehole and contributed to planning for an additional unplanned second hole in that approximate location.

**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 field exploration, mapping, drilling, and other field activity supporting North Ramp design were completed in November 1992, before the UE-25 NRG #1 borehole and its site were excavated by construction of the portal cut. A Scientific Notebook Plan for the engineering geophysical logging and check shot of UE-25 NRG #1 was written and approved. The borehole was unstable, and

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the density log was not run because of the danger of losing the nuclear source; the density data were obtained from the core. A caliper log was run and the checkshot was completed.

The position of UE-25 NRG #5 was relocated about 24.4 m (80 ft) southeast of the previous location because of a change in the alignment of the North Ramp. The boreholes UE-25 NRG #1, UE-25 NRG #2, UE-25 NRG #3, and USW NRG-6 were completed at total depths of 51.8 m (170 ft), 65.5 m (215 ft), 100.6 m (330 ft), and 335.3 m (1,100 ft), respectively. Lithologic logging and structural logging were performed on the cores from these holes. Poor core recovery and revealed geologic conditions led to an additional hole at this location. This hole, designated UE-25 NRG #2A, is to be started in April 1993.

Planning for South Ramp Geologic (SRG) holes is well under way and the first hole of this series, USW SRG-5, is expected to be started later in FY 1993.

The USGS presented an overview of drilling operations and results from UE-25 NRG #2 and a summary of possible structural geometry of the valley west of the Bow Ridge fault, with implications for what rocks might be encountered at ramp grade along the North Ramp. The USGS illustrated geometric constructions to assist the design and drilling groups in interpretation of geologic constraints impacting drilling difficulties in UE-25 NRG #2.

Relatively soft rock of the 11.3 Ma Rainier Mesa Member of the Timber Mountain Tuff will be encountered in the ESF TBM Starter Tunnel, or shortly beyond. The mechanical properties of this rock may require extra shoring in the North Ramp tunnel to ensure tunnel stability.

**Forecast:** The locations for additional leach field percolation tests will be identified. A pavement map will be prepared of the UE-25 SRG #1 drill pad [approximately 61 x 61 m (200 x 200 ft)] centered on the borehole. The location of the booster pump station test pits will be identified.

### 2.2.10.2 Study 8.3.1.14.2.2 - Laboratory Tests and Material Property Measurements

Laboratory testing of core from UE-25 NRG #1 was completed in November 1992. Laboratory testing of core from other NRG holes is continuing.

The USGS submitted the request for samples from UE-25 NRG #2 and USW NRG-6, to be used in geomechanical and thermal-mechanical tests, to the Sample Overview Committee for approval of release. USW NRG-6 samples from depths 0-100.6 m (0-330 ft) were approved and sent to the laboratory for mechanical testing.

**Forecast:** Thermal properties tests on USW NRG-6 samples and mechanical properties tests on core samples from each of the boreholes UE-25 NRG #2, USW NRG-6, UE-25 NRG #3, UE-25 NRG #2A, UE-25 NRG #5, UE-25 NRG #4, and USW SRG-5 will

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be performed. Laboratory tests will be performed on soil samples from the booster pump station test pits.

### **2.2.10.3 Study 8.3.1.14.2.3 - Field Tests and Characterization Measurements**

The report entitled "Soil and Rock Geotechnical Investigations, Field and Laboratory Studies, North Ramp Surface Facility, Exploratory Studies Facility, Yucca Mountain Project, Nevada" (USBR, 1992) was completed in December 1992. This report included pavement work and geophysical log data from UE-25 NRG #1.

**Forecast:** Samples from the depths of 100-167 m (330-550 ft) in the USW NRG-6 borehole will be transferred to the laboratory for mechanical testing under the supervision of SNL. Samples from UE-25 NRG #2, resulting from poor core recovery in the drilling, will also be considered. Analysis of available samples will continue in support of ramp design.

**Forecast:** Borehole logs will be generated for UE-25 NRG #2, USW NRG-6, UE-25 NRG #3, UE-25 NRG #2A, UE-25 NRG #5, UE-25 NRG #4, and USW SRG-5. Six in situ leach field percolation tests will be performed at the site of the proposed leach field and in situ soil tests will be performed.

### **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**

Resolved YMP technical comments for Study Plan 8.3.1.15.1.1, Revision 1, "Laboratory Thermal Properties," are being incorporated into the document. Revision 1 updates the study plan to make it consistent with the current configuration of the ESF.

**Activity 8.3.1.15.1.1.1 - Density and porosity characterization.** No progress during the reporting period; this is an unfunded activity.

**Activity 8.3.1.15.1.1.2 - Volumetric heat capacity characterization.** No progress during the reporting period; this is an unfunded activity.

**Activity 8.3.1.15.1.1.3 - Thermal conductivity characterization.** The scoping study on the effects of sample saturation on thermal conductivity was delayed in order to revise calibration procedures and due to the initial failure to successfully calibrate the C-Matic low-temperature instrument when using the moisture containment cell. The C-Matic low-temperature instrument is used to measure thermal conductivity at temperatures from 20 to 100°C; the moisture containment cell maintains the sample saturation during thermal conductivity measurements. The initial calibration failure was traced to the shrinking of the cell walls, which prevented the reference sample from setting flush on the lower plate. Increasing the inside diameter of the cell corrected the problem. The subsequent successful

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calibration of the C-Matic low-temperature system satisfied the requirement for verification of the data acquisition software.

Investigations then were conducted to improve the repeatability of the instrument when using the moisture containment cell. (Repeatability is 4 percent without the cell.) Parafilm M, a moisture-proof compound that will not absorb into the rock pores, was found to be superior to heat-sink compound as an interface medium between the sample and the moisture containment cell. Calibration verifications using five samples and three temperatures yielded differences between the highest and lowest measurements of -9.3, -6.6, and -3.3 percent at 20, 50, and 80°C, respectively. Repeating the calibration verification without removing the samples from the instrument yielded differences of 2.7, 0.9, and -0.3 percent. This suggested that the Parafilm M softened at higher temperatures to form a better interface. Calibration verifications were then run using Parafilm M as the interface medium and measuring the higher temperature first to allow the Parafilm M to soften. The differences between the highest and lowest measurement were 4.0, 5.4, and 4.9 percent at 80, 50, and 20°C. Additional runs indicate the repeatability is improved further if the moisture condensation is allowed to dry completely between runs. Calibration checks are being run to verify that a 4 percent repeatability can be maintained when using the moisture containment cell.

Revision 1 to Technical Procedure (TP)-207, "Calibration of Temperature Sensors Used for Thermal Properties Testing," was issued. This revision incorporates Interim Change Notices 01, 02, and 03 and reduces measurement uncertainties by minimizing the use of reference thermocouples. Transfer and disposable thermocouples were recalibrated in accordance with this procedure.

**Forecast:** The baseline-test-condition study to investigate the effects of sample saturation will begin within the next month. Three samples of welded devitrified tuff and three samples of nonwelded zeolitic tuff will be used for this study. The thermal conductivity of each sample will be measured at nominal temperatures of 30, 50, and 70°C at five different saturation states (fully saturated, oven-dry, air-dry, and two other intermediate states). This baseline-test-condition study is discussed in Study Plan 8.3.1.15.1.1 and will be conducted in accordance with Experiment Procedure (EP)-41, "Saturation Effects on Thermal Conductivity," and TP-202, "Measurement of Thermal Conductivity of Geologic Samples by the Guarded-Heat-Flow-Meter Method." The testing and subsequent data report for this baseline-test-condition study are scheduled to be completed in FY 1993.

The baseline-test-condition study on the effects of confining pressure and fractures will begin after test samples are machined and the EP is issued. Two samples of welded devitrified tuff will be measured at a nominal temperature of 30°C. Each sample will be then be cut in half perpendicular to the sample axis, the cut surfaces will be roughened, and the halves will be rejoined. The thermal conductivity will be remeasured at 30°C as a function of stress applied normal to the artificial fractures. Confining pressures of 0 MPa, 2.5 MPa, 5 MPa, 7.5 MPa, and 10 MPa will be used. This baseline-test-condition study is discussed in study plan for SCP Study 8.3.1.15.1.1 and will be conducted in accordance with TP-206, "Measurement of Thermal Conductivity of Geologic Samples by the Comparative Method."



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The data report for this baseline-test-condition study is scheduled to be completed in FY 1993.

### 2.2.11.2 Study 8.3.1.15.1.2 - Laboratory Thermal Expansion Testing

Technical comments for Study Plan 8.3.1.15.1.2, Revision 1, "Laboratory Thermal Expansion Testing," have been resolved and are being incorporated into the document. Revision 1 updates the study plan to make it consistent with the current ESF configuration.

Activity 8.3.1.15.1.2.1 - Thermal expansion characterization. The control program for the dilatometer was modified to allow heating rates of less than 1°C/min; slow heating rates may be needed to detect accurately the temperatures at which tridymite and cristobalite undergo  $\alpha$  to  $\beta$  polymorphic transformations. Significant changes in the instantaneous coefficient of thermal expansion (CTE) occur when these silica polymorphs undergo transformation during heating and cooling.

Calibration and calibration verification runs were completed for testing both large samples 102 mm (4 in long) and small samples 25 mm (1 in long). To facilitate the testing of small samples, a fused silica extension block is placed in the same holder and run in series with the sample. (The expansion of this block is accounted for in the calibration.) The calibrations were conducted using heating rates of 0.25°C/min and 1°C/min. These successful calibrations satisfied the requirement for verification of the data acquisition software.

A 25-mm sample and a 102-mm sample from Busted Butte Unit TSw2 were run using a 0.25°C/min heating rate and a 1°C/min cooling rate to establish the thermal expansion behavior for samples that do not contain tridymite and cristobalite. As anticipated, there were no significant changes in the instantaneous CTEs over the tested temperature range (ambient to 325°C).

A 25-mm sample from thermal/mechanical unit TSw1 from Borehole USW-G1 then was tested from ambient temperature to 325°C using a heating rate of 0.25°C/min. Two significant increases in the instantaneous CTE at ~165°C (from ~1.3 ppm/°C to ~3.3 ppm/°C) and ~250°C (from ~2.5 ppm/°C to 5.3 ppm/°C) were measured. These temperatures correspond to those at which  $\alpha$  to  $\beta$  polymorphic transformations occur for tridymite and cristobalite, respectively. These changes in the instantaneous CTE may have significant impacts on calculations of the rock mass properties. The sample was allowed to cool at a rate of less than 1°C/min while the CTE was measured. The significant change in the instantaneous CTE was measured at approximately 120°C, which is assumed to be a temperature hysteresis caused by the silica polymorphs reverting to their initial forms. The mineralogic and petrographic analysis of the sample confirmed the presence of tridymite and cristobalite. Tests to establish the appropriate heating rate are continuing using 102 mm samples and a 1°C/min heating rate.

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Twenty-three thermal expansion samples in 25.4-mm-long and 101.6-mm-long sizes were machined and inspected. These samples will be used in the baseline properties study on the effects of sample size on thermal expansion behavior.

TP-203, "Measurement of Thermal Expansion of Geologic Samples Using a Push Rod Dilatometer," has been issued for measuring the mean and instantaneous coefficients of linear thermal expansion of geologic samples in a temperature range of  $\sim 25^{\circ}\text{C}$  to  $\sim 300^{\circ}\text{C}$ . This procedure will be used to support the activities specified in Study Plan 8.3.1.15.1.2 and incorporates the use of a Saturation Test Apparatus for controlling the saturation state of samples up to  $\sim 100^{\circ}\text{C}$ .

TP-215, "Calibration of Lawson Board Systems," has been issued for the calibration of the thermocouple systems (thermocouple boards and A/D boards) to reference cold junction temperatures, and to convert thermocouple, heater, and heat flux transducer emf to a digital signal. This procedure will be used for calibrating the dilatometer and the thermal conductivity analyzer and adiabatic calorimeter.

**Forecast:** The baseline-test-condition study on the effects of sample size on thermal expansion will begin after the heating rate for samples with silica polymorphs is established and the EP is issued. The linear thermal expansion of five samples of each of four different lithologies for two different sample sizes will be measured during this study. The samples will be heated at a controlled rate of  $\leq 1^{\circ}\text{C}/\text{min}$ , and the atmosphere surrounding the sample during testing will be controlled to minimize sample dehydration at temperatures below the nominal boiling temperature of  $100^{\circ}\text{C}$ . When this temperature is reached, temperature will be held constant and the sample allowed to dehydrate until the length stabilizes. Heating will continue until the maximum temperature planned for the experiment is reached, and then the sample will be cooled at a controlled rate of  $\leq 1^{\circ}\text{C}/\text{min}$ . The testing and subsequent data report for this baseline-test-condition study are scheduled to be completed in FY 1993.

The baseline-test-condition study on the effects of sample saturation on thermal expansion will begin after completion of the baseline-test-condition study on the sample size effects. Three initial saturation states will be examined (fully saturated, air-dry, and oven-dry). For these tests, the preconditioned samples will be heated to  $100^{\circ}\text{C}$ , allowed to dehydrate, heated to  $125^{\circ}\text{C}$ , and then allowed to cool. The testing for this baseline-test-condition study is scheduled to be completed in FY 1993.

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

Activity 8.3.1.15.1.3.1 - Compressive mechanical properties of intact rock at baseline experiment conditions. Samples are not yet available for this testing effort; however, the prototype experiments have been completed and the TPs necessary for future testing at baseline conditions have been drafted and are in review in anticipation of sample availability in the next one to three years.

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Testing of several rock types has been conducted at eight government and private rock mechanics laboratories in support of the American Society for Testing and Materials (ASTM)/Institute for Standards Research (ISR) Steering Committee for the Interlaboratory Testing Program for Rock Properties (ITPRP). An SNL staff member is serving on the committee and has provided test data from contractors for the Phase I testing. The results have been reported in an ASTM/ISR report and summarized in a document submitted to the ASTM Geotechnical Testing Journal for publication in mid-1993. The article has not yet been published, but will be titled "Interlaboratory Testing Program for Rock Properties: Round 1 Longitudinal and Transverse Pulse Velocities, Unconfined Compressive Strength, Uniaxial Elastic Modulus, and Splitting Tensile Strength" (Pinius, et al.). The report suggests measures of precision for published rock-property standard ASTM test methods. SNL staff wrote the protocols 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 mid-1993.

Activity 8.3.1.15.1.3.2 - Effects of variable environmental conditions on mechanical properties. New England Research, Inc. (NER) is conducting a study involving experiments on samples of welded Topopah Spring Member tuff at low strain-rate and creep (constant stress) conditions to investigate the time-dependent behavior of the intact rock. Prior to all testing, the samples are dried and weighed for dry bulk density and then saturated and weighed for saturated bulk density. These values are used to calculate sample porosity and prepare the sample for testing in the saturated state. A computerized tomography scan is taken of one axial slice of each sample, and the ultrasonic wave velocities (p- and s-wave) are measured on each sample. These pre-test characterizations are very important aids in the interpretation of the mechanical property data.

The data have been collected and reduced for the completed series of six experiments on saturated samples tested at room temperature and pressure and a nominal axial strain rate of  $10^{-9} \text{ s}^{-1}$ . The data have been submitted to the local records center and are presently being analyzed. Data and analysis reports should be published later in 1993.

The third in a series of creep experiments is being performed. For each experiment, a sample is saturated and tested at a pore pressure of 4.5 MPa, a confining pressure of 5 MPa, and a maximum constant differential (or creep) stress of 80 MPa. Each experiment has two phases: the first phase is performed at room temperature for a week, and the second phase is performed at 250°C for two months. With the appropriate calibrations and aluminum system calibration checks, the tests will each take approximately four months to complete. The series should be completed in 1994.

A paper entitled "The Influence of Strain Rate and Sample Inhomogeneity on the Moduli and Strength of Topopah Spring Member Tuff" (Martin et al.), has been approved by YMPO for presentation and publication at the 34th U.S. Symposium on Rock Mechanics. The conference will be held on June 27-30, 1993, in Madison, Wisconsin.

**Forecast:** The forecast in PR 7 was based on anticipated funding levels that exceeded actual allocations. A revised forecast for the next six months that assumes the same level of

funding allocated in FY 1993 would allow the revision of the study plan to reflect an ESF with a North Ramp, long north-south drifts at the proposed repository level and in the Calico Hills tuff, and a South Ramp. In addition, some minor support will be provided to the ASTM/ISR Steering Committee for the ITPRP. Several experiments may be performed by NER, and SNL staff will continue to serve on the steering committee. Also, the high-temperature creep experiments at NER will continue, with at least two more experiments initiated in this time period. The results from the six low strain-rate experiments completed in 1992 will be analyzed and published. Other reports and conference papers will be initiated as data is completed and analyzed.

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

Study Plan 8.3.1.15.1.4 was submitted to YMPO on October 24, 1991. The plan has been reviewed by YMPO, is being revised in response to comments, and will be ready for comment verification by April 1993.

Several SNL staff members comprise the Fracture Properties Working Group, which met five times during the last six months. Discussions centered on revising the study plan.

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) has been 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 ASTM Committee D-18 on Soil and Rock Properties.

Detailed characterization and analysis of fracture surfaces will aid in the interpretation of mechanical properties (e.g., stiffness and shear strength) and transport properties. To accomplish this, a laser profilometer has been designed, built, and tested. During this six-month period, the existing profilometer system (profiler and software) has been used to characterize the topography of all samples used in the scoping experiments described in Activity 8.3.1.15.1.4.2. The ultimate goal of this program is to use the surface characterizations as a predictor of the mechanical properties.

The data from topographies of 17 natural fractures from various rock types (including tuff from Yucca Mountain) are being analyzed to quantify the roughness of each surface, its scaling properties, and the degree of mismatch between the two opposing surfaces. A simple mathematical model of rough fractures (together with an application computer code) has been

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developed based on these data for simulation of the frictional shear strength of rock fractures. The use of this code has allowed some physical insight into empirically derived relationships commonly used in engineering geology for design of structures in rock. The data and analyses are being included in an article for a technical journal.

Activity 8.3.1.15.1.4.2 - Effects of variable environmental conditions on mechanical properties of fractures. The time-dependent mechanical properties of fractures are being investigated to address long-term stability issues within the potential repository. A triaxial creep (constant shear stress) experiment has been conducted on a sample (a right-circular cylinder with a diameter of ~54 mm and a length-to-diameter ratio of 3:1) with an artificially produced fracture oriented approximately 35° to the sample axis. The confining pressure and the initial axial stress difference were both set at 10 MPa, which gives a ratio of shear-to-normal stress on the surface of ~0.36. The value for fully established sliding would be in the range of 0.6 to 0.7. The sample is at room temperature and vented to the atmosphere. Several levels of increased axial stress were applied to the sample and held for a minimum of several hours. Initial analysis of the data have shown the maximum slip rate at a given stress level ranged from 1 to 15 mm/yr.

In additional testing of time-dependent fracture properties, experiments have been completed on artificial (manmade) fractures in samples of welded Topopah Spring Member tuff to study the effect of water in rate-stepping experiments. Fracture samples were tested at room dry and saturated conditions, with rates varying from  $10^{-1}$  to  $10^2$   $\mu\text{m/s}$ . The results are being analyzed for inclusion in a report.

A few experiments on replicas of natural fractures have been performed to evaluate their use in a statistical approach to the investigation of the mechanical properties of fractures. The technique of producing a mirror image of a natural fracture surface with a rubber mold and a replicate of the surface with gypsum cement has been refined and is being evaluated. Both the surfaces of the rock fracture and the gypsum replicate are profiled and profiles compared.

**Forecast:** The forecast in PR 7 was based on anticipated funding levels that exceeded actual allocations. A revised forecast for the next six months that assumes the same level of funding as allocated in FY 1993 would allow the completion of the study plan revision. The simulation of joint shear properties will continue and the journal article will be completed. Also, the rate-stepping report will be completed, the time-dependent testing will continue, and a study will be initiated of the effect of varying roughness and material properties using replicates.

### 2.2.11.5 Study 8.3.1.15.1.5 - Excavation Investigations

Study Plan 8.3.1.15.1.5, "Excavation Investigations," was revised to reflect the current ESF configuration and proposed mining method, the current SNL QA program, and the current schedule. The study plan was submitted to YMPO for review in January 1993.

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Activities 8.3.1.15.1.5.1 through 8.3.1.15.1.5.3. No progress during the reporting period; these are out-year activities.

**Forecast:** Staff will work with YMPO reviewers to finalize the study plan.

### **2.2.11.6 Study 8.3.1.15.1.6 - In Situ Thermomechanical Properties**

A report "Test Instrumentation Requirements for the ESF In Situ Thermomechanical Experiments" (Pott) was submitted for internal SNL technical review, and the extended abstract "Instrumentation Requirements for the ESF Thermomechanical Experiments" (Pott and Brechtel, 1993) is in the Proceedings of the 1993 IHLRWM Conference. Preparation of a draft of Study Plan 8.3.1.15.1.6 began.

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

**Forecast:** SNL staff will work with LLNL staff, under Los Alamos coordination, to consolidate SNL's ESF thermomechanical testing with LLNL's hydrothermal testing. Staff will continue drafting the study plan for SCP Study 8.3.1.15.1.6 and will produce a final draft of the test instrumentation report in response to reviewers.

### **2.2.11.7 Study 8.3.1.15.1.7 - In Situ Mechanical Properties**

Preparation of a draft of Study Plan 8.3.1.15.1.7 began.

Activities 8.3.1.15.1.7.1 and 8.3.1.15.1.7.2. No progress during the reporting period; these are out-year activities.

**Forecast:** Staff will continue drafting the study plan for SCP Study 8.3.1.15.1.7.

### **2.2.11.8 Study 8.3.1.15.1.8 - In Situ Design Verification**

At a comment resolution meeting held on January 12, 1993, the final comments to Study Plan 8.3.1.15.1.8 were resolved. All 138 comments have now been resolved and a revision of the study plan incorporating comment resolutions was submitted to YMPO for approval and subsequently submitted to the NRC February 8, 1993. In its transmittal letter, OCRWM explained how the study plan addressed SCA Comments 4 and 56 open items.

Construction monitoring plans consistent with ESF test plans were developed for the ESF North Ramp Starter Tunnel. The monitoring plans include seismic monitoring for blasting, rock quality determination, ground support system performance evaluations, and excavation closure monitoring for stability assessments. An EP detailing the construction monitoring activities was developed. This EP, along with supporting material (including

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tracer fluids and materials data sheets) was supplied to the Test Coordination Office as SNL's input to the Test Planning Package and the Job Package. A Work Agreement was drafted, and a new QA Grading Report was developed.

Activities 8.3.1.15.1.8.1 through 8.3.1.15.1.8.4. No progress during the reporting period; these are out-year activities.

**Forecast:** Staff will continue to plan construction monitoring activities and procure and design instrumentation and a data acquisition system to field the tests. Staff will work with the Test Coordination Office to produce final drafts of the Test Planning Package and the Job Package. Tests will be fielded as the North Ramp Starter Tunnel construction proceeds.

### 2.2.11.9 Study 8.3.1.15.2.1 - Characterization of the Site Ambient Stress Conditions

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

**Forecast:** No activity is planned for FY 1993.

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

**Forecast:** No activity is planned for FY 1993.

### 2.2.11.10 Study 8.3.1.15.2.2 - Characterization of the site ambient thermal conditions.

The objective of this activity was changed to "evaluate available thermal data;" thermal data will be collected under Study 8.3.1.8.5.2 (Characterization of Igneous Intrusive Features).

### 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 is an unfunded study.

**Forecast:** No activity is planned for FY 1993.

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### **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 is an out-year study.

**Forecast:** No activity is planned for FY 1993.

### **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 is an out-year study.

**Forecast:** No activity is planned for FY 1993.

### **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 are unfunded activities.

**Forecast:** No activity is planned for the rest of FY 1993.

#### **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 are unfunded activities.

**Forecast:** No activity is planned for the rest of FY 1993.

#### **2.2.13.3 Study 8.3.1.17.3.1 - Relevant Earthquake Sources**

The State of Nevada submitted 32 comments on the study plan on January 7, 1993. The USGS assessed the impact of the State's comments in a letter to YMPO dated March 1, 1993. A response from YMPO to the State is pending.

Activity 8.3.1.17.3.1.1 and Activity 8.3.1.17.3.1.2. Discussions of alternative ways to analyze deterministic seismic hazard methodology were initiated. Participants attended a field trip to become familiarized with the Yucca Mountain site area.



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**Forecast:** Work planned for the remainder of FY 1993 will focus on identification and evaluation of potential earthquake source areas and potential earthquake magnitudes. Alternative ways to analyze deterministic seismic hazard methodology will be evaluated. Revision of the study plan may be necessary to reflect new methodologies available for deterministic seismic hazard evaluation. A scoping study will be conducted to test appropriate methodologies for estimation of earthquake magnitudes on Southern Great Basin faults. Participants will contribute to the YMPO topical report on a proposed seismic hazard approach for the NRC.

### 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 are out-year activities.

**Forecast:** No activity is planned for FY 1993.

### 2.2.13.5 Study 8.3.1.17.3.3 - Ground Motion From Regional Earthquakes and Underground Nuclear Explosions

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

Activity 8.3.1.17.3.3.1 - Select or develop empirical models for earthquake ground motions. No progress during the reporting period; this is an unfunded activity.

**Forecast:** A team of seismic hazard experts will convene a conference to either develop new models or modify existing empirical, numerical, and/or theoretical ground-motion models for use during site characterization. The information compiled by the team will be used to help YMP develop a topical report on appropriate ground motion models to be used for seismic hazards assessment of Yucca Mountain. A study plan will then be developed in accordance with methodologies stated in the topical report and based on the comment response record on the topical.

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 is an unfunded activity.

**Forecast:** The forecast in PR 7 was based on anticipated funding levels that were not allocated. There will be no activity in support of this study for the remainder of the FY.

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### 2.2.13.6 Study 8.3.1.17.3.4 - Effects of Local Site Geology on Surface and Subsurface Motions

The State of Nevada submitted 26 comments on the study plan on January 6, 1993. The USGS assessed the impact of the State's comments in a letter to YMPO dated March 1, 1993. A response from YMPO to the State is pending.

Activity 8.3.1.17.3.4.1 - Determine site effects from ground-motion recordings. The USGS assembled recordings made at portable stations near Yucca Mountain for over 100 earthquakes and requested Underground Nuclear Explosion seismograms recorded at Yucca Mountain from SNL. The USGS gathered information on the structure beneath Yucca Mountain, especially Midway Valley where surface facilities are proposed. An extensive literature review of strong motion studies was conducted.

Twelve sites were selected at Yucca Mountain for portable seismic stations as part of a seismic field experiment. Portable stations were removed from the Little Skull Mountain region and redeployed. A cluster test was conducted and the results examined in a qualitative manner for an indication of site effects at Yucca Mountain.

**Forecast:** Work will continue gathering all available information on geological and geophysical structure in the Yucca Mountain area as well as gathering all available seismograms. An initial ground motion model will be developed to predict ground motions at the site and a seismic field experiment will be conducted to record seismic events and test the model predictions. The data will be used to develop a one-dimensional velocity model for the site area. A preliminary report will present the results of these activities at the end of the FY.

### 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 is an out-year activity.

**Forecast:** No activity is planned for FY 1993.

### 2.2.13.8 Study 8.3.1.17.3.6 - Probabilistic Seismic Hazards Analyses

Activity 8.3.1.17.3.6.1. through 8.3.1.17.3.6.2. No progress during the reporting period; these are out-year activities.

**Forecast:** No activity is planned for FY 1993.

### 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. A computer code for two-dimensional dynamic stability calculations was developed and testing of the code was begun. Preliminary two-dimensional physical models for stability sliding were constructed. A field survey was begun of precariously balanced rocks in seismic and aseismic areas of western Nevada and northern and southern Sierra Nevada. Areas under study include Solitario Canyon, Yucca Mountain, Yerrington, and Caliente in Nevada, and in Baja, California just south of the U.S. border. Intensity maps for old, large Nevada and California earthquakes were collected. Earthquake records were compiled and correlations of precarious rocks with maps of historical seismicity in the west were made. Extensive comparisons were done between isoseismal maps and historic earthquakes and locations of precarious rocks. A study was conducted of Japanese papers and methodology on overturning of monuments by earthquakes. Horizontal forces necessary to topple a particular shape and weight object were measured in the laboratory. A talk on the preliminary findings on precarious rocks was prepared and presented for the fall 1992 AGU meeting in San Francisco (Brune).

Activity 8.3.1.17.4.1.2 - Monitor current seismicity. The University of Nevada, Reno Seismological Laboratory (UNRSL) recorded all Southern Great Basin Seismic Network (SGBSN) stations on their VAX CUSP data logging system and recorded backup data on develocorder film for the reporting period. The first stage was completed of an upgraded VAX cluster for running CUSP and microwave telemetry was upgraded for the node site at Slide Mountain. Software programs TIMIT and HYPOINVERSE were reviewed for use in the new VAX recording and analysis system. Technical procedures were prepared for develocorder reading and seismic instrument calibration (for one station; others pending). Work on retrieving data from portable REFTEK instruments and portable EDA instruments was begun. Four temporary stations were deployed near Beatty to reverse a refraction line under Yucca Mountain to constrain crustal velocities in the vicinity of Yucca Mountain.

The UNRSL took responsibility for the SGBSN on October 1, 1992. The USGS Branch of Geologic Risk Assessment relinquished responsibility on October 15. Bulletins of seismic events in the Southern Great Basin were completed for the months of August, September, and the first 15 days of October 1992, for an overlap study with the USGS. A draft report was completed and submitted to the USGS and YMPO on a comparison of UNR and USGS seismic events bulletins for the month of September 1992. The earthquake catalog for calendar year 1992 has been completed for the period October through January 1993.

The Little Skull Mountain earthquake aftershock studies continued. Work included event picking and data analysis, continued instrument maintenance and data collection (31 days of data), and determination of preliminary focal mechanisms for several hundred events. Instrument responses were assembled for the portable instruments which recorded the Little Skull Mountain aftershock sequence. The assembly of first-motion pick data and routine focal mechanism determinations for Little Skull Mountain aftershocks was started. A report entitled "Preliminary Report, the Little Skull Mountain Earthquake, June 29, 1992," (Anderson et al.) was completed and submitted for publication in the Journal of Geophysical

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Research. Analysis was completed on a cluster test to close out the Little Skull Mountain data recording experiment.

Activity 8.3.1.17.4.1.3 - Evaluate potential for induced seismicity at the site. No progress during the reporting period: this is an out-year activity.

**Forecast:** Work will continue compiling a record of historical seismic events in the southern Great Basin, performing literature surveys, updating a catalog of seismic events, refining magnitude estimates and epicentral intensities and other source parameters. Testing and revision of two-dimensional physical models for stability sliding will take place as well as field work to identify and evaluate newly found precariously balanced rock localities.

Monitoring of the SGBSN will continue through the remainder of FY 1993. Seismic equipment will continue to be upgraded and tested. Additional sites for seismic stations will be selected and prepared for installation. A final report on the analysis of the Little Skull Mountain earthquake will be submitted at the end of the FY. The earthquake catalog for the 1992 calendar year will also be produced.

### **2.2.13.10 Study 8.3.1.17.4.2 - Location and Recency of Faulting Near the Prospective Surface Facilities**

Activity 8.3.1.17.4.2.1 - Identify appropriate trench locations in Midway Valley. No progress was made during the reporting period; personnel were diverted to complete excavation and logging of trenches in the vicinity of the proposed ESF on the east side of Exile Hill.

Activity 8.3.1.17.4.2.2 - Conduct exploratory trenching in Midway Valley. Detailed mapping of trenches and soil test pits located in the vicinity of the proposed ESF east of Exile Hill in Midway Valley continued. Lithologic contacts, soil boundaries, sedimentary structures, and potential tectonic structures were mapped. Excavation of a new trench (MWV-T7) began late in October. The trench was excavated north of MWV-T5 to determine the origin of a bedrock step observed in the long trench (MWV-T5) on the south end of the ESF North Ramp pad. Mapping was completed in trenches MWV-T5a, MWV-T6, and MWV-T7, and in soil pits NRSF-TP7, NRSF-TP8, and NRSF-TP32. Descriptions of soils and deposits were completed in the westernmost 260 m of MWV-T5a, the other above mentioned excavations, and the following soil pits located in the area of the ESF: MWV-P1, MWV-P29, MWV-P30, MWV-P31, MWV-P32, NRSF-TP16, NRSF-TP25, NRSF-TP27A, NRSF-TP28, NRSF-TP29, NRSF-TP30, and NRSF-TP31. Mapping of the north wall and descriptions of geologic units in MWV-T4 was completed. Data analysis and initial report preparation for MWV-T4 was started.

The field mapping and descriptions of the existing trenches near the proposed ESF was completed. Fieldwork included description of soil profiles and review of the trench map for the eastern 70 m of MWV-T5. Data analysis and initial report preparation was started for the

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trenching investigations near the proposed ESF. In addition, selected soil pits were inspected in the field to determine if the deposits are suitable for thermoluminescence dating.

**Forecast:** The map and report on surficial deposits in Midway Valley will be completed during the second half of FY 1993. A report with trench log describing the results of trench mapping activities for trench 17 will be completed. The results of trench logging in the vicinity of the ESF will also be completed along with a preliminary summary report on Midway Valley. This study will be completed in FY 1993.

### **2.2.13.11 Study 8.3.1.17.4.3 Quaternary Faulting Within 100 km of Yucca Mountain, Including the Walker Lane**

Study Plan 8.3.1.17.4.3 was approved by OCRWM on January 21, 1993 and sent to the NRC on February 9, 1993. In the transmittal letter, OCRWM explained how the study plan addressed SCA Comments 59, 60, and 69 open items which were relevant to the study plan.

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 is an out-year activity.

Activity 8.3.1.17.4.3.2 - Evaluate Quaternary faults within 100 km of Yucca Mountain. Work continued on a map of Quaternary faults within 100 km of Yucca Mountain. To date, the locations and fault data for over 100 faults have been compiled and the map is near completion. Existing low-sun angle aerial photographs of the Pahrump/Stateline and Ash Meadows fault systems were obtained and scarps and lineaments in the Amargosa Desert area were examined. Field verification of the Beatty scarp was conducted as part of investigations of the Bare Mountain fault and a report on the origin of the scarp was started. Field study of the Death Valley - Furnace Creek fault zone was also initiated.

An item of work under this activity was removed and assigned its own activity (Activity 6 of Study Plan 8.3.1.17.4.3) in Revision 10 of the SCPB.

**Forecast:** A preliminary map of known and suspected Quaternary faults within 100 km of Yucca Mountain and a report on the origin of the Beatty scarp will be completed this FY. Other major fault systems southwest of Yucca Mountain will also be studied. A report identifying the need for additional study and sites for detailed study will be issued.

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 is an out-year activity.

Activity 8.3.1.17.4.3.4 - Evaluate the Bare Mountain Fault Zone. A verification of mapped faults and lineaments and their relationship to surficial deposits was conducted. Sites for the excavation of nine soil pits were identified as well as two additional trench sites across a suspected fault scarp associated with the Bare Mountain fault.

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**Forecast:** Detailed study will continue along the Bare Mountain fault. Based on the results of geologic mapping, soil profile descriptions, and trenching, a preliminary report on the late Quaternary history of the Bare Mountain fault will be prepared.

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 is 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. Los Alamos supports the USGS study; however, there was no progress during the reporting period because all staff effort was directed toward completing the Erosion Topical Report (DOE, 1993e).

A paper entitled "Elemental Relationships in Rock Varnish Stratigraphic Layers, Cima Volcanic Field, California: Implications for Varnish Development and the Interpretation of Varnish Chemistry" (Reneau et al., 1992) was published. Using scanning electron microscopy, the authors determined the elemental concentrations in rock varnish from the Cima volcanic field. This micrometer-scale analyses allowed the recognition of elemental associations in the varnish that defined the primary Mn, Fe, and silicate phases that constitute the bulk of the individual varnish layers. The concentration of many minor elements in varnish reflected the stratigraphic variations in major element composition.

**Forecast:** Los Alamos will provide age control for surface events by dating Quaternary alluvial surfaces using rock-varnish dating techniques and by evaluating other applicable surface-dating techniques. Los Alamos will date alluvial surfaces in the Yucca Mountain region to provide data on recurrence intervals of geomorphic events.

### 2.2.13.12 Study 8.3.1.17.4.4 - Quaternary Faulting Proximal to the Site Within Northeast-Trending Fault Zones

Study Plan 8.3.1.17.4.4 was revised in response to additional comments from YMPO and was approved March 18, 1993.

Activity 8.3.1.17.4.4.1 - Evaluate the Rock Valley fault system. Field work was conducted along the west end of the Rock Valley fault zone in the vicinity of Little Skull Mountain and along the projected trace of the Mine Mountain fault zone into Jackass Flats. Satellite images, air-photos, and base maps necessary for the detailed mapping and analysis of the Rock Valley fault zone were located and acquired. Low-sun angle photography and thermal infra-red aerial photography were obtained. Photo analysis of the Rock Valley fault zone was initiated. A combined field work/field trip was conducted in the vicinity of Yucca Mountain and Little Skull Mountain. Volcanic units and the criteria required to discriminate and identify those units; contact relations and ground-water effects related to contacts and faults as well as Quaternary deformation in and bordering Crater Flat were examined and discussed.

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An interim report, entitled "A Reconnaissance Study of Strike Slip Faulting Near Yucca Mountain, Nevada," (O'Leary) underwent USGS review and was submitted to YMPO as an administrative report.

Activity 8.3.1.17.4.4.2 - Evaluate the Mine Mountain fault system. No progress during the reporting period; this is an out-year activity.

Activity 8.3.1.17.4.4.3 - Evaluate the Stagecoach Road fault zone. The Stagecoach Road fault evaluation activity has been deleted from this study plan and its scope of work transferred to Study Plan 8.3.1.17.4.6 (Quaternary faulting in the site area) because geologic mapping has demonstrated that the Stagecoach Road fault is an extension of the Paintbrush Canyon fault. This change is recorded in Revision 10 of the SCPB.

Activity 8.3.1.17.4.4.4 - Evaluate the Cane Spring fault system. No progress during the reporting period; this is an out-year activity.

**Forecast:** Studies in FY 1993 will continue to focus on the Rock Valley fault zone. Field work will be completed, trench sites will be selected and a report submitted on fault-slip analysis of the Rock Valley fault system.

### **2.2.13.13 Study 8.3.1.17.4.5 - Detachment Faults at or Proximal to Yucca Mountain**

The study plan was approved by YMPO on July 20, 1992 and sent to NRC on August 12, 1992. In its transmittal letter, OCRWM explained how the study plan addressed SCA Comment 68 open item, which was relevant to the study plan. The NRC accepted the study plan in a Phase I review letter dated February 1, 1993.

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. Field work was conducted to examine low angle fault structures in the Paleozoic rocks in the core of the Calico Hills dome. Paleozoic stratigraphy in the upper plate of a possible extensional structure was established. Field trips to the Mine Mountain area and to the Calico Hills were attended to compare similar stratigraphic units and extensional structures. Portions of the Miocene-Paleozoic contact in the Calico Hills were examined during the course of field work and during field trips. The contact was later examined photogrammetrically to identify areas for further field work.

A PG-2 photogrammetric plotter was used to compile field work from aerial photographs to the 1:12,000 scale base map. The plotter was also used to conduct photogeologic interpretation. Mapping in the interior of the Calico Hills was focused on potential detachment faults. Areas for further field work were identified and plans were made to conduct additional evaluation of extensional features in the Calico Hills.

Activity 8.3.1.17.4.5.2 - Evaluate postulated detachment faults in the Beatty-Bare Mountain area. A field trip was conducted through volcanic rocks exposed in Crater Flat

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basin and adjacent structural domains, for members of both the rock characteristics and tectonics programs of the USGS Geologic Studies Program for Yucca Mountain. The ongoing mapping in the Crater Flat vicinity supports both programs. Chemical analyses (by the energy-dispersive x-ray fluorescence technique) of 22 Crater Flat volcanic rock samples were conducted. Initial results indicate that some rock units that are frequently difficult to distinguish with certainty in the field are notably different in trace-element abundances, including elements that are virtually immobile during weak hydrothermal alteration. Hence, rock chemical analysis is a promising technique for checking field correlations, especially where hydrothermal alteration is the cause of correlation uncertainties.

A new compilation of the Beatty 30 by 60 minute quadrangle, Nevada, was begun. New unpublished mapping in the east of Beatty Mountain 7.5 minute quadrangle was used to upgrade the compilation made by Frizzell and Shulters (1991).

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 is an out-year activity.

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 is an out-year activity.

Activity 8.3.1.17.4.5.5 - Evaluate the age of detachment faults using radiometric ages. No progress during the reporting period; this is an out-year activity.

**Forecast:** Work will continue on the structure and stratigraphy of the Calico Hills and a geologic map and report on the area will be completed along with an analysis of the Miocene-Paleozoic contact. Geologic mapping at the north and south ends of Bare Mountain where detachment faults are postulated will continue. Sampling of lower plate rocks at Bare Mountain will take place and petrographic studies will be conducted.

### **2.2.13.14 Study 8.3.1.17.4.6 - Quaternary Faulting Within the Site Area**

The State of Nevada submitted 14 comments on the study plan on January 4, 1993. YMPO responded to the State's comments on March 8, 1993.

Activity 8.3.1.17.4.6.1 - Evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain. Field mapping of Quaternary faults was completed during the reporting period. Locations of faults and fractures were mapped on aerial photos and offsets, orientations, and fault characteristics were measured and recorded. Field work was completed on the Paintbrush Canyon fault at Busted Butte and along the Stagecoach Road segment, along the Bow Ridge fault and Ghost Dance fault, and along the Solitario Canyon and Windy Wash faults. Fault data were compiled at 1:12,000 scale. Work was initiated on a 1:24,000 map compilation of Quaternary and bedrock faults along with an accompanying report.



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Activity 8.3.1.17.4.6.2 - Evaluate age and recurrence of movement on suspected and known Quaternary faults. Field logs showing stratigraphic units and fault structures were completed for both north and south faces of Trench 8 on the Solitario Canyon fault. A report with trench logs was completed.

Exposure #4 on the west side of Busted Butte was cleaned of colluvial cover and stratigraphic and structural contacts were identified and flagged. Stereo photographs were taken in preparation for mapping. A preliminary interpretation of faulting events was initiated. Two buried scarps on the upper part of exposure #4 were flagged and photographed in detail and a unit containing basaltic ash was identified and sampled. Thermoluminescence (TL) dating samples were collected from exposure #4 to determine the age of faulted soil horizons. In addition to exposure #4, exposures #1 and #2, also on the west side of Busted Butte, were cleaned and flagged.

Preparation for photogrammetric mapping was completed at a number of trenches in Crater Flat; CF-1, TR-8, SCR-T1, and SCR-T3. This mapping included cleaning exposures, planning photographic targets, photographing targeted trench walls, and surveying the targets. Samples were collected for TL dating and uranium-series dating in trench CF1.

Preliminary photo-interpretation and ground traverses near southern Windy Wash fault were begun in order to look for suitable sites for trenches. Reconnaissance mapping was conducted along northern Windy Wash fault to look for suitable study sites. Several sites were examined near trench 10A and 10B for the possible location of a new trench on the Solitario Canyon fault. In addition, field reconnaissance of several potential sites for new trenches at the southern end of Solitario Canyon fault was conducted.

Stratigraphic units and structures on the outer wall, north side, of Trench 14D on the Bow Ridge fault were cleaned and mapped. A text was prepared summarizing results from logging of Trenches 14 and 14D. A field review was conducted of the completed logs in Trench 14D (inner wall, north branch and outer wall, southwest branch). Arrangements were made to enter trench logs into the GIS data base. An abstract was prepared, revised, and submitted to the Geologic Society of America on the completed mapping of Trench 14D. Samples were collected for TL dating and uranium-series dating in Trench 14D.

A preliminary field review was conducted of logs for north and south walls of Trench 8 and Trench 8A on the Solitario Canyon fault. The south wall of trench SCF-T1 on the Solitario Canyon fault was cleaned and mapped. Samples were collected for TL dating and uranium-series dating in Trench T8.

As part of the concerted effort to develop credible methods for dating fault movements at Yucca Mountain, TL dating capabilities continue to be developed for use on soil samples. During surface rupture, soils on the down-thrown side of the faults are covered rapidly by a colluvial wedge of coarse material. When the soils are covered, and thus isolated from sunlight, they begin to acquire luminescence properties in proportion to the local radiation environment and their age of burial. Samples of buried vesicular A horizons have been collected from trenches in Midway Valley, Stagecoach Road, SCR-T1, and Crater Flat in

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order to constrain the recent history of surface rupture associated with the Bow Ridge, Stagecoach Road, Solitario Canyon, and Windy Wash faults. Suitability of these materials for TL dating is being investigated. Normalization procedures and calculated normalization factors for TL are being prototyped using the Midway Valley and Stagecoach Road soil characteristics.

Dating of fault-related carbonates using U-Th disequilibrium techniques focused on age relationships exposed in natural outcrops and trench walls associated with the Paintbrush Canyon, Bow Ridge, Stagecoach Road, and Solitario Canyon faults. Preliminary U-series results were obtained from two pedogenic carbonate horizons sampled on the Busted Butte sand ramps. Dates on these undisplaced and displaced soils provide an age bracket for the last surface rupture of the Paintbrush Canyon fault between 70,000 and 140,000 years. Additional older buried soils at Busted Butte are being analyzed to further constrain rates of displacement. Geochronological samples that have also been collected and prepared for analysis include several rhisolith-bearing horizons from the down thrown block in Trench SCR-T1, several distinct buried calcrete horizons in Trench T14c and T14d, and rhisoliths, vein and massive potassium carbonate from SCF-T8 in Crater Flat. Samples from the latter trench are related to the seismic event which produced a large surface-rupturing fissure along the Solitario Canyon fault which is filled, in part, with basaltic tephra. Dates from these samples may also provide control on the age of the prominent basaltic ash eruption (presumably from Lathrop Wells Cone).

Scoping activities for studies of U and Th isotopes analyzed by the thermal ionization mass spectrometry were initiated including establishing laboratory, filament loading and analytical protocols. Mass spectrometric analysis for U-series disequilibrium systematics produces more precise data on substantially smaller samples than those currently required using analysis by alpha spectrometry. These advantages are critical for determining ages of small samples of fault-associated secondary carbonate vein and fracture fillings obtained from drill core samples. Investigation of acquiring U and Th tracer solutions critical to the technique was completed and the appropriate radioactive isotopes were ordered from Oak Ridge National Lab for use as spikes.

Due to the importance of obtaining credible age control on fault motion, a plan for accelerated dating of fault movement at Yucca Mountain with particular reference to the Ghost Dance fault has been developed and submitted for funding consideration. The focus centers on U-series dating of calcite fracture fillings within the fault zone following detailed petrographic analysis and evaluation of samples. The plan also recommends the utilization of fission-track, Ar-Ar, TL and  $^{14}\text{C}$  dating where suitable materials exist.

**Forecast:** The Quaternary fault map for Yucca Mountain will soon be completed. Work will continue on trench mapping at Trenches 14C and 14D on the Bow Ridge fault, Trenches SCR-T1 and SCR-T2 on the Stagecoach Road fault, Trench CF-1 on the Fatigue Wash fault, and the natural exposures at Busted Butte on the Paintbrush Canyon fault. Excavation of new trenches will be coordinated on the Solitario Canyon fault, Bow Ridge fault, and the northern Paintbrush Canyon fault (Alice Ridge). A geophysical survey on the

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southern Windy Wash fault is scheduled to commence and an analysis of scarp degradation will also begin in FY 1993.

### **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 is an out-year study.

**Forecast:** No activity is planned for FY 1993.

### **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 are out-year activities.

**Forecast:** No activity is planned for FY 1993

### **2.2.13.17 Study 8.3.1.17.4.9 - Tectonic Geomorphology of the Yucca Mountain Region**

Activity 8.3.1.17.4.9.1 through 8.3.1.17.4.9.3. No progress during the reporting period; these are out-year activities.

**Forecast:** No activity is planned for FY 1993

### **2.2.13.18 Study 8.3.1.17.4.10 - Geodetic Leveling**

The State of Nevada submitted 16 comments on the study plan on January 29, 1993. The USGS has assessed the impact of the State's comments and a YMPO response is pending.

Activity 8.3.1.17.4.10.1 - Relevel base-station network, Yucca Mountain and vicinity. The bench marks that served as base-stations along previously surveyed level lines were reoccupied and resurveyed. The quadrilateral resurveying was completed by the end of December 1992. Two hundred kilometers of level line have been resurveyed including the main level line, five spurs, and a checkline, constituting 100 percent of the total level-line survey.

Activity 8.3.1.17.4.10.2 - Survey selected base stations, Yucca Mountain and vicinity, using global positioning satellite. Work on the field and laboratory technical procedures for the Global Positioning Satellite base-station survey was started.

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Activity 8.3.1.17.4.10.3 - Analyze existing releveled data, Yucca Mountain and vicinity. No progress during the reporting period; this is an out-year activity.

**Forecast:** A report assessing surface elevation changes in the vicinity of Little Skull Mountain will be prepared along with a progress report on geodetic leveling at Yucca Mountain. A Global Positioning Satellite survey will also be conducted to determine any horizontal changes in the last ten years.

### **2.2.13.19 Study 8.3.1.17.4.11 - Characterization of Regional Lateral Crustal Movement**

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

**Forecast:** A study plan is scheduled to be written in FY 1994.

### **2.2.13.20 Study 8.3.1.17.4.12 - Tectonic Models and Synthesis**

Study Plan 8.3.1.17.4.12 was completed and submitted for internal USGS review.

Activity 8.3.1.17.4.12.1 - Evaluate tectonic processes and tectonic stability at the site. Creation of a bibliography of the documents and data sources relevant to synthesis and evaluation of tectonic models was started. The compilation and drafting of a geologic/tectonic map of the Death Valley region was completed. A review of the linework was conducted, problems identified, and solutions explored. Integration of tectonic data from the literature as well as published geologic mapping and geophysical data was initiated.

Activity 8.3.1.17.4.12.2 - Evaluate tectonic models. Two strike-slip fault models have been singled out for consideration, the transfer fault model and the through going, deep-seated strike-slip fault model. One example of a through going, deep-seated strike-slip fault, the "Noble Hills" along the Southern Death Valley fault zone, was examined in the field. Preparations were made to write an article for outside publication comparing the two fault models. A contract was prepared for a boundary element modeling study to be conducted later in the FY.

Activity 8.3.1.17.4.12.3 - Evaluate tectonic disruption sequences. No progress during the reporting period; this is an out-year activity.

**Forecast:** The geologic/tectonic map of the Death Valley Region will be completed in FY 1993. Work will continue integrating all available tectonic data and evaluating relevant tectonic models applicable to the Yucca Mountain region.

## 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 potential repository. Also, rock mass properties for use in design activities are developed under this work.

An important component of this work involves developing and applying constitutive models capable of analyzing the response of jointed rock masses. SNL's current continuum jointed rock constitutive models represent state-of-the-art analysis capabilities in which the composite behavior of the intact rock and joints are modeled. 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. These models will be used in analyses that will support the ESF North Ramp design.

SNL continued its work in code documentation. The manual for JAC3D, a three-dimensional mechanical finite-element code has been completed, and work on the manual for JAC2D, a two-dimensional mechanical finite-element code, has begun.

SNL has also made progress in developing methods with coupled finite-element and boundary-element techniques. This capability will be particularly useful for repository-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. In this reporting period, the coupling of the two methods was developed for linear problems, and the coupling between nonlinear finite elements and linear boundary elements was begun.

There also has been an effort to develop a new discrete-element method that is well-suited to addressing the static and dynamic loads that are expected at Yucca Mountain. In cooperation with the University of Colorado, Boulder, an effort was initiated in which the discrete-element code, DDA, has been modified to increase its ability to resolve complex stress states. This was accomplished by introducing the concept of breaking large blocks of material into smaller sub-blocks. Refinement of this sub-blocking concept is currently being pursued.

Laboratory work continued on experiments involving layered polycarbonate models designed to provide well-controlled experimental data for code validation. In these experiments, Moiré fringe images are taken of the jointed samples as they are loaded. The Moiré grids are oriented to be sensitive to shear slip of the plates. During the reporting period, the experimental set-up was completed, including developing the testing technique and data-reduction software.

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A study of the surface characteristics of natural fractures and how to relate these to the frictional data gathered of replicas of the surfaces is continuing. This study places special emphasis on determining whether the fitting parameters in the so-called "Barton Model" for frictional behavior have physical significance. The samples have been prepared for testing, which will begin soon.

A series of experiments designed to study the effects of a non-standard loading condition on frictional properties was conducted at the University of Colorado. This work will result in several data and data analysis reports. These data are being used to develop more realistic joint constitutive models that can be incorporated into finite-element or discrete-element codes.

SNL staff initiated a series of analyses in support of the design of the ESF North Ramp. SNL will complete three-dimensional thermal/structural analyses of the repository to assess the impact of the potential repository thermal loading on the ESF drifts. SNL will also perform two-dimensional analyses of several cross sections of the ESF North Ramp to evaluate long-term stability. These analyses are expected to provide input for the 90 percent design review in August 1993.

**Forecast:** During the second part of FY 1993, SNL expects the theory and user's manual for JAC2D, SNL's principal thermomechanical analysis code, will be completed.

For the finite element-boundary element coupling work, SNL staff expects that the theoretical framework for coupling nonlinear finite elements and linear boundary elements will be developed. Also, a report covering the linear finite element-linear boundary element work will be issued.

In the discrete-element methods development, SNL expects that the sub-blocking concept will be theoretically developed and numerically implemented.

SNL will continue to develop and verify the continuum joint models. The efforts in the last half of FY 1993 will focus on improving the generality and robustness of the two-dimensional models while looking toward extensions into three dimensions.

A significant effort will be expended to complete the ESF North Ramp analyses in support of the 90 percent design review. Memo reports covering this work will be issued by the end of July.

Several laboratory tests on layered polycarbonate models will be conducted. Accompanying code validation analyses will be started in the next six months.

A number of ESF test support analyses will be conducted. These analyses are designed to help locate the tests to minimize test interference and to help design the instrumentation plans.

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### **2.3.2 Seismic Analyses (SCP Section 8.3.2.1.4.2)**

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

**Forecast:** No activity is planned for FY 1993.

### **2.3.3 Ventilation Analyses (SCP Section 8.3.2.1.4.3)**

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

**Forecast:** No activity is planned for FY 1993.

### **2.3.4 Safety Analyses (SCP Section 8.3.2.1.4.4)**

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

**Forecast:** No activity is planned for FY 1993.

## **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 is an out-year activity.

**Forecast:** No activity is planned for FY 1993.

#### **2.4.1.2 Design Activity 1.11.1.2 - Determine Adequacy of Existing Site Data**

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

**Forecast:** No activity is planned for FY 1993.

#### **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 is an out-year activity.

**Forecast:** No activity is planned for FY 1993.

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### **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 is an out-year activity.

**Forecast:** No activity is planned for FY 1993.

### **2.4.1.5 Design Activity 1.11.2.1 - Compile Waste Package Information Needed for Repository Design**

Work has been started in this area in support of systems engineering studies that are aimed at defining WP performance allocation, WP emplacement modes, and thermal density considerations.

**Forecast:** This activity will continue in the remainder of FY 1993.

### **2.4.1.6 Design Activity 1.11.3.1 - Area Needed Determination**

Investigations, with the development of layout sketches, have begun in this area based on the need to understand changes caused by increasing or decreasing the average thermal areal power density (APD).

**Forecast:** This activity will continue in the remainder of FY 1993.

### **2.4.1.7 Design Activity 1.11.3.2 - Usable Area and Flexibility Evaluation**

Like Activity 1.11.3.1, investigations began in this area in support of the need to understand changes in the underground layout caused by increasing and decreasing the thermal APD and relationships with known faults, overburden thickness and ESF features.

**Forecast:** This activity will continue in the remainder of FY 1993.

### **2.4.1.8 Design Activity 1.11.3.3 - Vertical and Horizontal Emplacement Orientation Decision**

Conceptual work is being done in this activity area as part of the ACD. Systems engineering studies addressing a wide variety of WPs have increased the scope of this activity to include in-drift emplacement.

**Forecast:** This activity will increase in depth and progress during the remainder of FY 1993 and beyond.



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### **2.4.1.9 Design Activity 1.11.3.4 - Drainage and Moisture Control Plan**

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

**Forecast:** No activity is planned for FY 1993.

### **2.4.1.10 Design Activity 1.11.3.5 - Criteria for Contingency Plan**

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

**Forecast:** No activity is planned for FY 1993.

### **2.4.1.11 Design Activity 1.11.4.1 - Chemical Changes Resulting From the Use of Construction Materials**

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

**Forecast:** No activity is planned for FY 1993.

### **2.4.1.12 Design Activity 1.11.4.2 - Material Inventory Criteria**

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

**Forecast:** No activity is planned for FY 1993.

### **2.4.1.13 Design Activity 1.11.4.3 - Water Management Criteria**

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

**Forecast:** No activity is planned for FY 1993.

### **2.4.1.14 Design Activity 1.11.5.1 - Excavation Methods Criteria**

Different excavation methods are being investigated. In particular, TBM development of the repository in contrast to the drill - blast approach used in the SCP conceptual design is being considered. Sketches have been developed for alternative approaches to layout development and considerations unique to TBM operational needs. This work is being performed in support of preliminary ACD studies.

**Forecast:** This activity will continue in FY 1993 and future years.

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### 2.4.1.15 Design Activity 1.11.5.2 - Long-Term Subsidence Control Strategy

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

**Forecast:** No activity is funded for FY 1993.

### 2.4.1.16 Design Activity 1.11.6.1 - Thermal Loading for Underground Facility

A report entitled "Comparison of Predicted Far-Field Temperatures for Discrete and Smeared Heat Sources" (Ryder, 1993), is in the Proceedings of the 1993 IHLRWM Conference. The study focuses on an evaluation of the use of extensive plate sources as opposed to discrete canister representations in three-dimensional thermal modeling. Results indicate that geometric features of a given layout affect the growth and coalescence of isothermal surfaces, and that single plate representations of the heat source may be inadequate to capture these interactions.

SNL staff continued to work with CRWMS M&O personnel and staff from LLNL to develop a plan for resolving numerous issues related to the thermal loading of the potential repository. Meetings were held at YMPO to begin an evaluation of the current state of repository modeling and to identify any additional modeling and laboratory-scale testing that may be required to provide the necessary level of confidence required to make a decision on thermal loading. A working group was formed to evaluate the LLNL extended-dry modeling results. Additional discussions have been held with the YMPO SCP thermal goals working group. This goal reevaluation is a critical step in defining the thermal envelope for ACD studies and for defining key information that needs to be obtained from the testing programs.

Near-field thermal calculations assuming an in-drift emplacement geometry were carried out for use by the CRWMS M&O's PWR WP design team. These calculations assumed a WP containing 21 PWR fuel elements with average burnups of 40 GWd/MTU and 45 GWd/MTU and an initial local APD of 100 kW/a. The rock-mass thermal response predicted by SNL is being incorporated by the M&O into detailed thermal models of the internal WP environment.

Preliminary investigations analyzing various layouts at differing thermal areal densities were started during the reporting period. This work is in support of M&O systems studies.

**Forecast:** SNL will continue to concentrate thermal design efforts on (1) evaluations of proposed thermal loading scenarios and (2) assistance in the reevaluation of thermal goals. These efforts may include additional two- and three-dimensional thermal modeling of the near- and far-fields. Additionally, thermal analysis support for CRWMS M&O systems studies will be defined and begun within the next six months. Deliverables will include SANDs, SLTRs, and briefings to design and PA personnel, as appropriate. Support of systems studies in the area will continue for the remainder of FY 1993.

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### 2.4.1.17 Design Activity 1.11.6.2 - Borehole Spacing Strategy

Some work was done in this area in support of CRWMS M&O systems engineering studies. Included in this area, is WP spacing for in-drift emplacement of very large WPs.

**Forecast:** Some work will continue in this area for both the systems studies and ACD in the remainder of FY 1993.

### 2.4.1.18 Design Activity 1.11.6.3 - Sensitivity Studies

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

**Forecast:** No activity is planned for FY 1993.

### 2.4.1.19 Design Activity 1.11.6.4 - Strategy for Containment Enhancement

The Ryder, 1993 report referenced in the discussion of Design Activity 1.11.6.1 also helps quantify the impacts of edge effects on the growth and duration of the predicted boiling isotherms. Results from this analysis form the foundation for additional containment enhancement calculations.

**Forecast:** Due to the prioritization of analysis directly supporting the design of the ESF's North Ramp, additional work in this area is not planned during FY 1993.

### 2.4.1.20 Design Activity 1.11.6.5 - Reference Calculations

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

**Forecast:** No activity is planned for FY 1993.

### 2.4.1.21 Design Activity 1.11.7.1 - Reference Postclosure Repository Design

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

**Forecast:** No activity is planned for FY 1993.

### 2.4.1.22 Design Activity 1.11.7.2 - Documentation of Compliance

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

**Forecast:** No activity is planned for FY 1993.

**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 is an out-year activity.

**Forecast:** No activity is planned for FY 1993.

**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**

The report "Drift Design Methodology and Preliminary Application for the Yucca Mountain Site Characterization Project," (Hardy and Bauer, 1989) details a drift design methodology that can be used in the development of future repository designs. The design methodology itself is independent of specific repository configuration and thermal loading; but, ensures that key elements of drift design such as thermal, seismic, and in situ loading are taken into account when developing a ground support system. The preliminary application of the methodology to the SCP-CDR repository design was used only for illustrative purposes in the report and demonstrated that the design was not complete and required further refinement, specifically in the case of the details of the rockbolt designs and shotcrete specifications. However, the preliminary application also suggests that these problems can be overcome. It should also be noted that it was not within the scope of the Hardy and Bauer report to suggest modified designs nor to evaluate the compliance of the SCP-CDR design and design and regulatory requirements at other APDs such as 114kW/a.

Confidence in the drift design methodology will be demonstrated by monitoring the performance of drifts during the site characterization. Specifically, four studies are directed toward gathering data for input to design, testing the design methodology by imposing thermal loads, and monitoring ground support system performance in a variety of geologic conditions. These studies are:

- 8.3.1.15.1.5 Excavation Investigations
- 8.3.1.15.1.6 In Situ Thermomechanical Properties
- 8.3.1.15.1.7 In Situ Mechanical Properties
- 8.3.1.15.1.8 Design Verification

As part of these studies, tests will be conducted to simulate repository conditions over a range of APDs that may be used in subsequent repository design. The data developed from these studies will provide a basis for improvement and validation of the design methodology. Subsequent repository designs should include ground support systems and components that meet the criteria established (and confirmed by testing) in the drift design methodology, and all other design requirements.

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The heat load per acre used in the baseline repository concept (57kW/a) has not changed since the issuance of the SCP. The SCP repository design concept is consistent with this heat load per acre. Studies, model validation, and testing programs concerning the heat load per acre are under way and planned for the future (including those reported below). These will provide information necessary to evaluate the heat load per acre. The repository concept will be altered, as appropriate, based on the results of these activities.

Section 2.6.1.3, Study 1.10.4.2, entitled, "Hydrologic Properties of Waste Package Environment," contains a related discussion of the effects of changes in heat load on heat-driven buoyant convection flow, temperature effects on ground water, and condensate drainage.

A report entitled "Yucca Mountain Site Characterization Project: New Three-Dimensional Far-Field Potential Repository Thermomechanical Calculations" (Hardy et al., 1992), has been published. The report documents a series of calculations that examine the temperature and stress changes predicted at all exploratory access and drift locations planned for construction during site characterization. Results were obtained using a three-dimensional, semi-analytic model assuming a conceptual layout that has been proposed for development using TBMs. Initial design-basis APDs of 57 kW/a and 80 kW/a were examined, and the models were run to 10,000 years following emplacement.

A report entitled "The Results of Near-Field Thermal and Mechanical Calculations of Thermal Loading Schemes" (Holland, 1993), is in the Proceedings of the 1993 IHLRWM Conference. This report partially documents a series of thermal/structural calculations completed for the CRWMS M&O's systems study on thermal loading. In-drift and in-borehole emplacement options were thermally evaluated in the near-field for a range of initial APDs and waste were examined using the compliant joint model for 100 kW/a and a range of rock qualities.

**Forecast:** Additional thermomechanical calculations have been defined to assess the impacts of a 100 kW/a initial thermal load on the stability of the ESF North Ramp. Calculations similar to those documented in Hardy, et al. (1992) will be carried out and used as partial input into SNL's implementation of the drift design methodology for the ESF's 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 is an out-year activity.

**Forecast:** No activity is planned for FY 1993.

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### **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**

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

**Forecast:** Some preliminary analyses will be started during the remainder of FY 1993. A report covering WP emplacement, operations, and maintenance will be issued at the end of the FY.

#### **2.4.4.2 Design Activity 4.4.3.2 - Operations Plan to Accompany the License Application Design**

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

**Forecast:** No activity is planned for FY 1993.

#### **2.4.4.3 Design Activity 4.4.4.1 - Repository Design Requirements for License Application Design**

A "Basis For Repository Design" is currently under development. While this document is focused on ACD, it will provide the background and lead into a license application design requirements document.

**Forecast:** The ACD basis for design will continue to be developed in FY 1993 and beyond.

### **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 are unfunded activities.

**Forecast:** No activity is funded for FY 1993.

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### **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 is an out-year activity.

**Forecast:** No activity is planned for FY 1993.

### **2.5.1.3 Study 1.12.2.3 - In Situ Testing of Seal Components**

Subsequent to submittal of the report "Initial Field Testing Definition of Subsurface Sealing and Backfilling Tests in Unsaturated Tuff" (Fernandez et al.) in the last reporting period, peer review comments, YMPO review comments, and editorial comments have been received and have been integrated into the report. Final technical editing and preparation of the camera-ready copy is now near completion.

**Forecast:** The final version of the report referenced above (SAND92-0960, Fernandez et. al.) will be submitted to YMP, printed, and distributed.

### **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.** Development of a strategy to seal exploratory boreholes continued during this reporting period. The existing borehole data base was reevaluated for consistency with the data base compiled at the end of FY 1991. This review was completed and new maps showing the locations of boreholes were generated. In addition to updating the borehole data base, the QA status of the SHAFT.SEAL user's manual was reviewed. Analytic calculations were completed examining airflow performance; relative significance of boreholes; hydrologic responses; stress induced by thermal, in situ, and backfill stresses; and casing stability. In addition to calculations, work proceeded on the development and documentation of sealing requirements and strategies. Significant progress has been made on writing the report documenting all analyses, as well as sealing requirements and strategies. SNL staff reviewed sealing requirements for the ESF that were documented for the early Title I designs and developed recommendations for tentative sealing requirements that should be incorporated in the current ESF Title II design packages. SNL also provided technical review and recommendations concerning near-term seal-related decisions on the UE-25 UZ #16 borehole.

**Design Subactivity 1.12.4.1.2 - Perform trade-off studies to support advanced design development.** Work proceeded in the evaluation of Defense Nuclear Agency (DNA) sealing technologies for underground testing. Photographs of DNA-related sealing have been obtained. These photographs cover seal-related components such as keyways, minebacks, large-scale bulkhead pores, and grout injection. These photos are being studied as part of the effort to assess available sealing technologies.

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**Forecast:** During the remainder of FY 1993, efforts will be focused on completing a report on the recommended strategy to sealing exploratory boreholes and on completing a report that reviews technologies to seal underground openings, including a review of DNA activities to date.

### 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 are out-year activities.

**Forecast:** No activity is planned for FY 1993.

## 2.6 WASTE PACKAGE DESIGN

The WP consists of the waste form and the container in which the waste form is placed. The WP design program includes the development of WP design bases, design analysis, container materials testing, the development of a reference design, waste form testing, and characterization of the WP emplacement environment. Status of the WP program is provided in this section.

Prior to the parametric evaluations a description of the different concepts was generated. For ACD, seven SNF WP concepts have been identified. In addition, a set of defense high-level waste (DHLW) WP concepts have been identified. The DHLW will be generated at three to four sites, each site is in the process of developing their waste form configuration. The basic ACD WP concepts are:

1. Metallic Multi-Barrier
2. Metallic Shielded
3. Small Metallic Multi-Barrier Borehole
4. Non-Metallic Multi-Barrier
5. Overpacked MPC
6. Universal Cask (MPU)
7. SCP-CDR (Single Container)
8. Defense High Level Waste, WP

Thermal, criticality, and shielding evaluations have been initiated in support of the ACD concepts. For different repository thermal regions, low, medium, and high, WP thermal calculations have been performed. The trends indicate that thermal loadings up to 100 kW/a are acceptable to the WP internal temperature limit of 350°C.

The evaluations have been investigating what is meant by a "self shielded" WP and how long must criticality material be present. There are different definitions of self shielded WPs. The one that is seen to provide the best definition is based on Title 10 CFR 20



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concerning radiation facilities. Based on this data shielding evaluations are proceeding. For the WP to meet Title 10 CFR 60.131 it must be shown that the  $K_{\text{eff}}$  stays below 0.95. For large WPs poison materials may need to be added to the basket material. Calculations are now under way to see how long the criticality control materials must be present.

The WP Design UNIX work station was installed and made operational. Structural, thermal, shielding, and criticality computer codes have been installed per QA procedures.

**Forecast:** The emphasis in this reporting period (and the remainder of FY 1993) is to perform parametric analyses of the ACD WP option. The parametric evaluations will be used in selecting the most promising WP concept(s) and to perform detailed concept analyses.

### **2.6.1 Postemplacement Near-Field Environment (SCP Section 8.3.4.2)**

The Preliminary NFE Report, Vol. I and II was approved and will soon be published as an LLNL report.

#### **2.6.1.1 Design Activity 1.10.1.1 - Consideration of 10 CFR Part 60.135 (a) Factors**

LLNL staff participated in the Thermal Workshop meeting held in Las Vegas on October 13, 1992. This meeting was hosted by the CRWMS M&O to focus on FY 1993 activities to develop a technical basis for an early ACD decision on thermal load.

Staff from LLNL, PNL, and Argonne National Laboratory (ANL) participated in and gave presentations at the NWTRB meeting held in Las Vegas October 14-15, 1992. The main topic was the source term, in particular waste form reactions, geochemical reactions, and how the source term has been used in PAs. An LLNL staff member participated in the field trip to Yucca Mountain with the NWTRB panel on October 16, 1992.

LLNL staff participated in the NWTRB Structural Geology & Geoengineering Panel workshop on the ESF design and construction strategy in Las Vegas November 4-5, 1992.

An LLNL staff member participated in the January 19-21, 1993, workshop in Las Vegas for the Evaluation of Natural Barriers Important to Waste Isolation. The workshop was convened by YMPO to assist the assessment team (in accordance with AP 6.17Q) with the identification of natural barriers appropriate for placement on the Q-list. The scope of this assessment was limited to the SCP design and strategy; several items including human intrusion, repository expansion areas, and extended-dry repository concepts, were not taken into consideration for this evaluation. Results of the Natural Barrier Evaluation Workshop were presented in a report to the assessment team.

V-TOUGH input files were transmitted to YMPO on February 22, 1993. These files will be forwarded to other participants who will run code-to-code benchmark calculations as a means of partially validating LLNL's extended dry calculations.

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The paper "Drift Emplaced Waste Package Thermal Response" (Ruffner et al., 1993) is in the Proceedings of the 1993 IHLRWM Conference.

### **2.6.1.2 Study 1.10.4.1 - Characterize Chemical and Mineralogical Changes in the Postemplacement Environment**

The review comments for Study Plan 8.3.4.2.4.1, "Characterization of the Chemical and Mineralogical Changes in the Post-Emplacement Environment" were fully incorporated in the text of the study plan. The study plan, originally written in 1986, is incomplete and out-of-date, and a more thoroughly revised version that more accurately reflects the current plans for the work in this task is near completion.

Initial runs with EQ3/6 to consider precipitation and dissolution effects on pore and fracture properties continued. The preliminary results are being used to evaluate the effects of mineral recrystallization on pore properties in regions dominated by slow fluid movement.

An LLNL staff member visited Dynamic Graphics, Inc. to discuss the use of their software package for three dimensional representation of geochemical processes in the WP environment.

Activity 1.10.4.1.1 - Rock-water interactions at elevated temperatures. Development of a plan for model validation at the New Zealand site continued, with an extended outline of required activities developed in draft form. This information will be folded into the revised study plan for this task.

B. Christenson, W. Giggenbach and A. Reyes from New Zealand visited LLNL on February 5, 1993, to discuss potential sites for conducting EQ3/6 validation activities. Several sites were identified as likely locations, based on data availability, observable or inferred processes at the sites, and accessibility. Plans were developed to have LLNL researchers visit these sites to go through the available data to determine if the data are complete enough to actually start the simulations. The group visited YMPO and the Yucca Mountain site on February 8, 1993. B. Christensen also spent several days working with LLNL scientists in the use of EQ3/6. Several specific problems regarding the New Zealand hydrothermal system were run on the code.

Efforts continued to refine the coupling of fluid-rock interaction with hydrological properties. Emphasis has been on identifying problems with the numerical interpolation techniques used to smooth data between different time slices. Also, the compilation of the reaction kinetics models that may be used to refine the knowledge of the distribution of equilibrium domains was initiated.

Activities related to definition of equilibrium vs. non-equilibrium domains continued. The possibility of using standard computational packages to undertake simple models of rock-fluid interaction, and how these interactions may influence hydrological properties is being explored. The possibility that cellular automata may be useful is being evaluated.

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Installation of software to enhance our capability to model equilibrium/disequilibrium domains in the vicinity of WPs was completed for the Silicon Graphics Indigo/XS-24 system. This software was used to develop a saturation grid for ambient conditions which will be used, along with ambient mineralogical data, to develop models of mineral evolution in the vicinity of WPs. This will expand our ability to visualize the evolution of chemical environments as the thermal regime around WP changes.

LLNL staff worked with YMPO and Los Alamos representatives to establish the collaborative activities necessary to address issues regarding flow, transport, rock-fluid interaction, and mineral stability. A better understanding of roles and efforts was developed from these consultations.

The close-out workshop of the Alligator Rivers Natural Analogue Project and the Natural Analogue Working Group meeting held in Toledo, Spain October 5-9, 1992, was participated in by an LLNL staff member.

An LLNL staff member participated in the workshop to coordinate activities between various project participants regarding coupling of geochemical and hydrological processes held February 1-3, 1993, at Asilomar, California. An outline of the conceptual model for geochemical evolution of the altered zone was developed. Discussions also outlined potential problems to be addressed.

The paper entitled "Validation of Hydrogeochemical Codes Using the New Zealand Geothermal System" (Glassley) was approved by YMPO. It will be published in the proceedings of the Natural Analog Working Group meeting held in Toledo, Spain on October 5-9, 1992.

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 Revision 9 of the SCPB.

Activity 1.10.4.1.3 - Composition of vadose water from the waste package environment. No progress during the reporting period; this is an unfunded activity.

Activity 1.10.4.1.4 - Dissolution of phases in the waste package environment.

A paper entitled "Dissolution Kinetics of Heulandite at pH 2-12 and 25°C" (Ragnarsdottir, Bristol University) was approved by YMPO and submitted to Geochimica Cosmochimica Acta.

Activity 1.10.4.1.5 - Effects of radiation on water chemistry. No progress during the reporting period; this is 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 is an unfunded activity.

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Activity 1.10.4.1.7 - Numerical analysis and modeling of rock-water interaction. This work was not funded during this reporting period. This activity is also reported under 1.10.4.5.1 as a result of Revision 8 of the SCPB, when this activity was divided between geochemistry and man-made material activities.

**Forecast:** Planned activities for FY 1993 include conducting the first simulations of geochemical processes for the New Zealand project, continuing the effort to evaluate coupled hydro-geochemical codes, and continuing to update EQ3/6 with new code modules and platform compatibility.

### 2.6.1.3 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, "Laboratory Study of Hydrological Properties of the Near Field Environment" has completed initial internal technical review and has been returned to the author for comment resolution. This first issue of the study plan will cover the laboratory experiment portion of the study; modeling will be added during a subsequent revision.

Activity 1.10.4.2.2 - Two-phase fluid system properties. The determination of the moisture retention curves of the eight disc-type Topopah Spring tuff samples from the U3hg-1 hole at a depth of 400 m (1,312 ft) and of the five Grouse Canyon member of the Belted Range tuff samples from G-Tunnel, NTS has been completed. A room-temperature constant-humidity chamber was used. The measurement of suction potential as a function of water saturation for a complete imbibition and draining cycle at 20°C has been completed. These results will be used, along with the previously determined one-dimensional imbibition rate, to calculate relative permeability of the U3hg-1 borehole rock. The result from the Grouse Canyon tuff samples will be used to compare the moisture retention in water vapor and in imbibition liquid water environments, which were previously observed on the same Grouse Canyon tuff samples.

Work continued on the measurement of electrical resistivity as a function of moisture content of Topopah Spring tuff samples from U3hg-1 and USW GU-3 holes at room temperature. The purpose of the measurement is to generate calibration curves of electrical resistivity of these samples with respect to moisture content so that laboratory and field determined resistivity can be interpreted in terms of degree of water saturation. A gold electrode was deposited on the flat surfaces of cylindrical disc samples. Two-electrode electrical resistance measurements were done on each one of the four samples with different thicknesses. Measurements have been made in both drying and wetting phases. These measurements were made by using distilled water as pore fluid; distilled water has an electrical conductivity of  $\sim 0.4 \mu\text{S}/\text{cm}$  at 20°C. The same measurements will be repeated using a synthetic water with an electrical conductivity similar to that of UE-25 J #13 water, which is about 33 S/m at 20°C. 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. At this point in the wetting phase of the measurement, the samples have reached a saturation level of about

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50 percent. The measured bulk resistivity using UE-25 J #13 water as pore fluid is the same as when distilled water is used. Investigations are under way to understand this phenomenon. One possible explanation is that at low levels of water saturation, the continuous layer of water on the mineral surface is dominating the conduction of electrical energy in the bulk rock and the chemical reaction between distilled water and the minerals within this layer is very efficient. This work will have significant implications for rock-water interactions.

Work continued on the investigation of the different moisture retention rates of water into a rock sample when the sample is either in a vapor environment or in liquid water. To understand the mechanism of the imbibition, capillary tubes of various inside diameters were put in a constant humidity chamber which will be set at various levels of humidity. The moisture retention rate of water into each capillary tube will be determined. The smallest inside diameter of the capillary tubes so far obtained was about 100  $\mu\text{m}$ , and these tubes were too large for the tubes to retain any moisture when they were put in a 95-98 percent relative humidity environment. Capillary tubes with inside diameter  $\sim 33 \mu\text{m}$  have been obtained. It was determined that even capillary tubes with an inside diameter as small as 33  $\mu\text{m}$  do not retain moisture in a 95-100 percent relative humidity environment. The effect of nucleation on the moisture retention will be investigated by placing a partially filled capillary tube in a vapor environment.

The experiment continued 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. Preliminary results indicate that fracture surface coatings decrease the water imbibition rate into the matrix by a factor of 0.15 to  $3 \times 10^{-5}$ , depending on the coating thickness. These findings agree with results obtained by University of New Mexico and SNL scientists on Tiva Canyon and Paintbrush Tuff samples. The mineralogy of the coating material and the pore size distribution in the coating layers will be determined.

Work has started to prepare Topopah Spring tuff samples from the USW G-4 hole for determining the moisture retention curve and one-dimensional imbibition as a function of temperature and initial moisture content.

LLNL staff continued to analyze the preliminary scoping calculations of the hydrothermal performance of the repository, using the Reference Information Base Version 4 thermal conductivity data and the new LLNL model that represents hydrothermal flow in the upper 1,000 m of the SZ as well as within the UZ. The focus has been the impact of hydrothermal flow in the SZ on hydrothermal flow in the UZ. Whether one chooses to treat the water table as a constant-temperature boundary or to model the SZ as part of a UZ-SZ hydrothermal system has a very pronounced impact on the long-term hydrothermal performance of the repository, affecting the duration of boiling at the repository by a factor of two.

The rationale for treating the water table as a constant-temperature heat sink is that natural convection in the SZ presumably transports heat away from the UZ-SZ boundary (i.e., the water table) as fast as it reaches this boundary. Investigations were begun on the impact

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of convection on heat flow in the SZ for a wide range of APDs, and it was found (as was the case for the UZ) that heat flow is dominated by heat conduction. Because convection does not carry away heat from the UZ-SZ boundary as fast as it reaches this boundary, it is necessary to include hydrothermal flow in the SZ in modeling the long-term hydrothermal performance of the UZ and the repository.

Although heat convection does not dominate SZ heat flow, SZ heat flow appears to dominate SZ fluid flow after approximately 1,000 yr. This dominant influence of repository-heat-driven flow was found to occur for all APDs investigated, ranging from 20 to 114 kW/a for 30- and 60-yr-old fuel. As the SZ temperatures below the repository rise, the accompanying decrease in mass density results in a significant upward component of flow from considerable depth, generating buoyant convection cells. Because the matrix permeability of the SZ is presumably quite small, these large-scale, buoyant convection cells require large-scale connectivity within the fracture system.

The magnitude of repository-heat-driven buoyant convection in the SZ was compared for three cases of 30-yr-old SNF having the same total mass of SNF: (1) 20 kW/a over a repository area of 3,162 acre, (2) 57 kW/a over 1,118 acre, and (3) 114 kW/a over 559 acre. Although the geometric details of the convection cells differ, the overall magnitude of repository-heat-driven buoyancy flow was found to be relatively insensitive to APD. For example, at  $t = 5,000$  yr, the maximum horizontal fracture velocity,  $(v_h)_{\max}$  is 1,182 m/yr for 20 kW/a, 1,513 m/yr for 57 kW/a, and 1,575 m/yr for 114 kW/a. Although the APD varies by a factor of 5.7, the difference in  $(v_h)_{\max}$  is only 33 percent between these cases. Overall, the SZ fracture velocities driven by repository heat are at least two orders of magnitude greater than those currently being attributed to the ambient system.

Thermally driven buoyant convection in the SZ is a result of changes in fluid volume,  $\Delta V$ , which occur as the region below the repository is heated. Because  $\Delta V$  increases with  $\Delta T$ , the magnitude of buoyancy flow generally increases with  $\Delta T$ . Although  $\Delta V$  per unit volume of heated SZ is less for lower APD, the larger "footprint" associated with the low-APD repository results in a larger overall region where this heat-driven change in volume takes place. Consequently, for a given amount of time-integrated heat, the cumulative effect of repository heating on driving convection cells in the SZ is similar over a wide range of APD. In general, the magnitude of repository-heat-driven buoyancy in the SZ is insensitive to the actual design of the repository and is primarily sensitive to the time-integrated heat (i.e., total mass of SNF emplaced in the repository). Consequently, the hydrothermal and potential geochemical consequences of heat in the SZ should not be considered a design issue, but rather the inherent response of the SZ to the emplacement of a given quantity of SNF.

The temperature effects in the SZ are potentially quite significant, even for low thermal loads. After about 100 yr, the water table begins to experience a temperature buildup,  $\Delta T$ . Even for 20 kW/a, the water table temperature rise is substantial and persists for tens of thousands of years. For 30-yr-old fuel emplaced at 20 kW/a, the water table peaks at 46.9°C ( $\Delta T = 16.5^\circ\text{C}$ ) at 6,900 yr, and remains above 40°C for over 26,000 yr. For 114 kW/a, 30-yr-old fuel, the water table peaks at 95°C at 830 yr, remains above 90°C for 670 yr, and remains above 70°C for over 12,000 yr. Even 250 m below the water table (475 m below the

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repository center),  $\Delta T$  is quite substantial, with a maximum temperature rise of 11, 22, and 23°C for APDs of 20, 57, and 114 kW/a, respectively. All of the prior repository-scale and drift-scale hydrothermal calculations considered 10-, 30-, and 60-yr-old SNF having the reference SCP-CDR burnup of 33,000 MWd per metric ton of heavy initial metal (MWd/MTU). At the request of the CRWMS M&O, repository-UZ-SZ-scale hydrothermal calculations for SNF have been conducted with other average ages and burnups. This request was made to investigate the hydrothermal performance of the repository-UZ-SZ system under thermal loads that are more specifically tied to potential SNF selection options for the MGDS. Two extreme SNF selection scenarios were considered, with the "oldest fuel first" (OFF) scenario yielding an average fuel age and burnup of 26 yr and 39,585 MWd/MTU, and the "youngest fuel first" (YFF) scenario yielding an average fuel age of 21 yr and a burnup of 43,573 MWd/MTU. The 21-yr-old OFF and 26-yr-old YFF scenarios were considered for APDs of 20 and 114 kW/a.

For the 20-kW/a cases, a 3,162-acre repository was considered. For the 21-yr-old YFF scenario, the 26-yr-old OFF scenario, and the 30-yr-old SNF reference case, an APD of 20 kW/a results in areal mass loadings (AML) of 16.61, 20.43, and 27.14 MTU/a, respectively. The 21-yr-old YFF scenario attains a peak average temperature at the repository center ( $T_{\text{peak}}$ ) of 55.45°C at a time to peak temperature ( $t_{\text{peak}}$ ) of 149.8 yr, while for the 26-yr-old OFF scenario,  $T_{\text{peak}} = 57.85^\circ\text{C}$  at  $t_{\text{peak}} = 235.6$  yr. For the 30-yr-old SNF reference case,  $T_{\text{peak}} = 59.94^\circ\text{C}$  at  $t_{\text{peak}} = 729.4$  yr. As has been previously observed,  $t_{\text{peak}}$  increases with average SNF age. Although  $t_{\text{peak}}$  varies among these three cases, there is little substantive difference among the respective temperature profiles because most of the temperature buildup occurs during the first 100 yr. For example, the 30-yr-old SNF case attains 94 percent of its ultimate temperature buildup during the first 100 yr, with the temperature only increasing another 2.2°C between  $t = 100$  and 729.4 yr. The 21-yr-old YFF and 26-yr-old OFF scenarios attain over 99 percent of their ultimate temperature buildup during the first 100 yr. Therefore, although  $t_{\text{peak}}$  may appear to vary considerably, actual differences in repository temperature at any given time are relatively minor among the three 20 kW/a cases.

For the 114-kW/a cases, a 559-a repository was considered. For the 21-yr-old YFF scenario, the 26-yr-old OFF scenario, and the 30-yr-old SNF reference case, an APD of 114 kW/a results in AMLs of 94.65, 116.45, and 154.7 MTU/a, respectively. For the 21-yr-old YFF scenario,  $T_{\text{peak}} = 177.52^\circ\text{C}$  at  $t_{\text{peak}} = 121.6$  yr. For the 26-yr-old OFF scenario,  $T_{\text{peak}} = 188.2^\circ\text{C}$  at  $t_{\text{peak}} = 453.6$  yr. For the 30-yr-old SNF case,  $T_{\text{peak}} = 202.8^\circ\text{C}$  at  $t_{\text{peak}} = 601.5$  yr. Although  $t_{\text{peak}}$  varies among these three cases, all three are effectively at their peak temperature within the first 100 yr. For the 21-yr-old YFF and 26-yr-old OFF cases, over 99 percent of the temperature buildup occurs during the first 100 yr, while 93.5 percent of the ultimate temperature buildup occurs for the 30-yr-old SNF case during the first 100 yr.

For the three 114-kW/a cases, the duration of the boiling period at the center of the repository ( $t_{\text{bp}}$ ) is roughly linearly proportional to the AML. For the 21-yr-old YFF scenario, the 26-yr-old OFF scenario, and the 30-yr-old SNF reference case,  $t_{\text{bp}}$  is 7331, 9125, and 11,450 yr, respectively. Had these scenarios been run with the same AML (rather than the same APD),  $t_{\text{bp}}$  would likely be similar for the three fuel ages, with the 21-yr-old YFF case

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having the highest  $T_{\text{peak}}$ . Because of the relatively large  $t_{\text{bp}}$ , thermal homogenization with the repository will have occurred prior to the end of the boiling period. Therefore, spatial variability in heat output due to variations between WPs will not cause local values of  $t_{\text{bp}}$  to significantly deviate from average conditions.

The reference burnup case (10-yr-old SNF, 57 kW/a, 33,000 MWd/MTU), resulting in an AML of 49.21 kW/a, was also considered; this is essentially the reference SCP-CDR case. For the model that includes hydrothermal flow in the upper 1,000 m of the SZ,  $T_{\text{peak}} = 100.3^{\circ}\text{C}$  at  $t_{\text{peak}} = 94.6$  yr, and  $t_{\text{bp}} = 666$  yr. For comparison, the model that treats the water table as being at a fixed depth at a constant temperature calculates  $T_{\text{peak}} = 100.0^{\circ}\text{C}$  at  $t_{\text{peak}} = 94.0$  yr, and  $t_{\text{bp}} = 553$  yr. The maximum temperature rise,  $\Delta T_{\text{max}}$ , at the top of the SZ (225 m below the center of the repository) is  $29.8^{\circ}\text{C}$ , occurring at  $t = 4140$  yr. The temperature at the water table does not respond to repository heating for the first 500 yr, with most of the temperature rise occurring between  $t = 1,000$  and  $2,000$  yr. At  $t = 20,000$  yr, the temperature at the water table is still  $19.7^{\circ}\text{C}$  above ambient. Approximately one-third of the way into the nonwelded zeolitized Calico Hills (CHnz) unit (106.5 m below the center of the repository),  $\Delta T_{\text{max}} = 45.4^{\circ}\text{C}$ , occurring at  $t = 1635$  yr. At  $t = 20,000$  yr, the temperature at this location in the CHnz is still  $21.1^{\circ}\text{C}$  above ambient. Such a substantial, persistent increase in temperature may modify the geochemical properties, thereby changing the transport properties of potential pathways for radionuclide transport.

The calculations also show considerable condensate drainage below the repository. For vertically connected preferential fracture pathways, the calculations indicate that condensate drainage can persist all the way to the water table. Condensate drainage along fractures may also contribute to the alteration of transport properties below the repository.

For high AMLs, which result in long-term boiling and sub-ambient saturation conditions, liquid-phase flux is much greater than the net recharge flux associated with pluvial climatic conditions. The higher liquid flux is associated with vapor flow and condensate drainage during the boiling period and with re-wetting the dry-out zone during the post-boiling period. Even for low AMLs, which result in insignificant dry-out due to boiling, repository-heat-driven hydrothermal flow will dominate SZ flow and also local flow conditions through much of the UZ. This is not to say that episodic nonequilibrium fracture flow from meteoric sources is not important. For sub-boiling conditions, while episodic events occur, fracture flow is likely to be the dominant source of liquid flux along preferential pathways connected to meteoric sources. Overall, however, repository-heat-driven hydrothermal flow is likely to be the main contributor of gas- and liquid-phase flow in the UZ. Therefore, an important hydrological consideration in determining whether the Yucca Mountain site is suitable for the emplacement of heat-producing, high-level nuclear waste is how heat moves fluid that is already present there; the impact of water that has yet to infiltrate is of secondary importance for high AMLs and, at best, of equal importance for low AMLs.

In cases for which rock dry-out is primarily driven by boiling (intermediate to high AMLs), it was found that thermo-hydrological performance can be classified into three distinct categories with respect to  $k_b$ . The low- $k_b$  category ( $k_b < 0.01$  darcy) corresponds to



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situations in which fracture density and connectivity throttle the rate of boiling and dry-out. Because heat flow is dominated by heat conduction, it is vertically symmetrical about the heater horizon. The low  $k_b$  results in large gas-phase pressure gradients that elevate the boiling temperature, thereby resulting in higher peak temperatures.

The intermediate- $k_b$  category ( $0.01 < k_b < 10$  darcy) corresponds to situations in which the fracture density and connectivity are sufficient to promote boiling that is not substantially throttled by flow resistance in the fractures. Because  $k_b$  is not large enough to promote substantial large-scale buoyant gas-phase convection, local boiling pressure gradients dominate the large-scale, buoyant, gas-phase pressure gradients, resulting in steam flow and condensate generation that are vertically symmetrical about the repository horizon. The heat convective effects in the heat-pipe zone have a local, transient effect on the temperature distribution, but because convection does not significantly enhance the heat loss from the boiling zone to the far-field, the duration of boiling conditions is not significantly reduced.

The high- $k_b$  category ( $k_b > 10$  darcy) corresponds to situations in which fracture density and connectivity are large enough to allow large-scale, buoyant, gas-phase gradients to dominate the local boiling pressure gradients, causing significant asymmetry in the vertical temperature distribution. For this category of thermo-hydrological performance,  $k_b = 84$  darcy was considered. Although far-field convection completely dominates the direction of steam flow, causing all of the steam to be driven to the upper condensation zone, heat flow is still dominated by heat conduction, and the duration of the boiling period,  $t_{bp}$ , is not substantially reduced (for high AMLs) relative to the intermediate- $k_b$  case. Because large-scale buoyant convection enhances the heat loss for the boiling zone to the far-field, heat convection has a definite influence on heat flow (e.g., lowering peak temperatures), yet it accounts for less than 50 percent of the overall heat flow. Therefore, this situation is referred to as convection-influenced heat flow. The term convection-dominated heat flow is reserved for cases in which convection accounts for more than 50 percent of overall heat flow.

For 27.1 MTU/a (30-yr-old SNF, and an APD of 20 kW/acre), bulk permeabilities of 0.28, 10, 20, 40, 84, 168, 410 and 840 darcy were considered. It was realized that the average  $k_b$  in the UZ is not likely to approach the latter two values of  $k_b$ ; however, calculations may be applicable to the local thermo-hydrological performance in highly fractured areas such as shear or fault zones. The primary purpose of this study was to identify the averaged conditions (thermal loading and  $k_b$ ) required to result in heat flow being dominated by large-scale, buoyant, gas-phase convection. Also considered were an intermediate and high bulk permeability for 49.2 MTU/a (10-yr-old SNF and an APD of 57 kW/a, corresponding to the reference SCP-CDR thermal loading); these values are 0.28 darcy and 84 darcy. In addition to these two permeabilities, 1, 5, 10, and 40 darcy were considered. Note that the high value is only a factor of 2 greater than some of the  $k_b$  values that have been measured in TSw2 (the host rock for the repository horizon).

For the 49.2-MTU/a reference SCP-CDR thermal-loading case, large-scale, buoyant, gas-phase convection occurring in the high- $k_b$  (84-darcy) case reduces the duration of the boiling period,  $t_{bp}$ , from 666 yr to only 117 yr, relative to the intermediate- $k_b$  (0.28-darcy) case. At  $t = 1,000$  yr, the temperature at the center of the repository is reduced by 13.1°C

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relative to the  $k_b$  case. Interestingly, an SNL subcontractor has conducted a calculation for a case with nearly the same AML (47.5 MTU/acre), with the primary differences being that a 30-yr-old SNF was assumed, yielding an APD of 35 kW/a, and a  $k_b$  of 50 darcy. At  $t = 1,000$  yr, the SNL subcontractor found that buoyant gas-phase convection has reduced the temperature at the center of the repository by approximately  $9.5^\circ\text{C}$ , relative to the conduction-only calculation. When it is taken into account that the Rayleigh number for this case is approximately 45 percent less than that applicable to LLNL's calculation, the two models are seen to be in reasonably good agreement. Moreover, the shapes of the temperature curves predicted by the two different models are very similar.

For cases that never get significantly above the nominal boiling point, large-scale, buoyant, gas-phase convection can affect the duration of boiling. This buoyant convective effect can only impact repository temperatures if substantial quantities of water vapor are transported from the repository horizon to the far-field. The transport of water vapor (and latent heat) that is sufficiently large to reduce repository temperatures is also associated with dramatic changes in the moisture redistribution. Simply put, in order for the hydrological (buoyant gas-phase) flow system to dominate heat flow generated by the repository, that repository-generated heat flow must have had a dominant impact on the hydrological flow system, including both liquid-phase and gas-phase flow.

For the reference SCP-CDR case, the intermediate  $k_b$  (0.28 darcy) results in a very small vertical dry-out zone thickness ( $h_{dz}$ ). For example, at  $t = 100$  yr,  $h_{dz}$  is only 12.2 m. The maximum  $h_{dz}$  (14.4 m) occurs at  $t = 300$  yr. At  $t = 1,000$  yr, the dry-out zone has nearly re-wetted back to ambient saturation. For the high- $k_b$  case,  $h_{dz}$  at  $t = 300$  yr is 23.3 m, nearly twice the  $h_{dz}$  of the intermediate- $k_b$  case. Although boiling ceases at  $t = 117$  yr,  $h_{dz}$  continues to increase as a result of the large-scale, buoyant, gas-phase convection of water vapor under sub-boiling conditions, resulting in  $h_{dz} = 109$  m at  $t = 1,000$  yr. At  $t = 5,000$  yr,  $h_{dz}$  has grown to 167 m and the overlying condensate zone (where the liquid saturation,  $S_l$ , is greater than 90 percent) is 213 m in thickness. It was also found that the net increase in  $S_l$  within the condensate zone exceeds the net decrease in  $S_l$  within the dry-out zone. This indicates that large-scale, buoyant, gas-phase convection is transporting water vapor from the lower dry-out zone (which in turn is supplied by water that is imbibed from the SZ) faster than the rate at which buoyant gas-phase convection can transport water vapor to the atmosphere.

It was found that between 1 and 5 darcy, large-scale, buoyant convection of water vapor has a pronounced effect on generating condensate above the repository horizon. This effect was found to persist for tens of thousands of years. Note that this range in  $k_b$  is well within measurements made on the repository horizon host rock, TSw2.

For 27.1 MTU/a (30-yr-old SNF, yielding an APD of 20 kW/acre), the intermediate- $k_b$  case (0.28 darcy) results in virtually no net change in liquid saturation distribution; however, significant sub-boiling refluxing of water vapor and condensate does occur. This sub-boiling refluxing occurs as large-scale, buoyant, gas-phase convection drives water vapor upward to where it condenses and drains downward. The intermediate- $k_b$  case does not result in an upward mass flow rate of water vapor that is sufficiently large to exceed the mass flow rate at which condensate returns. For  $k_b = 10$  darcy, large-scale, buoyant convection of water vapor

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begins to have a pronounced effect on generating condensate drainage above the repository horizon. Because some of this condensate drainage will occur as nonequilibrium fracture flow, it is likely to return to the repository horizon (and possibly to the water table). Therefore, if the definition of a "cold" repository is one that does not significantly perturb the ambient hydrological system, it appears very unlikely that a cold repository can be achieved.

It is important to note that it is not necessary for convection to dominate heat flow in order for heat flow to dominate fluid flow. Not until  $k_b = 84$  darcy does convection begin to influence heat flow. B. Ross' analysis indicates that it requires about 1,000 yr for large-scale, buoyancy-driven, gas-phase convection cells in the UZ to become fully developed. LLNL's calculations also indicate that it requires about 1,000 yr for large-scale, buoyant, gas-phase convection cells to begin to significantly impact thermo-hydrological performance under sub-boiling conditions. Therefore, regardless of how substantial buoyant, gas-phase convective effects may eventually become, the peak repository temperature,  $T_{peak}$ , for 30-yr-old SNF (which generally occurs within the first 600 yr) is not significantly influenced by large-scale, gas-phase convective effects. For 30-yr-old SNF (an APD of 20 kW/acre),  $T_{peak}$  is 59.9, 59.9, 58.8 and 59.0°C for  $k_b$  of 0.28, 84, 414, and 840 darcy, respectively.

The SNL subcontractor's SCP-CDR thermal loading case (47.5 MTU/acre) indicates that a  $k_b$  of 50 darcy ( $5.0 \times 10^{-11} \text{m}^2$ ) is sufficiently large to allow large-scale, buoyant, gas-phase convection to significantly lower repository temperatures relative to the conduction-only case. LLNL's SCP-CDR thermal loading case (49.2 MTU/acre) indicates that 40 darcy is large enough to significantly lower repository temperatures relative to what is effectively a conduction-only case. For 27.1 MTU/a (30-yr-old SNF and 20 kW/acre), LLNL's calculations indicate that a  $k_b$  of about 84 darcy is large enough to result in large-scale, buoyant, gas-phase convection significantly affecting repository temperatures, and that a  $k_b$  of 20 darcy is sufficient to cause substantial moisture redistribution. Therefore, LLNL's determination of the "threshold" thermal loading and bulk permeability conditions for which sub- or marginal-boiling performance begin to become significantly affected by large-scale, buoyant, gas-phase convection is corroborated by the SNL subcontractor's analysis.

The subject of hydrological model validation has generated considerable debate. LLNL agrees with scientists who believe that the terms "model validation" and "verification" are misleading in ground-water science and should be replaced with the following process: (1) using models to obtain a better fundamental understanding of the system, (2) asking what it is about the system that needs to be predicted, (3) utilizing this understanding to formulate fundamental hypotheses that are the basis of the conceptual model and performance attributes of the system, and (4) performing analyses and experiments in an attempt to test or invalidate the conceptual models (or hypotheses).

Past LLNL monthly reports have described calculations of repository-heat-driven hydrothermal flow in the repository UZ-SZ system to a broad range of thermal loading design parameters, thermo-hydrological properties, and boundary conditions. A broad range of parameters have been, and continue to be, investigated in order to identify:

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1. Distinct regimes of thermo-hydrological performance
2. Conditions that invalidate the following hypotheses:
  - a. Repository-driven heat flow will be dominated by heat conduction.
  - b. The region of above-boiling temperatures surrounding the repository corresponds to the absence of liquid water in the WP environment.
  - c. Fracture density and connectivity are sufficient to promote rock dry-out due to boiling and condensate shedding.
  - d. Rewetting of the dry-out zone lags significantly behind the end of the boiling period.

In addressing these hypotheses, it will be determined whether hydrothermal-geochemical-geomechanical coupling must be dynamically accounted for in performance models or whether it can be conservatively accounted for by bounding analyses. A primary goal of site characterization, laboratory tests, and in situ heater tests will be to look for conditions or processes that have been identified as potentially invalidating any of the fundamental hypotheses. Knowledge of such conditions (e.g., a highly fractured fault zone) will be valuable in selecting the location of the repository or WPs.

It is LLNL's position that hypothesis testing can be more readily applied to models that predict the period of radionuclide containment in WPs before radionuclide mobilization, release, and transport, than to models that predict how radionuclides are isolated by the natural barriers during the period of radionuclide migration. For sub- or marginal-boiling conditions, the episodic infiltration of meteoric water and condensate drainage are controlled by the heterogeneous distribution of hydrological properties, while for above-boiling conditions, they are largely determined thermodynamically by the heat capacity of the rock. Therefore, it is believed that hypothesis testing is more readily applied to high AMLs, expressed in metric tons of uranium per acre (MTU/acre), which produce long-term, above-boiling conditions surrounding the repository.

LLNL's recent investigations have focused on the impact of large-scale, buoyant, gas-phase convection on thermo-hydrological performance. It is important to appreciate the fundamental distinction between moisture redistribution driven by above-boiling conditions and that driven by sub- to marginal-boiling conditions. The performance of the ambient hydrological system is critically dependent on whether vertically connected fracture pathways exist with sufficient aperture to generate fracture-dominated flow to the repository horizon (and possibly to the water table). Similarly, fracture networks of sufficient aperture and connectivity are required for repository heat to drive buoyant convection of water vapor from hotter to cooler locations, where condensation occurs. For AMLs that generate sub- or marginal-boiling conditions at the repository horizon, whether condensate can drain back to the repository horizon is determined by the highly heterogeneous distribution of fracture and matrix hydrological properties. For high AMLs, as long as a large enough zone of

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above-boiling conditions surrounds the repository, condensate drainage is unlikely at WP locations. However, after the boiling period, large-scale buoyant convection of water vapor has the potential to eventually generate enough condensate to result in nonequilibrium fracture flow at the repository horizon. Even for low AMLs, large-scale buoyant convection of water vapor in highly fractured zones could generate enough condensate to drive nonequilibrium fracture flow to the repository horizon for tens of thousands of years.

The potential for large-scale, buoyant convection of water vapor to generate enough condensate to drive nonequilibrium fracture flow to the repository horizon is influenced by the following factors:

1. Whether condensate drainage is primarily controlled by hydrological heterogeneity or thermodynamically.
2. The temperature gradients driving large-scale, buoyant, gas-phase convection.
3. The availability of liquid water.
4. The connectivity and permeability of fracture networks between locations where water is evaporating and where it is condensing.
5. The connectivity and permeability of preferential fracture pathways between locations where water vapor is condensing and the repository horizon.

If a large enough zone of above-boiling conditions surrounds the repository, condensate drainage is extremely unlikely at the repository horizon. Future calculations will focus on how factors 2 through 5 impact post-boiling performance. It is useful, therefore, to compare conditions just as the boiling period ends. With respect to factor 2, the temperature gradients associated with intermediate AMLs are found to be steeper than those associated with high AMLs. Therefore, the driving force for the post-boiling-period, buoyant convection of water vapor increases with decreasing AML.

Both during and after the boiling period, factors 3 and 4 depend on the vertical thickness of the dry-out zone,  $h_{dz}$ . Large-scale, buoyant, gas-phase convection depends on the large-scale connectivity of fracture networks, which generally decreases with increasing distance between two points (e.g., from the lower to the upper dry-out front), with the tortuosity of the connected fracture pathways increasing. Note that even while the dry-out zone is subjected to above-boiling conditions, large-scale buoyant convection eventually dominates the local boiling pressure gradients ( $t > 1,000$  yr), resulting in the buoyant convection of water vapor from the lower to the upper dry-out front. The water vapor that is evaporated from the lower dry-out zone is at least partially replenished by water imbibed from the SZ. The actual distribution of fracture permeability and connectivity is probably extremely heterogeneous. The assumption that  $k_f$  is homogeneous and isotropic overpredicts the transport of water vapor. Therefore, LLNL's models of high AMLs conservatively predict the time it takes the upper dry-out front to retreat back to the repository horizon.

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For post-boiling period performance, a critical consideration is the value of  $h_{dz}$  at the end of the boiling period. Similarly, factor 5 is dependent on the distance from the upper dry-out front to the repository horizon, which is roughly half of  $h_{dz}$ . At the end of the boiling period for the reference  $k_b$  case ( $2.8 \times 10^{-13} \text{m}^2$  or 280 millidarcy),  $h_{dz}$  is 14.4, 110, and 248 m for AMLs of 49.2, 77.4, and 154.7 MTU/a, respectively. Therefore, the potential for post-boiling period drainage of condensate to the repository horizon is greater for low AMLs associated with small dry-out zones.

Work continued on the hydrothermal calculations of large-scale in situ heater tests with a focus on analyzing the feasibility of using small thermal probes (approximately 20 W) for determining the thermal conductivity and diffusivity of the rock in the vicinity of the heaters. This work is being done in collaboration with the Mackay School of Mines (G. Danko) at the University of Nevada, Reno. The capability of the thermal probes to detect the effects of heat conduction and convection for a range of conditions is being tested. These include ambient conditions prior to heating, conditions during the transition from sub-boiling to boiling, conditions during boiling with gravity-driven refluxing effects, and above-boiling conditions (the dry-out zone). Preliminary results show that the thermal probe can very accurately determine the in situ thermal properties of the rock. This in situ measurement technique will be extremely useful in validating the applicability of laboratory-based measurements for determining the in situ thermal properties in the UZ and SZ. It is planned that the LLNL LBT thermal probes will be tested.

Low to medium AMLs generate sub- to marginal-boiling conditions. Under such conditions, the large-scale, buoyant convection of water vapor in highly fractured zones can cause condensate drainage at the repository horizon that is orders of magnitude greater than the recharge flux due to a pluvial climate. It was found that large-scale, buoyant convection of water vapor can also significantly influence repository temperatures. This effect only occurs if water vapor is convected in very large quantities from below the repository to cooler locations above the repository, where it condenses and drains back toward the repository. The analysis of Ross et al. indicates that it requires about 1,000 yr for large-scale, buoyant, gas-phase convection cells to fully develop in the UZ. LLNL's calculations also indicate that it requires about 1,000 yr for convection cells to impact sub-boiling performance.

Therefore, it will not be possible to observe such effects during either : (1) heater tests conducted under sub- to marginal-boiling conditions, or (2) the period of performance confirmation.

In order to assess the potential for large-scale, buoyant vapor flow to result in condensate drainage at the repository horizon under sub-boiling conditions, it will be necessary to rely on heater tests conducted under above-boiling conditions. There are very distinct differences in the vertical temperature profile between the intermediate- and high- $k_b$  heater test cases. The high- $k_b$  case uses the same value of  $k_b$  (84 darcy or  $8.4 \times 10^{-11} \text{m}^2$ ) that produced very large condensate drainage fluxes for AMLs of 49.2 and 27.1 MTU/a. Such large fluxes could result in nonequilibrium fracture flow at the repository horizon for tens of thousands of years. The potential for significant condensate flow at the repository horizon cannot be resolved without above-boiling heater tests.

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One LLNL staff member is investigating a proposed modification to the V-TOUGH code. For some of the high-APD, UZ-SZ model calculations, the performance of V-TOUGH slows down considerably, causing it to use unacceptable amounts of computer time. One possible cause is that when the condensate zone above the boiling zone is at or very close to 100 percent liquid-phase saturation, fluctuations in the gas-phase relative permeability between zero and a finite value result in convergence problems. Because two-phase flow in randomly oriented, variable-aperture fractures is likely to be highly channelized, it is extremely unlikely that gravity-driven condensate drainage will be capable of saturating 100 percent of the fracture porosity within the two-phase, boiling/condensate zone. Therefore, some portion of the fracture porosity in this zone will be gas-filled at all times. An additional relative permeability curve option is being added to the subroutine "initpc," which allows the user to specify an irreducible gas-phase saturation. The user will be able to specify this feature by choosing either option 9 or 13. These changes are being tested by using input deck, g130rrsi (114 kW/a, 60-yr-old fuel) on the LLNL Open Computing Facility.

A directory has been set up on node s70 that contains the current suite of test problems for verifying V-TOUGH. A new test file has been added that tests most of the user options of the V-TOUGH time history option.

As required by the Individual Software Plan ISP-NF-1, a script was set up that will perform a backup of all pertinent V-TOUGH development directories. Currently, the monthly backups are done by manually storing the files on floppy disks. This new feature will automatically perform the monthly backup so that all that will be needed is to load a floppy into the drive. Options are also being investigated to perform periodic backups on the hard disk drives.

An LLNL staff member is currently testing a prototype version of the NUFT code (Nonisothermal Unsaturated Flow and Transport) for nonisothermal radionuclide transport problems. NUFT, which can handle multiphase heat flow and aqueous-phase multiple species transport, was primarily developed outside of YMP. This staff member sent a description of NUFT to CRWMS M&O/INTERA staff, so that it could be included in the CRWMS M&O report "Review and Selection of Unsaturated Flow Models."

An LLNL staff member developed an input "checker" for V-TOUGH to look for input that is obviously incompatible with input format. She continues to work on the documentation for V-TOUGH. Another LLNL staff member released Version 5.6 of V-TOUGH, which has: a new option (14) for the relative permeability and capillary pressure curves, and an interrupt capability for the Sun and IBM workstations. The new interrupt capability allows V-TOUGH to write an "emergency" restart file if it senses that the operating system is about to abort the run. There is also an option for the user to produce a restart file by typing in a control-C, which then terminates the run after creating the restart file. Option 14 prevents the gas-phase relative permeability from being reduced to zero as a liquid saturation of 1.0 is approached. This option may be applicable to unsaturated fracture flow. Heterogeneous condensate drainage in fractures will probably make it very unlikely that 100 percent of the fracture porosity could be saturated with liquid, particularly above the repository. This option translates the original relative permeability curve to a curve that

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approaches a maximum liquid-phase saturation that is less than one. A finite gas-phase relative permeability will remain at all times. This option will allow more conservative investigation of the potential thermo-hydrological effects of large-scale, buoyant, gas-phase convection.

Activity 1.10.4.2.3 - Numerical analysis of flow and transport in laboratory systems.  
Study Plan 8.3.4.2.4.2, "Laboratory Study of Hydrological Properties of the Near-Field Environment," has completed the first phase of internal technical review and has been returned to the author for comment resolution. The initial issue of the study plan will cover the laboratory experiment portion of the study; modeling will be added during a subsequent revision.

An LLNL staff member completed a prototype version of the NUFT (Nonisothermal Unsaturated Flow and Transport) code that can handle multiphase heat flow. Previous prototype versions of NUFT were isothermal. The new version of NUFT can also handle aqueous-phase species transport.

A workshop on flow and transport in unsaturated fractured rocks was attended January 25-28, 1993, in Tucson, Arizona, and a presentation given on some results of using electrical resistivity tomography in the laboratory and in the field to monitor water flow by an LLNL staff member.

The following papers were presented at the AGU Fall meeting in San Francisco, December 8-11, 1992: "Electrical Resistivity of Topopah Spring Tuff as a Function of Water Saturation" (Roberts and Lin) and "Suction Potential, Imbibition; and Relative Permeability of Topopah Spring Tuff" (Lin et al.).

The following papers are in the Proceedings of the 1993 IHLRWM Conference: "The Analysis of Repository-Heat-Driven Hydrothermal Flow at Yucca Mountain" (Buscheck and Nitao, 1993); "Large-Scale In Situ Heater Tests for Hydrothermal Characterization at Yucca Mountain" (Buscheck et al., 1993); "Single-Hole In Situ Thermal Probe for Hydrothermal Characterization at Yucca Mountain" (Danko and Buscheck, 1993); and "Alternative Strategies--A Means for Saving Money and Time on the Yucca Mountain Project" (Wilder, 1993).

**Forecast:** The study plan for Laboratory Study of Hydrological Properties of the Near-Field Environment has been divided into two parts, laboratory testing and modeling. The laboratory testing portion of the study plan has been completed and work will continue on resolving comments as they arise. The modeling portion of the study plan will be completed this FY.

Work continues on model validation and measurements of hydrological properties.

Work will continue on the modeling calculations of the hydrothermal performance of the repository.



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### 2.6.1.4 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 the NRC on December 31, 1992. In its transmittal letter, OCRWM explained how SCA Question 17 open item was addressed in the study plan. Revision 10 of the SCPB changed the name of this study and subdivided the scope of work encompassed in it into three activities.

The setup of initial computations of stress in the NFE for the extended dry concept has been started. This is in response to the suggestion by YMPO that the NFE team gather relevant information on the extended dry concept.

Activity Plans were started for borehole damage and block stability investigations for the laboratory scale block testing in support of Study Plan 8.3.4.2.4.3 and the LBT. Technicians were interviewed for support of the testing, and instrumentation systems for physical property measurements were reviewed.

Activity 1.10.4.3.1 - Block stability analysis. No progress during the reporting period; this is an unfunded activity.

Activity 1.10.4.3.2 - Borehole damage analysis. No progress during the reporting period; this is an unfunded activity.

Activity 1.10.4.3.3 - Geomechanical properties analysis. No progress during the reporting period; this is an unfunded activity.

**Forecast:** Work will start on activity plans for this task. NRC comments have been received on the study plan and are being reviewed.

### 2.6.1.5 Study 1.10.4.4 - Engineered Barrier System Field Tests

Activity 1.10.4.4.1 - Repository horizon near-field hydrologic properties. Study Plan 8.3.4.2.4.4, "Engineered Barrier System Field Tests (EBSFT)" has been revised according to the initial internal technical review and has been returned to the reviewer for re-review.

The SIP for "Large Block Testing of Coupled Thermal-Mechanical-Hydrological-Chemical Processes" is in internal technical review.

An LLNL staff member met with Los Alamos staff in October 1992, to discuss layout of EBS heater Tests in an accelerated ESF. LLNL testing is being modified in response to the proposed accelerated-ESF schedule. Two tests will be required in the North Ramp and two additional tests will be required on the Main Test Level to provide the data needed for the Site Suitability determination and the LA.

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LLNL staff worked with CRWMS M&O and the Test Coordination Office to adapt the ESF heater tests to the ESF construction schedule and assisted in the production of the ESF movie.

### LBT

The SIP for Large Block Testing of Coupled Thermal-Mechanical-Hydrological-Chemical Processes is in internal technical review.

LLNL staff and a Los Alamos staff member evaluated the Fran Ridge test pits and the pavement area on the west flank of Busted Butte on October 6, 1992 as potential sites for quarrying blocks for the LBT. The Fran Ridge site is much more accessible and the rock type there is geochemically acceptable.

LLNL staff and SNL staff visited the NTS to inspect rock outcroppings for possible samples for the LBT. Contacts with SNL and REEC Co have been made to evaluate various ways of obtaining blocks of Topopah Spring tuff from either Fran Ridge or Busted Butte. One facility has been identified that can finish the blocks according to LLNL's requirements for size and accuracy.

An alternative to assembling the large block from 1 m<sup>3</sup> cubes is being considered. In this case, a 3 m x 3 m x 4.5 m block would be carved into Fran Ridge and the loading frame would be constructed on site.

An LLNL staff member collected some small pieces of Topopah Spring tuff from the Fran Ridge outcrop for determining the present moisture content in the rock and it was found to be about 30 percent. Work will continue to refine the moisture content determination. This information will be used in the design of the LBT.

LLNL staff met with SNL staff on December 1, 1992, at the Fran Ridge and Busted Butte sites to investigate the cutting of blocks. One staff member has completed preliminary QA grading for the LBT.

The initial design of the loading frame has been completed. A drawing of the design will be available for bidding in May 1993.

Activity 1.10.4.4.2 - Repository horizon rock-water interaction. No progress during the reporting period; this is 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 is an unfunded activity.

**Forecast:** Continue work on study plan and complete activity plan.

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### 2.6.1.6 Study 1.10.4.5 - Characterize the Effects of Man-Made Materials on Water Chemistry in the Postemplacement Environment

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 in draft form and is in revision by a technical editor. The Work Breakdown Structure dictionary was changed to include this area which addresses the portions of the SCP Issues 1.4 and 1.5 that pertain to the impacts of man-made materials on the local water chemistry.

Activity 1.10.4.5.1 - Effect of grout, concrete, and other repository materials on water composition. As a consequence of no funding during FY 1992, and undetermined funding during early FY 1993, the following activities reflect work accomplished in the past three months in this activity.

The revision of the Man-Made Materials study plan has begun. The revisions are primarily those made necessary by the changes in study plan requirements during the period that the Man-Made Materials task was not funded.

Staff supplied a draft of a white paper entitled "Chemical and Mineralogical Concerns for the Use of Man-Made Materials in the Post-Emplacement Environment" (Meike) to the CRWMS M&O. This paper discusses concerns for materials introduced into the ESF.

In the anticipation of concern about organic materials (including diesel fumes and exhaust) that may be introduced into the ESF, a program of study is being designed to assess the present capabilities of the GEMBOCHS computer data base in this area, and to identify deficiencies. This program is distinct from the literature review of colloids, completed in 1991, which included some organic materials, but did not address chemical stability (and conversely, reactivity) or degradation. A decision making strategy for identifying the data base deficiencies of greatest concern, and thus the direction of experimental work, is being developed in tandem with this program.

The search of the GEMBOCHS thermodynamic data base that supports the EQ3/6 codes for aqueous species, glass, and solids that contain carbon has been completed. The search for organic compounds was expanded in recognition of the important role that carbon bearing compounds play in the following three mechanisms, all of which may operate within the ESF and the potential repository site: (1) aerobic microbial degradation of hydrocarbon compounds may increase carbonate species and thus significantly alter pH; (2) abiotic thermal degradation of organic compounds may generate large amounts of carbon dioxide that may also significantly alter pH; and (3) carbonate complexation. These mechanisms are particularly important to the determination of SNF solubility.

As a consequence of these results, the following actions are being taken:

1. The data base is being evaluated to identify the organic compounds that are likely to be introduced into the ESF and the potential radioactive waste repository for which the thermodynamic and kinetic properties are not well established.

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2. An experimental plan for the organic materials study program is being developed.
3. Laboratory facilities for these experiments are being assembled.

Activity 1.10.4.5.2 - Effects of container and borehole liner corrosion products on water chemistry. No progress during the reporting period; this is 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 is 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 is an unfunded activity.

**Forecast:** Work will continue on preparation of the study plan. The evaluation of the impact of diesel on the repository will be studied.

### **2.6.2 Characteristics and Behavior of the Waste Form (SCP Section 8.3.5.10)**

#### **2.6.2.1 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 on October 8, 1992.

SIP-WF-01, Revision 1.0, "YMP Spent Fuel Waste Form Testing" was completed and sent to YMPO for acceptance.

LLNL, YMPO, and CRWMS M&O staff members met at ANL on February 3, 1993, to present ANL's range of experimental and analytical capabilities, along with ANL's interests in support of the YMP WP effort.

Subactivity 1.5.1.1.2 - Integrate glass waste form information. SIP-WF-02, Revision 0, "YMP Glass Waste Form Testing" was sent to YMPO for acceptance.

Subactivity 1.5.1.1.3 - Integrate waste package and repository design information. No progress during the reporting period; this is an unfunded activity.

**Forecast:** The currently available Materials Characterization Center (MCC) spent fuel inventory of Approved Testing Materials (ATM) consists of several assemblies of rods. Previous, ongoing and planned spent fuel testing matrices in LLNL activities will not require the large amounts of existing inventory from these ATMs. Currently, plans are underway to dispose of substantial amounts of this existing hot cell inventory. A planning document is being written to procure new ATMs, consisting of only small amounts of spent fuels, to augment the breadth of available spent fuel characteristic variables such as burnup, fission gas

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release, and different PWR/BWR type fuels. This planning document will be completed during the following reporting period.

### 2.6.2.2 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 WP design activities and repository PAs. The dissolution response testing addresses spent fuel types (PWR & BWR), fuel burnups ( $0 \rightarrow \sim 60$  Mwd/kgM), in-reactor fission gas released ( $\sim 0$ -20 percent), oxidation phases ( $\text{UO}_2 \rightarrow \text{U}_4\text{O}_9 \rightarrow \text{U}_3\text{O}_8 \ll \text{UO}_3$ ), heterogeneous effects of radionuclides on and in pellet fragments, potential water temperatures ( $25^\circ\text{C} \rightarrow \sim 95^\circ\text{C}$ ), and water chemistries (aggressive [upper bound] and nominal J-13). 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.

A test matrix for  $\text{UO}_2$  spent fuel was just completed at PNL using aggressive water chemistries with prescribed carbonate/bicarbonate concentrations, high pH values (basic), oxygen fugacities, and temperatures. A similar test matrix is just being finished for unirradiated  $\text{UO}_2$  at LLNL. The results of these two tests matrices will be combined to complete a model that addresses burnup, upper bound water chemistries, and temperature effects on  $\text{UO}_2$  spent fuel dissolution rates. Preliminary dissolution rate results indicate that oxygen fugacity dependence is not expected to be significant for an unsaturated repository; water temperature has about an order of magnitude effect over the expected water temperature domain.

Some scoping flow-through dissolution tests have been completed on the  $\text{U}_4\text{O}_9$  oxidation state of spent fuel; some effects of exposed grain boundary dissolution were observed in these preliminary tests. However, the intrinsic dissolution rate ( $\text{mg}/\text{m}^2/\text{day}$ ) from grain volume surfaces were not significantly different from that of  $\text{UO}_2$  spent fuel. There were some preliminary indications that technetium releases were higher from the  $\text{U}_4\text{O}_9$  oxidization phase than the  $\text{UO}_2$  phase tests; this was attributed to a grain boundary effect. Grain boundaries of  $\text{UO}_2$  spent fuel crack open during the spent fuel oxidation phase transformation of  $\text{UO}_2$  to  $\text{U}_4\text{O}_9$ .

Because the intrinsic dissolution rates for the  $\text{UO}_2$  and  $\text{U}_4\text{O}_9$  phases are not showing significant differences, and since it is known that the next oxidation phase of  $\text{U}_3\text{O}_8$  has a large volume increase ( $\sim 30$  percent) that potentially degrades the spent fuel grains to a flaked-powdered form, the next test matrices for flow-through dissolution will concentrate on the  $\text{U}_3\text{O}_8$  spent fuels and unirradiated  $\text{U}_3\text{O}_8$ . The oxidation of  $\text{UO}_2$  to  $\text{U}_3\text{O}_8$  flaked-powdered forms greatly increases the exposed surface area of spent fuel that may be potentially wetted by water. For flow-through testing, accurate measurements of the surface of the spent fuel test samples are required. For this purpose, a BET apparatus has been installed inside a hot cell at PNL. Calibration of the BET system has been completed by using unirradiated

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samples of known surface areas. The data obtained on dissolution rates of the  $U_3O_8$  phases will address worst case waste forms in WP design and repository PA scenarios.

A paper entitled "Effects of Air Oxidation on the Dissolution Rate of LWR Spent Fuel" (Gray, 1992) was approved, presented at the Materials Research Society meeting in Boston, Massachusetts, November 30-December 4, 1992, and published in the Proceedings.

Subactivity 1.5.2.1.2 - Oxidation of spent fuel. The oxidation drybath 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 over seven 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 " $UO_{2.4}$ ". The excess oxygen atoms means that the  $U_4O_9$  phase is non-stoichiometric. Also, the  $U_4O_9$  with an O to U of ( $<2.4$ ) is metastable, because the  $U_3O_7$  ( $UO_{2.33}$ ) lattice structure is also stoichiometrically accessible. Some 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 spent fuel degradation by oxidation and the potential for higher dissolution rates of the higher oxidation phases, plans are being completed to run a drybath at a higher temperature ( $\sim 250^\circ\text{C}$ ). In this temperature range, the transition of some existing  $U_4O_9$  (at  $UO_{2.4}$ ) and some "fresh"  $UO_2$  spent fuel multi-fragment samples will be tested. 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.

In addition to the drybath oxidation activity, the phase transition kinetics will also be quantified by a restart of the TGA activities. Although the support is limited, planning documents are being completed and a limited amount of TGA testing will be performed in FY 1993. Results of the transition kinetics, and a measure of the relative stability of  $U_4O_9$  lattice are important to obtaining a spent fuel oxidation/degradation time response model. Based on preliminary spent fuel dissolution rate testing, the  $U_4O_9$  phase (with  $UO_{2.4}$  oxygen) is not much different in dissolution rate from the  $UO_2$  phase. However, a transition of  $U_4O_9$  to other phases, particularly  $U_3O_8$ , results in a  $\sim 30$  percent volume increase and a highly degraded spent fuel waste form. The  $U_3O_8$  oxidized waste form is highly degraded because the volume increase can create a flaked-powdered form and significantly increase the exposed spent fuel surface area which may be potentially wetted with water. The higher temperature ( $\sim 250^\circ\text{C}$ ) drybath testing and a restart of the TGA testing activities will address the phase transitions kinetics for a range of available spent fuel types. Furthermore,  $U_3O_8$  created in the drybath testing will be well-characterized and will provide quality controlled samples to the ongoing spent fuel dissolution activities.

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A PNL staff member visited LLNL to discuss plans for the startup of a new dry bath oxidation test. This test, to be performed at 255°C, will be used to determine the  $U_4O_9$  to  $U_3O_8$  transition. A test plan addendum was completed and sent to LLNL for review and approval.

The paper entitled "Methodology for Determining MCC Spent Fuel Acquisitions" (Marschman et al.) was reviewed by LLNL technical staff and returned to the first author with review comments.

Activity Plan D-20-44, Revision 1, "Thermogravimetric Analysis for Spent Fuel Oxidation Testing" and Activity Plan D-20-45, Revision 1, "Low-Temperature Oven Method for Spent Fuel Oxidation Testing" were completed and distributed. A Change Notice was completed for Activity plan D-20-45 which added an appendix to perform the drybath tests at ~250°C.

A paper entitled "Kinematics and Thermodynamics of Non-Stoichiometric Oxidation Phase Transitions in Spent Fuel" (Stout, et al., 1993) was presented at the Materials Research Society meeting in Boston, Massachusetts, November 30-December 4, 1992.

A paper entitled "Effects of Fission Products on Air-Oxidation of LWR Spent Fuel" (Thomas, 1992) was approved and submitted to the Journal of Nuclear Materials.

Subactivity 1.5.2.1.3 - Corrosion of zircaloy. No progress during the reporting period; this is 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 is 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 is an unfunded activity.

Subactivity 1.5.2.1.6 - Other experiments on the spent fuel waste form. No progress during the reporting period; this is an unfunded activity.

**Forecast:** The oven dry bath oxidation testing of spent fuel at PNL will continue and will provide oxidized spent fuel samples for spent fuel dissolution activities. A set of oven dry bath oxidation tests will be initiated at a temperature of ~255°C to obtain  $UO_2$  to  $U_4O_9$  to  $U_3O_8$  phase transition and oxidation kinetic data on spent fuels. The phase transition kinetics of  $U_3O_8$  results in a highly degraded waste form that significantly increases potential waste form surface area. TGA oxidation testing at PNL will also be initiated to characterize the  $U_4O_9$  to  $U_3O_8$  oxidation phase transformation. The spent fuel (PNL) and  $UO_2$  (LLNL) dissolution activities will continue; an oxidized spent fuel dissolution test matrix will be planned. Available spent fuel waste form information will be incorporated into the Waste Form Characteristics Report for WP design and PA use.

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### 2.6.2.3 Activity 1.5.2.2 - Characterization of the Glass Waste Form

#### Subactivity 1.5.2.2.1 - Leach testing of glass.

The glass leach testing activity has received limited funding in FY 1993. The N2 tests (SRL actinide-doped glass) continue with no sampling period occurring this reporting period. These tests have been in progress for 364 weeks. The N3 tests (ATM-10, a West Valley actinide-doped glass) continue and have been in progress for 282 weeks.

SIP-WF-02, Revision 0, "YMP Glass Waste Form Testing" was transmitted to YMPO for approval.

A draft was completed of the Technical Implementing Procedure "Procedure for Flow-Through Leach Experiments" which will be reviewed and submitted for approval as a controlled document.

Subactivity 1.5.2.2.2 - Materials interactions affecting glass leaching. No progress during the reporting period; this is an unfunded activity.

Subactivity 1.5.2.2.3 - Cooperative testing with waste producers. No progress during the reporting period; this is an unfunded activity.

**Forecast:** The long-term glass waste form alteration testing at ANL will be maintained but no additional characterization activities will take place at existing funding allocations. Available glass waste form modeling information will be reviewed and incorporated into the Waste Form Characteristics Report for WP design and PA use.

### 2.6.2.4 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 (YMIM) has been revised in language C++ for added flexibility. Simple models are being developed to assess thermal loading scenarios and ACD designs.

Subactivity 1.5.3.1.2 - Separate scenarios into anticipated and unanticipated categories. No progress during the reporting period; this is an unfunded activity.

Subactivity 1.5.3.1.3 - Development of parameters describing the scenarios. Development of YMIM to analyze scenario inputs continued.

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.

**Forecast:** The YMIM is being converted to C++ and distributed to YMP participants for collaborative analysis. Scenarios will be studied for TSPA-2.



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### 2.6.2.5 Activity 1.5.3.2 - Develop Geochemical Speciation and Reaction Model

Subactivity 1.5.3.2.1 - Develop data base for geochemical modeling. The GEMBOCHS data base and software library were transferred from the local Sun 3/260 server to a new, dedicated Sun SPARCstation2. This transfer, which involved upgrading (to Version 6.4/03) and expanding (to include WINDOWS/4GL and INGRES/net) the local INGRES installation as well as dependent modification of all GEMBOCHS components (GEMBOCHS, CNGBOCHS, DBAPP, D0OUT, etc.) has resulted in dramatically improved performance for each data base and software module.

The detailed testing of program D0OUT using the recently restructured (August 1992) GEMBOCHS data base was initiated and completed. This critical testing activity was carefully documented in the report entitled "Test Report for D0OUT-8612-SRC-V25, Revision 0" (Lundeen).

The prototype development of a WINDOWS/4GL (mouse-driven) version of D0OUT, was completed. This Graphical User Interface (GUI) software facilitates interactive point-and-click generation of thermodynamic data files for use with EQ3/6, GT and other geochemical modeling packages. The program is currently undergoing local beta testing.

A dedicated directory was established on the GEMBOCHS SPARCstation2 where the new generation of GUI GEMBOCHS software will reside; the D0OUT prototype is the first such program available.

Programs DBAPP and D0OUT were used to generate two revised suites of thermodynamic data files (DATA0 suites R17-R18) that support the EQ3/6 geochemical modeling package. These new data files together with the corresponding DATA1 suites were transferred to a dedicated directory where they can be accessed by local EQ3/6 users.

D0OUT was modified to permit generation of DATA0.SUP files (limited to the SUPCRT92 subset of species) that contain P/T-dependent volume and enthalpy grids in addition to the usual equilibrium-constant grids. These files were generated for use with a new development version of EQ3/6 that accounts for pressure effects in the calculation of activity coefficients.

DBAPP was modified such that anyone having a log-in account on the local Sun network can now run this code and review GEMBOCHS data from their own account. Addition, deletion, or modification of these data remains password-restricted to GEMBOCHS staff members.

Extensive modifications of the CNGBOCHS package were initiated and completed; these were necessitated by: (1) transfer of the GEMBOCHS system to the SPARCstation 2 with its upgraded INGRES environment; and (2) planned use of this automated change-request package by other LLNL research groups (in addition to GEMBOCHS and EQ3/6, for whom the package was originally designed).

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A paper entitled "CNGBOCHS: An Integrated Ingres-Email-Interleaf System for Processing Change Request Associated with the GEMBOCHS Data Base and EQ3/6" (Daveler) has completed the internal review process and been returned to the author for comment resolution.

Subactivity 1.5.3.2.2 - Develop geochemical modeling code. This activity maintains and develops the EQ3/6 software package for use in NFE characterization, site characterization and performance analysis. The most recently released version is Version 7 which is being maintained. Documentation for this version to satisfy the requirements of NUREG-0856 was completed and published during the review period. Version 7 is also the subject of a qualification activity independent of the code author. Version 8 of EQ3/6 is now being developed.

Three documents pertaining to the development of Version 8 were written, reviewed, and approved: (1) ISP-NF-08, "Individual Software Plan for EQ3/6 Version 8 and Subsequent Versions", (2) "Software Requirements Specification for Version 8 of EQ3/6", and (3) "Software Design Documentation for EQ3/6 Version 8".

The actual hands-on development of Version 8 has started. New capabilities are being added to model ion exchange redox disequilibrium along reaction paths and thermodynamic pressure correction. Some new numerical methods are also being implemented.

A 486 PC was received and installed in December. This will be used as a second host platform for EQ3/6 (the first is a Sun SPARCstation). The Lahey F77L EM/32 FORTRAN compiler was received and is being installed on the 486 PC. Future versions of EQ3/6 will be supported on both platforms.

A DOS emulator was set up on the Sun SPARCstation to perform UNIX to DOS conversions (the emulator is roughly equivalent to a 286 PC). The SPARC is now capable of writing compressed DOS files on DOS-formatted floppies. Version 7.1 of EQ3/6 was transferred to the 486 PC in this manner. It is being ported onto this machine. A few minor bugs in the Version 7.1 release were reported by users at ANL and the CNWRA. These bugs are being analyzed.

A Version 7.2 update is being prepared to address all bugs discovered in Version 7.1. It will be PC-compatible.

An LLNL staff member met with I. Puigdomenech of the Nuclear Energy Agency Data Bank on December 7, 1992 to discuss the state of EQ3/6 development.

The second geochemical code user manual entitled "EQPT, A Data File Preprocessor for the EQ3/6 Software Package: User's Guide and Related Documentation, Version 7.0, Part II" (Daveler and Wolery, 1992) was approved by the OCRWM. The third geochemical code user manual entitled "EQ3NR, A Computer Program for Geochemical Aqueous Speciation-Solubility Calculations: Theoretical Manual, User's Guide and Related Documentation, Version 7.0, Part III" (Wolery, 1992) was approved by OCRWM. The fourth

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geochemical code user manual entitled "EQ6, A Computer Program for Reaction Path Modeling of Aqueous Geochemical Systems: Theoretical Manual, User's Guide and Related Documentation, Version 7.0, Part IV" (Wolery and Daveler, 1992) was approved by OCRWM.

**Forecast:** A GEMBOCHS patron account will be established; this log-in 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 on-line services will provide convenient and timely access to GEMBOCHS for offsite YMP participants. A WINDOWS/4GL (GUI) version of D0OUT will be completed and added to the GEMBOCHS software library. This extremely user-friendly, mouse-driven code will facilitate point-and-click generation of thermodynamic datafiles for use with EQ3/6, GT, and other geochemical modeling packages. Development will begin on a WINDOWS/4GL version of DBAPP; a prototype version will be completed. This code will permit point-and-click review of GEMBOCHS data by on- and offsite GEMBOCHS users; addition, deletion, or modification of these data will remain password-restricted to GEMBOCHS staff members. 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 D0OUT. As required by GEMBOCHS and/or EQ3/6 modifications, DBAPP and D0OUT will be used to generate revised suites of thermodynamic datafiles (DATA0 suites) that support EQ3/6.

### 2.6.2.6 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 1993.

### 2.6.2.7 Activity 1.5.3.4 - Generate Models for Release From Glass Waste Forms

A paper entitled "Modeling SRL Glass Dissolution: Combined Constraints from Varying SA/V, Flow-Through, Surface Titration, AEM and NMR Experiments" (Bourcier et al.) is being prepared for presentation at the 95th American Ceramic Society meeting in Cincinnati, Ohio April 18-22, 1993.

Subactivity 1.5.3.4.1 - Generate release models for glass waste forms. No progress during the reporting period; this is an unfunded activity.

**Forecast:** No activity is planned for FY 1993.

### 2.6.2.8 Activity 1.5.3.5 - Waste Package Performance Assessment Model Development

Subactivity 1.5.3.5.1 - Development of system model. Information combined from geochemical, waste form, and hydrology areas indicates that the water-to-fuel-surface ratio inside breached WPs is likely to be low, the waste form itself may then dominate the water chemistry, and the wetted spent fuel alteration rate may be high. Early work on geochemical reaction progress was combined with recent determinations of spent fuel and  $\text{UO}_2$  surface reaction rates in various water chemistries and with hydrologic estimates of water flux and spent fuel surface wetted. The water flux to surface area ratio is estimated to be of the order of 5 mm/year or perhaps much lower. Even at the lower end of the surface reaction rates, enough uranium is reacted to precipitate most of the silica in the ground water. Then, the solubility of uranium increases by several orders of magnitude and the surface reaction rate increases at least in some low-silica chemical conditions studied to date. Conclusions at this early stage are: (1) a low water-to-fuel ratio is an important parameter range to be studied in spent fuel reaction measurements, and (2) a high reaction rate under repository conditions is at least plausible now.

The performance allocations assigned at the time of writing the SCP can be reconsidered based on recent data and PAs. The concept of spatial variability in the downward ground-water infiltration, combined with existing estimates of the range of infiltration values to be anticipated, makes it plausible that more than 10 percent of the WPs can become "wet" (i.e., have some trickling water flow). Mass transfer resistance (e.g., limited diffusion) was also assigned a role in the performance allocation, as a multiplicative factor to reduce any release rate. It is now known that the effect of diffusion combines with other processes as a time convolution rather than a multiplicative factor. Hence, diffusion is less effective in some geometric designs, although diffusion could become a controlling factor for other designs. The spent fuel alteration rate could thus be much higher than allocated. On the favorable side, hydrologic considerations indicate that only a small fraction of the spent fuel within a breached container could be wetted by the limited amount of water available. Cladding could also play a major role. The compact repository design concept could also make a major contribution because of its extended dryout condition.

Modeling has been done to determine whether spent fuel cladding breach will occur for a variety of repository configurations. The phenomenon involves the temperature history of the cladding, stress from internal gas pressure, and creep toward eventual failure of the cladding by creep rupture. The creep rate is strongly temperature dependent. The model parametrizes the cladding's temperature time history as a function of several repository design parameters. This has been parametrized for the compact repository (large spent fuel packages in drifts), using thermal calculations from the paper "Drift Emplaced Waste Package Thermal Response" (Ruffner et al., 1993) for the drift and container-surface temperatures, and using an analysis of an equal-sized transportation container (with an adjustment for a disposal-only function) to get the edge-to-center temperature rise as a function of container heat generation rate. The creep rate and creep failure equations are taken from Chin and Gilbert (1989). Some of the repository configurations used in the parametric study of Ruffner et al. will preserve a median spent fuel rod from creep rupture and some will not. For example, the configuration with 21 PWR assemblies per package, 33 GWd/MTU burnup, 30-year age at

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emplacement, and 22 m (72 ft) spacing of packages will give creep only up to about 25 percent of the limit, and has an AML of 71 MTU/a (about 1.5 times the SCP-CDR AML), enough to provide substantial dryout of the host rock within and above the repository.

The modeling of thermal response was extended for drift-emplaced-package repository design concepts, to calculate container temperature history as well as cladding temperature history. The model is a parameterization of detailed calculations done in other tasks as just described. The container material has not been selected, and therefore the upper temperature limit has not been selected. Trial analyses show that feasible design parameters can meet temperature limits in the 200 to 300°C range with different AMLs. One selection has 155 MTU/a and a container temperature limit of 300°C; another has 92 MTU/a and a container temperature limit of 200°C. A container temperature limit even of 300°C is more of a constraint than is a cladding temperature limit of 350°C. This is not an optimization study; it is a feasibility study to select an appropriate design as the subject of a PA.

Revisions are being made to the PANDORA theoretical manual entitled "Post-Closure Performance Assessment of Waste Packages for the Yucca Mountain Project" by W. O'Connell, T. Ueng and L. Lewis and to the "PANDORA 1.1 User's Manual" by L. Lewis and C. Hardenbrook, as a result of technical publication review comments.

WP Subsystem Model software requirements analysis is continuing using the prototype code PANDORA 1.1. Computational procedures were modified in the prototype code to allow longer analysis time spans (>10,000 years) for application to higher APD repository design scenarios.

The LLNL EBS/NFE PA staff began a series of meetings to discuss issues and ideas for a source term description incorporating explicit thermal effects. LLNL hosted a two day visit by the TSPA staff from SNL to discuss the source term scope for TSPA-2. A preliminary scope has been prepared to elicit feedback from other participants. A series of technical work sessions has begun with Waste Form, WP Materials, and NFE personnel to develop mechanistic process descriptions to be abstracted into the improved source term.

Subactivity 1.5.3.5.2 - Development of uncertainty methodology. The paper entitled "The Role of Multiple Barriers in Assuring Waste Package Reliability" (Bradford) has completed internal review and has been returned to the author for comment resolution.

Subactivity 1.5.3.5.3 - Water flow into and out of a breached container. No progress during the reporting period; this is an unfunded activity.

**Forecast:** Work will continue on sensitivity analyses using PANDORA 1.1, the TSPA-1 source term and the controlled samples system. Thermal effects on NFE and EBS processes will be abstracted into the TSPA-2 source term.

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### 2.6.2.9 Activity 1.5.4.1 - Deterministic Calculation of Releases From the Waste Package

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

**Forecast:** No activity is planned for FY 1993.

### 2.6.2.10 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 SIP for WP PA has been approved for interim use and has been submitted to YMPO.

**Forecast:** No activity is planned for FY 1993.

### 2.6.2.11 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.

#### Determination of Elemental Profiles in Rocks, Minerals, and Glasses using the Ion Microscope

Diffusion experiments continued using single crystals of clinoptilolite which were saturated with Na, Ca, and K using 1 N salts. These crystals were mounted in stainless steel rings using epoxy and polished in preparation for secondary ion mass spectroscopy (SIMS) analysis. A tentative SIMS analysis protocol was developed.

Preliminary samples were selected and a preliminary experimental protocol for elevated temperature cation exchange measurements on clinoptilolite was developed and experiments have begun.

Optimum etching times and temperatures for developing autoradiography film were identified. Development of techniques to obtain high contrast positives from radiography film were initiated.

#### Interactions of Actinide-bearing Solutions with Rock Core Samples

The core was removed from the core flow-through apparatus. Examination of the jacket and seals surrounding the core indicated that the synthetic oil used to apply the confining pressure to the core had reacted with the epoxy sealer.

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Preparation of a new sample for the flow-through apparatus was initiated. To simulate a fractured sample, a cylindrical core of Topopah Spring tuff was taken and then sawed in half longitudinally. The core was oven dried to a constant weight and then immersed in filtered (0.2  $\mu\text{m}$ ) deionized water for hydration prior to the flow tests.

Programming and hardware changes to the flow-through apparatus were begun to automate the measurement of fluid flux. The balance, data logging cables and Lab View software options for automating flow rate measurements were installed. Work continues on altering the balance to accept the effluent feed tube.

The saw-cut face of as-cut, rinsed in deionized water, and ultrasonically cleaned samples of tuff were examined under the SEM to look for fine particles that could be mobilized in flow experiments. The as-cut and rinsed samples showed significantly more fine ( $\sim 1 \text{ mm}$ ) particles than did the sample that had been ultrasonically cleaned. The surface of the saw-cut was cleansed of adhering particles using an ultrasonic probe. The core was assembled and jacketed in preparation for emplacement in the flow-through apparatus. The core was sterilized in situ by subjecting it to two heat treatments at  $140^\circ\text{C}$ . Room temperature hydraulic measurements were begun.

Later testing found that the saw-cut fracture provided too much resistance to flow. The core was removed from the jacket and gold spacers (1 mil) were placed between the core halves. Initial tests suggest that flow rates were adequate at the differential pressures expected to be used in the experiment.

An isoparaffinic solvent was found to be compatible with materials in the flow-through apparatus and will be used for applying confining pressure to the core. The material was tested by using a sample of jacket material with epoxy sealer and immersing it in the vent and heating it at  $150^\circ\text{C}$  and 50 bar pressure to test compatibility of the materials under the maximum temperature expected in the flow-through apparatus.

The deionized (Milli-Q) water used for making input solutions for the flow tests was examined using TEM. It was found that small ( $<0.2 \text{ mm}$ ) particles of silica were present in the unfiltered water. All water used in the initial flow tests was filtered through 0.015 mm membrane filters to prevent introduction of colloidal silica. Further results now indicate that the silica particles previously observed are no longer present and that filtration of the Milli-Q water resulted in a very low background of suspended particles. Analysis of holey-carbon coated TEM grids supplied by various vendors showed that a significant difference exists in the background colloidal particle load on the grids. Grids with the lowest background of particles were ordered.

**Forecast:** The preliminary experiment to measure the effusion profiles of Cs, Sr, and U in single crystals of clinoptilolite at various temperatures has begun and will continue through the end of the FY.

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### **2.6.3 Characteristics and Configurations of the Waste Packages (SCP Section 8.3.4.3)**

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

**Forecast:** No activity is planned for FY 1993.

### **2.6.4 Waste Package Production Technologies (SCP Section 8.3.4.4)**

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

**Forecast:** No activity is planned for FY 1993.

### **2.6.5 Waste Package Performance (SCP Section 8.3.5.9)**

#### **2.6.5.1 Activity 1.4.1.1 - Integrate Design and Materials Information (Metal Container)**

An LLNL staff member attended the ASTM meeting in Miami, Florida, November 16-18, 1992. Container materials researchers from the NRC and the international community presented their results. ANL presented data from 19,000 hrs of accelerated testing in UE-25 J #13 water of Incoloy 825, stainless steel 304 and stainless steel 316; these tests began under LLNL sponsorship and have continued using ANL internal funds. During the test, which is equivalent to 300 to 1,000 years of service environment exposure, no environmentally assisted cracks formed in the specimens. Another 35 months of testing would extend the equivalent service life exposure to 10,000 years.

Members of the EBS Materials Characterization Technical Area met with representatives of YMPO and the CRWMS M&O on February 11, 1993, to discuss recent developments in WP designs, fabrication, and materials. An outline for a limited amount of experimental work was developed. The purpose of this work is to support thermal load decisions on the extended dry concept for long term containment.

At the request of the CRWMS M&O, an LLNL staff member provided estimates of the material costs for the three materials recommended for the YMP Conceptual Design (single, material, thin-walled container), nickel-rich Alloy 825, nickel-base Alloy C-4, and Grade 12 titanium. The costs were based on manufacturing estimates for plate stock.

Laboratory equipment was moved and reinstalled in readiness for performing some experimental work. A purchase order for a TGA system was submitted for a capital equipment purchase. The TGA system will be used for sensitively determining the corrosion and oxidation rates of metals as a function of temperature and humidity.

**Subactivity 1.4.1.1.1- Mechanical properties.** No progress during the reporting period; this is an unfunded activity.



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Subactivity 1.4.1.1.2 - Microstructural properties. At the request of the Performance Analysis Technical Area, estimates were provided of the reduction of container wall thickness of carbon steel engineered barrier overpacks for 10,000 years based on the extended dry WP design concept. These estimates were based on low temperature oxidation of steel as the operable degradation mode.

Subactivity 1.4.1.1.3 - Physical properties. A copy of LLNL files was provided to the CRWMS M&O. The thermal calculations performed by LLNL staff have been archived in the LLNL computer center. They will be printed and provided to CRWMS M&O. These activities will complete the transition to the CRWMS M&O.

Subactivity 1.4.1.1.4 - State of stress in the container. No progress during the reporting period; this is an unfunded activity.

Subactivity 1.4.1.1.5 - Characterization and inspection of weld integrity. No progress during the reporting period; this is an unfunded activity.

Subactivity 1.4.1.1.6 - Characterization of the container surface. No progress during the reporting period; this is an unfunded activity.

Forecast: The revision of the SIP for the Metal Barrier Selection and Testing Task - WBS 1.2.2.3.2 will be completed.

Acquisition of the TGA system will continue. The TGA system will be used for sensitively determining the corrosion and oxidation rates of metals as a function of temperature and humidity.

The slow crack growth monitoring system at LLNL will be started. The crack growth studies at ANL will be resumed.

### **2.6.5.2 Activity 1.4.1.2 - Integrate Design and Materials Information (Alternate Barriers Investigation)**

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

Forecast: No activity is planned for FY 1993.

### **2.6.5.3 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. The paper entitled "Selection of Candidate Container Materials for the Conceptual Waste Package Design for a Potential High Level Nuclear Waste Repository at Yucca Mountain" (Van Konynenburg et al., 1993) was approved by OCRWM and published.

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Subactivity 1.4.2.1.2 - Material selection. No progress during the reporting period; this is an unfunded activity.

Forecast: No activity is planned for FY 1993.

### **2.6.5.4 Activity 1.4.2.2 - Degradation Modes Affecting Candidate Copper-Based Container Materials**

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

Forecast: No activity is planned for FY 1993.

### **2.6.5.5 Activity 1.4.2.3 - Degradation Modes Affecting Candidate Austenitic Materials**

Subactivities 1.4.2.3.1 through 1.4.2.3.9. No progress during the reporting period; these are unfunded activities.

Forecast: No activity is planned for FY 1993.

### **2.6.5.6 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 is 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 is an unfunded activity.

Subactivity 1.4.2.4.3 - Assessment of degradation modes affecting bimetallic metal systems. Work is continuing on compiling information on carbon steels, low alloy steels, and cast irons for a degradation mode survey on this class of materials. Thick sections of these iron-base materials could be used as an overpack for multiple purpose containers, and their use would be consistent with strategies toward high thermal loads to keep the NFE dry for an extended period of time.

Forecast: A draft of the degradation mode survey is expected to be completed by the end of 1993.

Subactivity 1.4.2.4.4 - Laboratory test plan for bimetallic/single metal material systems. No progress during the reporting period; this is an unfunded activity.

Subactivity 1.4.2.4.5 - Assessment of degradation modes in coatings and filler systems. No progress during the reporting period; this is an unfunded activity.

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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 is an unfunded activity.

**Forecast:** For the unfunded activities, no activity is planned for FY 1993.

### **2.6.5.7 Activity 1.4.3.1 - Models for Copper and Copper Alloy Degradation**

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

**Forecast:** No activity is planned for FY 1993.

### **2.6.5.8 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 are unfunded activities.

Subactivity 1.4.3.2.6 - Pitting, crevice, and other localized attack. The paper entitled "Modeling Pitting Corrosion Damage of High-Level Radioactive-Waste Containers, with Emphasis on the Stochastic Approach" (Henshall, 1993) was approved by OCRWM and published.

Subactivities 1.4.3.2.7 and 1.4.3.2.8. No progress during the reporting period; these are unfunded activities.

**Forecast:** No activity is planned for FY 1993.

### **2.6.5.9 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 is an unfunded activity.

**Forecast:** No activity is planned for FY 1993.

### **2.6.5.10 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 is an out-year activity.

**Forecast:** No activity is planned for FY 1993.

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### **2.6.5.11 Activity 1.4.5.1 - Determination of Whether the Substantially Complete Containment Requirement is Satisfied**

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

**Forecast:** No activity is planned for FY 1993.

### **2.6.5.12 Activity 1.5.5.2 - Radionuclide Transport Modeling in the Near-Field Waste Package Environment**

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

**Forecast:** No activity is planned for FY 1993.

## **2.7 PERFORMANCE ASSESSMENT**

### **2.7.1 Waste Retrievability (SCP Section 8.3.5.2)**

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

**Forecast:** No activity is planned for FY 1993.

### **2.7.2 Public Radiological Exposure - Normal Conditions (SCP Section 8.3.5.3)**

Throughout this reporting period, SNL staff met regularly with YMPO and T&MSS staff to discuss the development and application of methodologies for evaluating IITS and Items Important to Waste Isolation (IITWI). Before initiating work on IITS, several meetings were held with CRWMS M&O reviewers to resolve comments on the report, "Identification of Structures, Systems, and Components Important to Safety at the Potential Repository at Yucca Mountain" (Hartman and Miller, 1991).

Standard probabilistic risk assessment methods were used 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. The results of this work are presented in a report entitled "Preclosure Radiological Safety Evaluation: Exploratory Studies Facility" (Schelling and Smith), which is currently undergoing YMP policy review for publication. The report will be used to support the determination by the Assessment Team of IITS for the ESF.

**Forecast:** The report referenced above will be published following YMP approval. Future probabilistic risk assessments for determining IITS will be performed by the CRWMS M&O. SNL staff will work with CRWMS M&O to ensure continuity of the work. The CRWMS M&O also has responsibility for performing analyses for the determination of

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IITWI. SNL will provide PA support for addressing concerns regarding waste isolation impacts of activities that could impact barrier performance.

### **2.7.3 Worker Radiological Safety - Normal Conditions (SCP Section 8.3.5.4)**

The CRWMS M&O wrote a draft plan to perform a preclosure probabilistic risk assessment on the Items IITS for the MGDS components present in the ESF. This plan was presented to YMPO and members of the Assessment Team. The plan entails conducting additional justification for accident scenario probabilities, to include radiological pathways, as well as performing sensitivity/uncertainty analysis of consequences associated with any likely or unlikely accidents.

The CRWMS M&O used the radiological pathways code GENII and a spreadsheet program to calculate 50-year committed dose-conversion factors for drinking water pathways containing multiple radionuclides of importance to long-term releases from the MGDS. To enhance inhalation dose models analytical approximations were developed for empirical plume depletion graphs contained in NRC Regulatory Guides. These will allow inclusion of depletion parameters in uncertainty and sensitivity analysis.

The CRWMS M&O initiated review of previously published preclosure MGDS accident-induced releases. Accident/reliability data was obtained for underground structures and equipment.

Spreadsheet calculations were begun using dose conversion factors generated by GENII (the radiological pathways code), to calculate the dose consequences outside the controlled area of an accidental underground release at the MGDS. The CRWMS M&O began integrating spreadsheets containing the following: (1) radionuclide inventories of solid and volatile components of SNF (PWR and BWR) at selected burnup levels and decay times, high-level defense waste, and fuel assembly crud, (2) inhalation 70-year committed dose conversion factor for each organ and each isotope, and (3) a spreadsheet to calculate atmospheric dispersion coefficients for user-defined atmospheric stability conditions, wind speeds and building wake effects. The above data area was used to identify the set of radionuclides that contribute 99.9 percent of the dose to the four highest exposed organs. The results showed that over the short term (to the sealing of the repository) the full inventory of the SNF can, without loss of accuracy, be reduced to eight isotopes and that the most important organ is the bone surface for particulate releases. The radioisotope inventories (from Characteristics Database) were defined to be used in ESF investigation for range of SNFs and high-level defense waste requested by the Assessment Team.

The CRWMS M&O developed a simple three-dimensional transport model of two WP designs and emplacements for parametric evaluations using the MCNP (Monte Carlo Neutral Particle) transport code. Currently evaluating results by comparison to MicroShield-4 calculations. The calculations represent Neutron Dose, Neutron generated Secondary Photon Dose, and primary Photon Dose for a wide variety of WP capacities and thickness. The results indicate that the borehole design can be modified such that radiation doses in the

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access drifts will be low enough to allow for manned operations. The analyses completed to date indicate a high value in commencing quality assured radiation dose rate calculations to provide the guidance necessary to focus Repository and EBS ACD.

PA activities supporting specific studies or activities are discussed in the appropriate portions of Section 2.7.

**Forecast:** These efforts will continue to be refined during FY 1993 and presented to the Assessment Team as part of a Probabilistic Risk Assessment.

### **2.7.4 Accidental Radiological Release (SCP Section 8.3.5.5)**

Progress on this activity during the reporting period is discussed in the previous section (2.7.3).

**Forecast:** The forecast for this effort is provided in the previous section (2.7.3).

### **2.7.5 Ground-Water Travel Time (SCP Section 8.3.5.12)**

#### **2.7.5.1 Activity 1.6.2.1 - Model Development**

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

**Subactivity 1.6.2.1.1 - Development of a theoretical framework for calculational models.** The development of a mathematical framework for the modeling of ground-water travel, as well as for other purposes, currently depends heavily on the acquisition of experimental data. The SCP activity under which such data are acquired is Activity 1.6.2.2.2, and the current work is summarized there.

**Subactivity 1.6.2.1.2 - Development of calculational models.** No progress during the reporting period; this is an unfunded activity.

**Forecast:** The forecast for Activity 1.6.2.2 also applies to Activity 1.6.2.1.

#### **2.7.5.2 Activity 1.6.2.2 - Verification and Validation**

**Subactivity 1.6.2.2.1 - Verification of codes.** Two abstracts by SNL authors were accepted for presentation at the winter AGU meeting in December, 1992: "An Experimental Investigation of Matrix Interaction on Fracture Flow" (Foltz et al., 1992); and "Efforts to Verify and Validate the Lagrangian-Eulerian Model of Hydrogeochemical Transport (LEHGC)" (Hopkins et al., 1992).

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The paper "Comparison of Numerical and Analytical Estimates for Effective Unsaturated Conductivities for Stratified, Heterogeneous Media" (Eaton and McCord, 1992) discusses results obtained with the LLUVIA-II code. It was also presented in the winter AGU meeting and published in the proceedings. It also briefly describes an investigation of non-isotopic aspects of nonstratified heterogeneous media. This investigation will aid in the understanding of the applicability of one-dimensional flow for the TSPA study.

The CRWMS M&O released an internal review draft of a report entitled "Review and Selection of Unsaturated Flow Models" to other PA contractors for comment. This review concluded that fracture-matrix interactions and nonequilibrium flow were not adequately addressed in codes currently in use within YMP. From among the codes available in YMP several were recommended to serve as host structures for the development needed to address these identified technical needs. A synopsis of this work, also entitled "Review and Selection of Unsaturated Flow Models" (Reeves et al., 1993) was submitted for presentation at the 1993 IHLRWM Conference. The report was reviewed by SNL staff. The report reviewed 17 unsaturated flow codes that have been developed for modeling water flow through unsaturated porous media. Of the 17 codes, seven were selected for further testing. One of the codes chosen was LLUVIA-II. Long execution times were encountered when LLUVIA-II was used to compute the Jornada Trench test problem. A copy of the LLUVIA-II deck that was modified for PC use was obtained and studied at SNL. The modifications appear to have been done correctly. A test case was executed on the Sun and Cray computers. In addition, a timing test program was written and run on the SPARC 2 and 10 and Cray computers. The resulting execution times appeared to be consistent. The results of these investigations were supplied to the CRWMS M&O staff.

Subsequent calculations by the CRWMS M&O staff compared LLUVIA-II results with those of five other YMP codes for Jornada Trench test problems. These calculations suggested that LLUVIA-II was very robust with respect to the rather severe nonlinearity present in the "Case B" test problem. They also indicated that the method-of-lines solver in LLUVIA-II requires a much higher level of accuracy than is generally necessary to characterize field data. This demand for high accuracy in turn causes LLUVIA-II execution times to be long compared to those of other codes.

A presentation on modeling flow in unsaturated fractured media was presented to a newly formed WIPP working group on modeling effects of fracturing for PA. The presentation summarized some of the work done for YMP to model flow in unsaturated fractured media.

Subactivity 1.6.2.2.2 - Validation of models. Numerous tours of the YMP flow and contaminant transport model validation laboratory were given for OCRWM, LLNL, University of Texas, LBL, Institut Francais du Petrole, and SNL.

The YMP flow and contaminant transport model validation laboratory supported research and education opportunities for four doctoral students, four masters candidates, and nine undergraduate students during the past six months. All students were supported through

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a variety of OCRWM and SNL fellowship programs designed to promote interest in science and engineering related to waste management issues.

### Unsaturated Flow Through Single Fractures:

Four papers were prepared for presentation and are in the Proceedings of the 1993 IHLRWM Conference to provide a good synopsis of current investigations of unsaturated flow through single fractures. "Small-Scale Behavior of Single Gravity-Driven Fingers in an Initially Dry Fracture" (Nicholl et al., 1993a) presents experiments that investigate the behavior of individual, gravity-driven fingers in an initially dry, rough-walled analog fracture. "Wetting Front Instability in an Initially Wet Unsaturated Fracture" (Nicholl et al., 1993b) presents experimental results exploring gravity-driven wetting front instability in a pre-wetted, rough-walled analog fracture. "Aperture Characteristics, Saturated Fluid-Flow, and Tracer-Transport Calculations for a Natural Fracture" (Reimus et al., 1993) discusses the determination of the aperture distribution within a natural fracture from surface profile data taken with a noncontact laser profilometer. "Modeling Gravity-Driven Fingering in Rough-Walled Fractures Using Modified Percolation Theory:" (Glass, 1993) discusses the modification of pore-scale invasion percolation theory for imbibition of wetting fluids into fractures.

A natural tuff fracture, collected from the Bandelier tuff near Los Alamos, New Mexico, was prepared for manufacture of cast replicas. The fracture was diamond-sawn to a rectangular shape. After careful removal of surface debris, the sample was allowed to equilibrate with ambient conditions in the laboratory. Both sides of the fracture were fixed in plastic outer containers with epoxy and set aside to cure. The epoxy surrounding the rock is then milled flat to provide a level reference surface. The prepared originals are used to cast silicon rubber molds for manufacture of epoxy replicas of the original surfaces. This preliminary run is being used as a test bed to refine the manufacturing process; staff then expects to investigate a variety of fracture surfaces.

A natural fracture from the Bandelier tuff was used in an experiment demonstrating gravity-driven wetting front instability. The fracture measured 33 cm x 66 cm. Thirteen milliliters of deionized water tagged with a blue dye was introduced to the top of the vertically oriented fracture through an array of fifteen 10cc syringes. The fluid was allowed to infiltrate for several minutes and the fracture disassembled for inspection. The wetted structure clearly showed the development of individual fingers oriented primarily in the downward direction.

Preliminary experiments investigating the effects of air entrapment on fracture permeability and tracer migration were begun. Scoping experiments were performed to help delineate an appropriate methodology. In an attempt to improve spatial resolution, efforts are being made to match the index of refraction between the experimental fluid and the analog fracture. Concurrent development of a computer-controlled solenoid valve system to control dye pulses is progressing.



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### Fracture-Matrix Interaction:

The results of the efforts relative to the investigation of fracture-matrix interaction have culminated in the completion of two papers. The first was presented at the 1992 Fall Meeting of the AGU in San Francisco, California, entitled "An Experimental Investigation of Matrix Interaction on Fracture Flow" (Foltz et al., 1992), and the second was developed for the 1993 IHLRWM Conference, "Experimental Investigation of Fracture-Matrix Interaction with Comparison to Numerical Simulation" (Foltz et al., 1993). Paramount to the modeling of unsaturated flow and transport through fractured porous media is a clear understanding of the processes controlling fracture-matrix interaction. As a first step toward such an understanding, two preliminary experiments have been performed to investigate the influence of matrix imbibition on water percolation through unsaturated fractures in the plane normal to the fracture. Test systems consisted of thin slabs of either tuff or analog material cut by a single vertical fracture into which a constant fluid flux was introduced. Transient moisture content and solute concentration fields were imaged by means of x-ray absorption. Flow fields associated with the two different media were significantly different owing to differences in material properties relative to the imposed flux. Richards' equation was found to be a valid means of modeling the imbibition of water into the tuff matrix from a saturated fracture for the current experiment.

### Field, Lab, and Numerical Experimentation to Determine Scaling Laws for Effective Media Properties in Heterogeneous Media:

Efforts toward understanding factors influencing the scaling of effective media properties were reported in a paper prepared for the 1993 IHLRWM Conference, "Scale Dependence of Effective Media Properties" (Tidwell et al., 1993) which discusses problems in which medial properties are measured at one scale and applied at another, scaling laws or models must be used to define effective properties at the scale of interest.

To facilitate the work described above, efforts have been made to design and construct an automated gas permeameter test system. The system is composed of a series of electronic mass flow meters and a pressure transducer coupled with an x-y positioning system, all of which are computer-controlled. The test system has recently been completed and is currently being tested and calibrated.

### Development/Validation of Seeps and Weeps Model:

Efforts under this activity were delayed due to uncertainty in the FY 1993 budget early in the FY. Initial work focuses on identification of analog field sites for study of fast pathways in the UZ. A contract is being established with the University of New Mexico to participate in this activity.

### Development of Experimental Capabilities:

To enhance the visualization capabilities of the SNL flow and contaminant transport laboratory, a Philips MG-1651 x-ray generator and tube head have been purchased. This

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system will be used to image moisture content and solute concentration fields in thin slabs of tuff or other porous materials at high temporal and spatial resolution. Current efforts are being made to purchase an x-ray film developer that will further facilitate the imaging process.

### Caisson Test:

The geochemical properties of a porous sand and several tracers (Ni, Br, and Li) have been characterized to design a joint SNL/Los Alamos caisson experiment for validation of reactive transport models. The mineralogy of the Wedron 510 sand was characterized by powder XRD; morphologies of sand grains and surface coatings were examined by petrographic microscope and scanning electron microscopy with energy dispersive analysis. The surface area was measured with the BET (Brunauer, Emmett, and Teller) method.

Chemical analyses of bulk compositions and surface coatings were made of several particle-size fractions and indicate that the surface coatings contain significant fractions of the Mg, Ca, Fe, and Ni in all size fractions. Acidimetric-alkalimetric titration curves for Wedron 510 sand and Min-U-Sil 5, a reference  $\alpha$ -quartz from the Pennsylvania Glass Corp. were obtained over the pH range 2.65 to 10 at increments of  $\sim 1$  pH unit. The pH shifts for pH  $< 9$  are consistent with the dissolution of the conjugate base of a weak acid and provide an estimate of the minimum carbonate content ( $0.96 \mu\text{moles/g}$ ) of the sand. Titration curves were obtained on the sand and Min-U-Sil 5 in both raw and surface-cleaned states to evaluate the effects of mineral surface coatings.

Studies of the adsorption of Ni as a function of pH by several kinds of laboratory ware used for sample collection tubes, syringes, and centrifuge tubes were carried out. These include low-density polyethylene, polypropylene, polyallomar, and polycarbonate. The results indicate that each of the plastics becomes a significant sorber of Ni under neutral and alkaline conditions; this effect will have to be accounted for in sorption and solubility experiments. To mimic long-term storage of acidified samples, a set of test samples containing either 0 ppb, 5 ppb, or 50 ppb of added Ni are being periodically sampled and monitored for evaporative losses. Initial results covering two weeks show negligible evaporation and no change in concentration. These studies also indicate that all of the plastics are suitable for use as geochemical sampling vessels for acidified solutions.

Long-term Ni solubility studies were carried out under  $\text{CO}_2$ -free conditions in 30 m/0.001 M NaCl electrolyte over the pH range 5 to 10. The results to date establish that the published curve of Baes and Mesmer (1982) is a conservative lower limit for solubility on time scales of weeks.

Ni sorption was measured in batch experiments at solid:solution ratios of approximately 1:1 over the pH range 5 to 9.5 under  $\text{CO}_2$ -free conditions. Batch studies of sorption of Li and Br by Wedron 510 sand in 0.001 M NaCl were carried out under atmospheric conditions. Preliminary studies of sorption of mixtures of 100 ppb Ni, 10 ppm Li, and 115 ppm Br by the Wedron 510 sand under  $\text{CO}_2$ -free conditions were completed. Between pH 6 and 8, the amount of Ni sorbed increases from 0 to 100 percent. The calculated  $K_d$  values from pH 6.8

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to 7.8 range from 1.6 to 4.2 mL/g, and from pH 8.2 to 8.5,  $K_d$  values increase from 42 to 1,000 mL/g. The data suggest that the presence of Li may inhibit Ni sorption by the sand to a small degree.

Based on the above studies, the following geochemical parameter values were used for the purposes of caisson design:

Influent Ni tracer concentrations:	100 ng/g
Expected range of Ni $K_d$ :	15-90 mL/g
Influent Li concentration:	10 $\mu$ g/g
Expected Li $K_d$ :	0.2 mL/g
Influent Br concentration:	115 $\mu$ g/g
Expected Br $K_d$ value:	0 mL/g

Although the bulk chemistry and mineralogy suggest that the sand is predominately quartz, the surface studies indicate the presence of non-trivial amounts of carbonate, kaolinite, and iron-oxyhydroxides. It is proposed that the chemical composition of pore fluids with the caisson will be controlled by dissolution of quartz, carbonate cement, diffusion of atmospheric  $\text{CO}_2$  into pore fluids, hydrolysis of silanol ( $\text{SiOH}$ ) groups, and hydrolysis of  $\text{FeOOH}$  surface groups. It is anticipated that chemical conditions within the caisson will initially be transient, but that a steady-state chemical profile may eventually develop. The geochemical data obtained in preliminary characterization studies suggest that the range of probable tracer velocities will allow for detection of the tracers at sufficient depths (>100 cm) for modeling and within relatively short (<6 months) breakthrough times.

The experimental data suggest that a linear ( $K_d$ ) or an isotherm sorption model may adequately describe transport of Li. The sharp pH-dependent sorption edge for Ni suggests that a model describing the changes of pH and the concentrations of other solution species as a function of time and position within the caisson, and the concomitant effects of Ni sorption, may be required for accurate predictions of Ni transport. The results of future experiments will be interpreted under the formalisms of linear sorption ( $K_d$ s), nonlinear sorption, ion exchange, and the triple-layer model. The different approaches will be used to simulate transport of the tracers in the caisson; the validates of the sorption models for the conditions of the caisson experiment will be evaluated by comparing predicted and measured elution curves.

### Reactive Transport Model Development/Experimentation:

Review of the first draft of a User's Manual for the LEHGC code was initiated. Efforts to implement the LEHGC coupled reaction-transport computer code on a massively parallel architecture continued. Several benchmark test problems to evaluate the geochemical equilibrium calculation subroutines were designed and used to identify potential errors in the code. Additional features added to LEHGC 1.0 include multiple sorption sites and multiple ion-exchange sites. The computational efficiency of the code was enhanced by adding a new backward tracking routine and improving the computation of pointer arrays. A post-processor to produce files for two-dimensional concentration contour plots was developed.

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The draft technical procedure for Ni analysis using the graphite-furnace atomic absorption spectrophotometer has been revised to reflect improvements in operating procedures and data reduction. Operating procedures have been improved by eliminating spurious readings caused by sublimation of the sample matrix (e.g., NaCl and HNO<sub>3</sub>) and poor reproducibility of the configuration of the tip of the capillary tube of the auto-sampler. Data reduction has been improved by refining the calculation of the calibration curve and correcting for evaporation from the auto-sampler vial. Data quality has improved as a result of these optimizations. The useful dynamic range is 0 - 200 ppb Ni using standard operating parameters and a quadratic calibration curve. Precision appears to be approximately  $\pm 0.5$  percent or 0.2 ppb ( $1\sigma$ ), whichever is greater; the limit of detection appears to be  $\pm 0.2$  ppb.

Two techniques are being developed at the Massachusetts Institute of Technology to carry out in situ sorption studies in unsaturated media (sand). One method measures the concentration of aqueous uranium in wet sand using laser excitation. During the first six months of the FY, all equipment, including a Nd-YAG laser, optical breadboard, data acquisition software and hardware, and optomechanical pieces, was assembled. The technique was demonstrated by obtaining a clear time-dependent fluorescence signal from a 2 ppm uranium solution without use of a phosphorescence enhancer.

In the second method, sand-water systems at low degrees of saturation are equilibrated with enriched <sup>235</sup>U solution in a Turbula mixer and then flushed with enriched <sup>238</sup>U solution at a higher uranium content. With this technique it should be possible to extract the pore solution for analysis without causing the <sup>235</sup>U to desorb. The  $K_d$  of the unsaturated system can then be calculated from the <sup>235</sup>U/<sup>238</sup>U ratio of the extracted solution. Initial results are encouraging. A uniform distribution of water within an unsaturated sand was achieved with the Turbula mixer using about 1 mL in a 1-L chamber. It was observed that the Turbula produces little net directional head; once a uniform moisture distribution has been established, it appears that the Turbula will maintain it indefinitely. Evaluations started during the last six months have included uranium sorption onto the test vessels, kinetic studies of uranium sorption/desorption from the sand, and the effect of the solution/solid ratio on sorption.

**Forecast:** Primary efforts in the next six months are associated with studies of unsaturated flow through single fractures and include the completion of two journal articles. One article describes experiments and analysis of saturated flow through fractures to determine the effect of entrapped air and variable contact area on fracture permeability, and the other article describes experiments and analysis of gravity-driven fingering in fractures following the cessation of rainfall events in initially dry fractures. A report also will be completed describing situations in which gravity-driven fingering must be included in PA. A report will be published summarizing the preliminary results of scoping studies in large scales saturated pathways through unsaturated fractured rock, "seeps and weeps."

The caisson will be filled and instrumented, and the transport experiment will begin. Studies of the surface chemistry of natural and analog materials for the caisson experiment will continue. Ion exchange and surface complexation constants describing potential sorption of tracers (B, I, Ni, Li) will be obtained. The chemical evolution of water in caisson under

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steady and transient unsaturated and saturated flow and reactive transport in caisson will be modeled using the LEHGC code. Development of model of sorption of Ni onto mixtures of minerals and development of a method for measurement of  $K_d$  in unsaturated media will continue. The User's Manual for LEHGC will be submitted for SNL and QA management review by the end of the FY.

### 2.7.5.3 Activity 1.6.3.1 - Analysis of Unsaturated Flow System

Subactivity 1.6.3.1.1 - Unsaturated zone flow analysis. Papers that were accepted for the 1993 IHLRWM Conference include: "Recent Developments in Stochastic Modeling and Upscaling of Hydrologic Properties in Tuff" (Rautman and Robey, 1993) and "Numerical Methods for Fluid Flow in Unsaturated Heterogeneous Tuff" (Robey, 1993a).

"Geostatistics and Upscaling of Hydrologic Properties for an Adaptive Mixed Finite Element Method Applied to Unsaturated Porous Media Flow" (Robey, 1993b) was submitted for the Society for Industrial and Applied Mathematics Conference on Mathematical and Computational Issues in the Geosciences, to be held in Houston, Texas, April 19-21, 1993.

"Processes, Mechanisms, Parameters and Modeling Approaches for Partially Saturated Flow in Solid and Rock Media" (Wang and Narasimhan) has completed technical review and is now in SNL management review.

SNL staff attended the INTRAVAL meeting in San Antonio, Texas, November 9-12, 1992. At the meeting, SNL staff gave a presentation entitled "Geostatistics and Unsaturated Flow" (Wilson).

Two members from the SNL staff attended the INTRAVAL workshop in Las Vegas, Nevada, on December 7, 1992. One of the members presented the results from the preliminary modeling of the Yucca Mountain test case. The purpose of the meeting was to exchange information among the participants regarding modeling strategies.

As part of the continuing effort to develop probability models for the UZ, a member of the SNL staff attended the National Ground Water Association short course, "Probability, Statistics, and Geostatistics for the Environmental Professional," in Tampa, Florida, January 26-28, 1993.

A member of the staff participated in an NRC workshop in Tucson, Arizona, January 25-28, 1993, entitled "Flow and Transport Through Unsaturated Fracture Rock."

Because large amounts of data are expected to be included in the Performance Assessment Data Base (PADB), it has been necessary to design a special tracking system, with associated practices, in order to meet project requirements that control the flow of data through compilation and their use in analyses.

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The tracking system for the PADB now tracks source documents submitted to the PADB. The system records citation number, Project Data Tracking Number, title, date of document, type of data available in submittal, date each type of data was entered in the PADB, QA level of each type of data, and job number under which the work was done. Each submittal is assigned a unique number called the PA Number. The tracking system provides detailed information on discrete types of hydrogeologic parameters, rather than providing information only under broad categories.

The system now generates review sheets for each type of data. These sheets will be used by staff while reviewing data for possible submittal to the PADB. This use will improve the process of getting data into the data base by identifying needs for including test conditions and other required data.

### Data Compilation and Analysis:

Working through this new system, SNL staff completed a search and review of the Yucca Mountain hydrologic data in over 20 USGS and SNL documents. In addition, analog data were also extracted from reports on tuffs from Apache Leap (Arizona) and Mortendad Canyon (New Mexico). These tabular data, with particular emphasis on porosity and saturated hydraulic conductivity, were identified and provided for addition to the PADB.

The compilation for porosity and saturated hydraulic conductivity data for inclusion in the SNL PADB is essentially completed. Over ten documents have been reviewed to date. Data-review sheets were prepared for the PADB.

Bulk transmissivities and permeabilities were provided to SNL modelers working on the second cycle of the TSPA. The modelers requested bulk values to allow the models and analyses to replicate actual physical processes more representatively and realistically than if values from small, laboratory-derived samples were used.

Retrieval of saturated hydraulic conductivities from an old data base no longer maintained by SNL and from other documents (predominantly USGS Open File Reports) was completed. A data search and review for the next data of interest, bulk-permeability parameters, is under way. A review and evaluation of the Yucca Mountain borehole descriptive and geophysical logs has begun. The following information has been obtained to date:

- Porosity data from 4 submittals (852 records)
- Bulk-density data from 5 submittals (1745 records)
- Grain-density data from 2 submittals (63 records)
- Saturated hydraulic conductivity from 4 submittals (466 records)
- Permeability from 3 submittals (419 records)

The stratigraphy review of 21 boreholes, which started at the end of October, continues. The borehole data are compared with representations of Yucca Mountain. The review has produced an initial interpretation of holes USW G-4 and USW H-4. Comparison of borehole

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information for correlation will continue. The review compared borehole logs to determine major stratigraphy breaks for comparison with the analyst's generated sections.

The SNL staff developed methods to evaluate the stratigraphic (lithologic), core-photograph, and geophysical logs for Yucca Mountain; they prepared draft documentation. To support the analyst's modeling requirements, the stratigraphy was summarized according to degrees of welding, vitrification, and zeolitization. The boreholes examined during the reporting period were: USW H-1 & 3; UE-25a #1, 4, 5, 6 & 7; UE-25B #1; USW UZ #1, 4, 5, 6 & 7; and USW WT-2.

Saturated transmissivities, conductivities, and permeabilities were acquired or derived from YMP borehole and laboratory tests and analysis and provided to the SNL analysts. Since the bulk of the data was derived from small-scale core samples, some concerns are present with respect to scaling issues. Bulk properties were also requested and identified for a more realistic representation of the total Yucca Mountain hydrologic system that includes not only the matrix properties seen in the small core, but also includes the effects of any fractures present. The limited bulk hydrologic measurements from in situ tests performed on hydrologic field tests were identified and provided to the SNL analysts. A limited set of gas-permeability values derived from barometric-pumping tests was located and provided as additional collaborating data.

All the Yucca Mountain borehole stratigraphy interpretation needed for the TSPA was completed. Additional borehole descriptions for UE-25C #1, 2, & 3 were developed to provide more detail for model-stratigraphy development. This development was produced in nine or ten model columns representing the total Yucca Mountain stratigraphy; they will be the basis for the TSPA analyses of flow under certain conceptual models. The stratigraphy between holes USW H-4 and UE-25 UZ #16 shows very little dip. This area is bounded by faults that offset the regional dip of  $6^\circ$  to the southeast. Even the "accepted" regional dip of  $6^\circ$  may be too shallow by about  $0.8^\circ$ .

A GIS system is being utilized to establish a link to the PADB and provide easy accessibility by the analysts. This system has produced map coverages and location maps with transects, the perimeter drift boundary, topography, and borehole locations for a publication being prepared by an SNL staff member. A review of the available coverages in the GENISES data base, maintained for the project by EG&G, was accomplished, and documentation is being produced to provide traceability and explanation of the coverages provided by EG&G. Gaps in basic information have been identified. Coverages from GENISES were exported and provided to analysts for querying and display using ARC/View on their personal computers.

Work proceeded in the continuing effort to develop realistic ground-water flow models of Yucca Mountain. Presently, the effort has several fronts, including upscaling of hydrologic properties, correlating hydrologic parameters to attach hydraulic conductivities and moisture-retention curves to the porosity-based geostatistical stratigraphies, developing graphical images, and incorporating an analytical integration method for constructing element matrices in the porous-media flow solver DUAL.

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Three-dimensional geostatistical simulations using the sequential Gaussian simulator have been attempted for the region containing the repository, but these did not produce good results because of the sparsity of data and short correlation length. However, indicator simulations should perform better because more data are available and the correlation length should be substantially greater. The sequential indicator simulation program has been implemented, and three-dimensional simulations were produced for the welded and nonwelded tuff classes. The results are much better for the indicator simulations, although they deteriorate somewhat if there is a lack of nearby data.

Improvements in the north-south INTRAVAL cross-section study have been continuing. The simulations produce infiltration rates at the top of the Topopah Spring Member. The data and input parameters for the east-west INTRAVAL problem were updated, and the geostatistical indicator simulation was rerun.

The three-dimensional geostatistical indicator simulations for welded and nonwelded classes using sequential indicator simulation program from GSLIB continues to be refined. The breakpoint between welded and nonwelded tuff in Prow Pass was revised after reviewing the Scott and Bonk (1984) cross section and the borehole data.

A program was written to convert the digitized polygons from the Scott and Bonk (1984) geologic map to a regular grid with the corresponding unit assigned. The program has been tried out on a test file. The output is to be used to compute variograms for the indicator simulations.

The code DUAL was revised to use analytical integration instead of Gaussian integration for constructing element matrices. With the Gaussian integration, the calculation of the conductivities differs slightly for the Picard solver. With analytical integration, the conductivities used for the Picard solver are the same as for the nonlinear equations. Although the differences are small, the change results in a big improvement in the ability of the Picard solver to provide good initial guesses, and the number of nonlinear iterations decreases significantly.

Subactivity 1.6.3.1.2 - Saturated zone flow analysis. Work performed under this subactivity is discussed in Subactivity 1.6.3.1.1.

**Forecast:** Work to be accomplished in the analysis of the unsaturated and saturated flow systems is described in the forecast for Activity 1.6.4.1.

### **2.7.5.4 Activity 1.6.4.1 - Calculation of Pre-Waste-Emplacement Ground-Water Travel Time**

Subactivity 1.6.4.1.1 - Performance allocation for Issue 1.6. Analysis material that might be used in reallocation of PA activities is discussed under Subactivity 1.6.4.1.3.



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Subactivity 1.6.4.1.2 - Sensitivity and uncertainty analyses of ground-water travel time. Work performed under this topic is discussed in Subactivity 1.6.4.1.3.

Subactivity 1.6.4.1.3 - Determination of the pre-waste-emplacement ground-water travel time. Major YMP review comments on the report, "Pre-Waste-Emplacement Groundwater Travel Time Sensitivity and Uncertainty Analyses for Yucca Mountain, Nevada" (Kaplan, 1993), were addressed and the document has been published.

**Forecast:** Model development will include work on probability models used to quantify uncertainties in the site data base, the conceptual process models, and the prediction of compliance with the regulatory criteria. A report on the conceptual basis for estimating compliance with the regulatory criteria is scheduled for July 1993. Geohydrologic data development is continuing. Additional bulk properties and moisture-retention data will be identified for use by TSPA modelers. Further refinements in the comparisons with geostatistical simulations will include better definition of zeolitized and vitric zones. The status and evaluation of current data in support of ground-water travel time will be discussed in a report in June 1993.

### **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 is an out-year activity.

**Forecast:** No activity is planned for FY 1993.

### **2.7.5.6 Activity 1.6.5.2 - Definition of the Disturbed Zone**

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

**Forecast:** No activity is planned for FY 1993.

## **2.7.6 Total System Performance (SCP Section 8.3.5.13)**

### **2.7.6.1 Performance Assessment Activity 1.1.2.1 - Preliminary Identification of Potentially Significant Release Scenario Classes**

The performance measure, estimated partial performance measure (EPPM) was replaced with CCDF throughout this section in Revision 10 of the SCPB. This change maintains consistency with current planning and implementation of the PA program. EPPMs are no longer used in PA.

Subactivity 1.1.2.1.1 - Preliminary identification of potentially significant sequences of events and processes at the Yucca Mountain repository site. Preliminary work on the

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construction of event trees in support of scenario development for tectonics has begun and will form the basis upon which scenario selection will be performed. The work will be described in a report documenting the scenario selection.

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 technical review and SNL management review. It has been submitted to YMP for programmatic review.

SNL staff is continuing to add material to the first internal draft of the scenario report for the nominal flow case, particularly on the effects of mine ventilation. External drafting of the basic drawings for the nominal-flow scenarios is complete. SNL staff will use them for making the detailed "sketches" and "tree segments" that are the primary means of communication in the series of scenario documents. Approximately 20 sketches illustrating the events and processes making up the scenarios have been drafted. Drafting of the tree segments is continuing. Drafting constitutes the bulk of the work remaining to be done; about 100 sketches and 20 tree segments will be in the final report. The work continues to be on schedule.

**Forecast:** The development and selection of scenarios for modeling will continue. Deliverables will include completion of the reports for basaltic volcanism, tectonic phenomena, and for nominal flow. Progress on scenarios for human intrusion, if any, will be reported in a memo at the end of the FY.

### **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 is an out-year activity.

**Forecast:** No activity is planned for FY 1993.

### **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. Work related to this subactivity is described under Sections 2.7.5.3 and 2.7.6.6.

Subactivity 1.1.3.1.2 - Development of a model for gas-phase releases. A report entitled "Implications of Stability Analysis for Heat Transfer at Yucca Mountain" (Wilson et al., 1993), was submitted to the 1993 IHLRWM Conference.

SAND92-7032J, "Predicted Gas-Phase Movement of Carbon-14 from a Radioactive Waste Repository" (Ross et al.), was accepted for the special Yucca Mountain issue of Radioactive Waste Management and the Nuclear Fuel Cycle.

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### Subactivity 1.1.3.1.3 - Development of a model of releases through basaltic volcanism.

Work related to this subactivity is described under Sections 2.7.5.3 and 2.7.6.6.

### Subactivity 1.1.3.1.4 - Development of a model of releases through human intrusion.

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

**Forecast:** During FY 1993, a gas-flow model for total-system analysis will be extended to include the effects of barometric pumping, the capability to handle higher temperatures, and other improvements. The code that includes the gas-flow model, TGIF2, will be benchmarked. The deliverable for this activity, due in September 1993, includes a report describing the code and the results obtained with it.

#### **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 Activity 1.1.2.1.

#### **2.7.6.5 Performance Assessment Activity 1.1.4.2 - The Provision of Simplified, Computationally Efficient Models of the Final Scenario Classes Representing the Significant Processes and Events Mentioned in Proposed 10 CFR 60.112 and 60.115**

Work related to this activity is reported under Activity 1.1.5.1.

#### **2.7.6.6 Performance Assessment Activity 1.1.5.1 - Calculation of an Empirical Complementary Cumulative Distribution Function**

Papers written by SNL staff that have been approved by YMPO and in the Proceedings of the 1993 IHLRWM Conference include: "Sensitivity Analyses for Total-System Performance Assessment" (Wilson, 1993), "The Most Likely Groundwater Flux Through the Unsaturated Tuff Matrix at USW H-1" (Gauthier, 1993), "A Working Definition of Scenarios and a Method of Scenario Construction" (Barr and Dunn, 1993), and "Scenario Development for Performance Assessment — Some Questions for the Near-Field Modelers" (Barr and Barnard, 1993).

The following report was accepted for the special Yucca Mountain issue of Radioactive Waste Management and the Nuclear Fuel Cycle: "A Preliminary Total-System Performance Assessment for the Potential Repository Site at Yucca Mountain" (Wilson et al.). The report "A Semianalytical Method of Path Line Computation for Transient Finite-Difference Ground Water Flow Models" (Lu) was submitted to YMP for programmatic review.

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SNL staff made presentations on the problem definition and results of the TSPA begun in 1991 (TSPA-91) at the NRC Technical Exchange on PA in Bethesda, Maryland, December 14-15, 1992. An abbreviated version of the same presentation was given before the ACNW, also in Maryland, on December 16, 1992.

In an effort to increase the technical cooperation among PIs at various participants and PA staff, SNL cooperated with YMPO in presenting a series of presentations on PA. The first series of presentations was held at Los Alamos on March 17, 1993. SNL staff presentations covered a general description of the steps followed to obtain a TSPA, using TSPA-91 as an example. The progressive changes in the conceptualization of gaseous and aqueous flow and transport and in the near-field modeling for TSPA-91 and TSPA-92 were also described. Specific questions were posed concerning the validity of the assumptions about the geochemistry for these elements of the PA analyses. Recommendations for additional information and interactions were the final product of this meeting. A similar meeting was held at the USGS in Denver, Colorado. The presentations were changed somewhat to reflect the research interests of the USGS PIs. Information was solicited for infiltration and ground-water flux, stratigraphic interpretation, geohydrologic parameters, and SZ flow.

SNL staff attended the meeting of the NWTRB on the subject of development of a source term for radionuclide releases from the engineered-barrier system. The meeting was held October 14-15, 1992, in Las Vegas, Nevada. SNL presentations before the Board were "Source Term for the Sandia National Laboratories Total System Performance Assessment" (Robey) and "Source Term Sensitivity Studies Done in TSPA-91" (Robey). The former talk focused on the incorporation of source-term information in the recently released TSPA-91. The latter presentation was on the use of a modified source term that recognized the spent fuel was not of uniform age or burnup. Therefore, the releases could vary depending on the age and burnup of the radionuclides modeled.

In November 1992 and February 1993, SNL and LLNL staff defined the source terms that LLNL will be supplying for the next TSPA analyses. LLNL is working on thermal effects associated with alternative container placement configurations and higher heat loads. The members agreed that they would use a source term that had two waste-package emplacement configurations. One would be the standard thin-wall package vertically placed in boreholes; the other would be the robust WP in drift emplacement. An agreement was made to consider a limited number of thermal scenarios—the current heat load for the borehole emplacement case, and a higher heat load for the drift emplacement problem. The model for container failure will address the mechanisms that cause both waste-package degradation and fuel-rod failure. Staff members from SNL and LLNL also agreed to try to include a model for production of colloids in the source term. They agreed that a modification of the  $^{14}\text{C}$  source term to include releases due to cladding failure and fuel-assembly failure would be desirable.

The general scenario to be modeled in the TSPA for 1993 (TSPA-93) was agreed to be thermally driven condensate interacting with selected WPs. The greatest emphasis will be placed on thermal effects, including effects on container environments and on processes

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occurring within containers. LLNL agreed to provide SNL with a source term that included the thermal history of the WP. Source term releases at various times during repository lifetime will then be dependent on both water-contact modes and prior thermal exposure. LLNL has implemented their models in the code YMIM (a stand-alone program), and LLNL provided SNL with the algorithms for inclusion in the Total-System Analyzer (TSA). SNL transmitted a portion of the TSA program so LLNL could use it for some sensitivity studies. A new source term is being encoded and the TSA is being run for colloid sensitivity studies.

The CRWMS M&O and SNL staff were part of the Electric Power Research Institute (EPRI) PA Working Group in Palo Alto, California, December 3-4, 1992. The results of the contractors working for EPRI on Yucca Mountain was the focus of this meeting. An SNL staff member made several informal presentations of specific aspects of TSPA-91 at the request of the working group members.

After the work with LLNL and EPRI, SNL staff members defined the near-field interactions for the source term for the next TSPA iteration. They will assume that throughout the thermal history of the repository it will be possible to have weeps dripping on WPs. Furthermore, throughout the history, locally saturated conditions will be assumed to allow fracture flow from the repository to the water table. SNL has also started developing the features, events, and processes diagrams to describe these interactions.

Source terms were generated for a transmuted-waste aqueous analysis that will allow a direct comparison with the TSPA-91 analyses using a spent-fuel source term. TOSAPAC analyses using the TSPA-91 aqueous-flow configuration (i.e., six columns composed of the 5-layer stratigraphy) and a "transmuted" source term were completed. The source assumed partitioning and transmutation of the nuclear waste, resulting in a different mix of radionuclides from spent fuel. Work also continues on a report that will cover the TSPA source-term sensitivity studies presented at an NWTRB meeting.

Work is continuing on the development of a report on the selection of radionuclides to be used in performance-assessment analyses. The current effort expands the list of nuclides by incorporating more geochemical sorption and solubility data.

A number of SNL staff attended the Expert Judgment workshop, held in Albuquerque, New Mexico, November 11-19, 1992. Support for the meeting included staff work on the steering committee and staff presentations. The presentations included "Experience From the 1991 Total System Performance Assessment" (P. Kaplan) and "Expert Judgement as a Data Supplement" (M. Harr). The CRWMS M&O provided two session chairs, a number of presentations, staff support for the workshop, and aided YMPO in preparing a workshop report.

A series of three-dimensional stratigraphies of Yucca Mountain for TSPA-93, along with the necessary data sets, is being developed. The stratigraphies will be based on welded and nonwelded categories. Two-dimensional slices through the baseline stratigraphy will be used for gas-flow calculations. For the composite-porosity ground-water-flow calculations,

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10 one-dimensional columns through the baseline stratigraphy and perhaps 10 other stratigraphies will be taken.

A new automatic mesh generator for TOSPAC was designed and programmed. The new mesh generator will allow the TSA to run with many different stratigraphies without having to construct each calculational mesh by hand.

SNL staff have developed a three-pronged plan to address the thermal modeling problem for TSPA-93: (1) performing laboratory experiments, (2) modeling laboratory experiments, and (3) modeling Yucca Mountain. One proposed experiment involves a container filled with glass beads and water with a 60° heat source at the bottom and a 20° source at the top. The experiment is expected to provide information about the relative importance of convection and conduction under these conditions. Discussions with a member of the LBL staff have resulted in a number of changes to ensure that competing effects are reduced and to decrease the possibility that three-dimensional effects are introduced into a two-dimensional problem. The experiment is currently being designed (reported under Activity 1.6.2.1) and is expected to be completed in the summer. At that time, SNL staff will attempt to model the phenomena observed using TOUGH.

Some very simple models of thermal effects were developed in February 1993 to guide LLNL in developing an adequate source term for the models used in TSPA-93. The models are based on more detailed calculations by both LLNL and SNL personnel. Basically, the models will allow calculations of the times when water will contact a container (after or perhaps during the potential repository's thermal pulse) and of how much water will contact the container.

A report is being written to help in defining the calculational regimes in which one-dimensional calculations are appropriate. One-dimensional codes are currently the only feasible way to compute multiple realizations of water and solute transport through Yucca Mountain because of their relatively short execution-time requirements. Therefore, it is desirable to approximate as many two-dimensional effects in these one-dimensional codes as possible.

SNL staff have implemented variably sized flowing fractures and variable flow patterns in the TSA-version of the weeps model (WEEPSTSA). Preliminary results with the new version show releases of radionuclides to be less than those predicted by TSPA-91.

In February, a simple model of colloid transport was implemented in the TSA and some preliminary calculations were performed. Basically, the colloid-transport model uses the solute-transport model (TRANS), but it assigns no retardation to Pu and Am in the fractures and in the matrix of the porous geologic units. In the impermeable welded units, an extreme retardation is assigned, and no movement from the fractures into the matrix is allowed. At the interface with welded units, colloids are allowed to enter the tuff matrix, where they are trapped because of the high retardation. Although this effect is not conservative, it does represent filtering of the colloids. Preliminary results, using the TSPA-91 source model and

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parameters, shows less release of radionuclides than was expected. The calculation is presently being re-examined.

PNL issued the report "Preliminary Total System Analysis of a Potential High-Level Nuclear Waste Repository at Yucca Mountain" (Eslinger et al., 1992) in November 1992. The report describes modeling performed at PNL addressing the performance of the entire repository system related to regulatory criteria established by the EPA in 40 CFR Part 191. The geologic stratigraphy and material properties used in this study were chosen in cooperation with PA modelers at SNL. SNL modeled a similar problem using different computer codes and a different modeling philosophy. The SNL work is documented in the report "TSPA 91: An Initial Total-System Performance Assessment for Yucca Mountain" (Barnard et al., 1992). PNL performed a few model runs with very complex models, and SNL performed many runs with much simpler (abstracted) models.

The modeling presented in the PNL report is substantially different from previous modeling attempts. Models have been added for gas-phase movement of  $^{14}\text{C}$ , human intrusion, volcanic intrusion, glass waste forms, and tectonic induced variations. When compared to earlier calculations, a much broader set of conditions has been addressed. The new models consider thermally driven gas-phase movement of radionuclides, and movement of radionuclides in the SZ. In addition to model development, new information on radionuclide sorption has been obtained, and new geochemical calculations have been performed to estimate the waste form solubility.

In addition to the cumulative release modeling, PNL estimated doses for several of the release scenarios. Working Draft 4 of 40 CFR Part 191 (February 3, 1992) includes the possibility that both individual and population dose limits may be established as repository performance criteria. The dose results presented in the PNL report indicate that the potential repository may be able to meet both individual and population dose criteria. Substantial work is still required to define the exposure scenarios and environmental radionuclide concentrations needed to complete a definitive analysis of the doses that will be caused by postclosure repository operation.

The scenarios modeled in the PNL report were not exhaustive of all possible scenarios that will have to be considered for licensing. However, they were selected because they are believed to contribute the largest releases of any scenarios to be considered. In summary, the analyses accomplished for this report support the continued site characterization of Yucca Mountain as a potential site for a high-level nuclear waste repository and indicate that the limits established by the EPA relative to cumulative release of radionuclides are not exceeded.

PNL staff presented the paper "AREST: The Next Generation" (Engel, et al., 1993) at the 1993 IHLRWM Conference. The paper discusses the limitations of current source term models, the requirements for new models, and the development of the next version of the AREST code. Simple mass transport models using constant boundary conditions at the waste form surface and at the host rock boundary do not always result in realistic predictions of the performance of an underground repository for the disposal of high-level radioactive waste. What is needed is a model that couples the important processes that cannot be modeled

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independently, including (1) thermal modeling, (2) geochemical modeling, (3) containment degradation, (4) waste form dissolution, and (5) radionuclide transport. Such a model is being developed by modifying the AREST code and is described in this paper.

Another paper by PNL staff, "Coupled Process Modeling and Waste Package Performance" (McGrail and Engel, 1992) was approved by YMPO and presented at the conference Science Basis for Nuclear Waste Management XII sponsored by the Materials Research Society in Pittsburgh, PA. This paper features the geochemical model incorporated into the AREST code to examine the coupled processes of glass dissolution and transport within the EBS. PNL calculations show that the typical assumptions used in PA analyses, such as fixed solubilities or constant reaction rate at the waste form surface, do not always give conservative or realistic predictions of radionuclide release. Varying the transport properties of the WP materials is shown to give counterintuitive effects on the release rates of some radionuclides. The use of noncoupled PA models could lead a repository designer to an erroneous conclusion regarding the relative benefit of one WP design or host rock setting over another.

PNL also released the document "AREST Model Description" (Engel and McGrail, 1993). This description includes logic, model structure, and mathematical description of the models and includes sample analyses for each release model.

**Forecast:** The second cycle of TSPA will proceed through analyses to enhance the first cycle, completed in FY 1992. These analyses will cover the topics described above as areas identified for study in TSPA-93. In addition to those topics, the TSPA-93 will include some analyses of basaltic volcanism and tectonics not covered in TSPA-91, simple dose modeling, improved modeling of the SZ, and analyses of cross correlations. A report containing the results of the TSPA-93 analyses will be presented for YMPO review in September 1993. A memo describing the performance of the visual integrated data base will be delivered in September 1993. A memo on the planning status of a generic methodology for using expert judgment and a report on the elicitation of probability distributions will be completed by September 1993.

### **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 is an out-year activity.

**Forecast:** No activity is planned for FY 1993.

#### **2.7.7.2 Activity 1.2.2.1 - Calculation of Transport of Gaseous Carbon-14 Dioxide Through the Overburden**

Work for this activity is reported under Subactivity 1.1.3.1.2.



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### **2.7.7.3 Activity 1.2.2.2 - Calculation of Land-Surface Dose and Dose to the Public in the Accessible Environment Through the Gaseous Pathway of Carbon-14**

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

**Forecast:** No activity is planned for FY 1993.

### **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 is an out-year activity.

**Forecast:** No activity is planned for FY 1993.

#### **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 is an out-year activity.

**Forecast:** No activity is planned for FY 1993.

### **2.7.9 Performance Confirmation (SCP Section 8.3.5.16)**

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

**Forecast:** No activity is planned for FY 1993.

### **2.7.10 U.S. Nuclear Regulatory Commission Siting Criteria (SCP Section 8.3.5.17)**

On March 9, 1993, the Erosion Topical Report (DOE, 1993e) was issued by OCRWM and sent to the NRC. The report was prepared to address 10 CFR Part 60.122(c)(16), and provides evidence that the potentially adverse condition is absent because extreme erosion has not occurred at Yucca Mountain during the Quaternary period. By addressing 10 CFR 60.122(c)(16), the corresponding siting criterion in SCP Section 8.3.5.17 is also resolved.

**Forecast:** No activity is planned for the remainder of FY 1993. NRC comments or questions on the Erosion Topical Report are not anticipated until FY 1994.

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Additional items will be resolved as the ongoing scientific investigations provide the necessary data and evaluation.

### **2.7.11 Higher-Level Findings--Postclosure System and Technical Guidelines (SCP Section 8.3.5.18)**

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

**Forecast:** No activity is planned for FY 1993.

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### 3. SCHEDULE

In late November 1989, a new proposed program schedule was announced in the Secretary's report to Congress (DOE, 1989). The new schedule was based on consideration of the duration required to obtain Yucca Mountain site access from the NRC, the State of Nevada, and others; and the work scope described in the SCP and the more-detailed study plans. In January 1990, the schedule presented in the Secretary's report to Congress was finalized by OCRWM in the Program Cost and Schedule Baseline (DOE, 1990e). 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 obtaining future environmental permits, program funding levels, and Study Plan review, may continue to affect the program schedule.

This section presents the schedule baseline for YMP as of the end of this reporting period (March 31, 1993). More detailed schedules are maintained at YMPO, in combination with work scopes and the dollars needed to accomplish this work. The schedule focuses on the early evaluation of site suitability of the Yucca Mountain site.

Table 3-1 presents the summary milestones for YMP. Figure 3-1 shows the relationship of the summary milestones to the major activities.

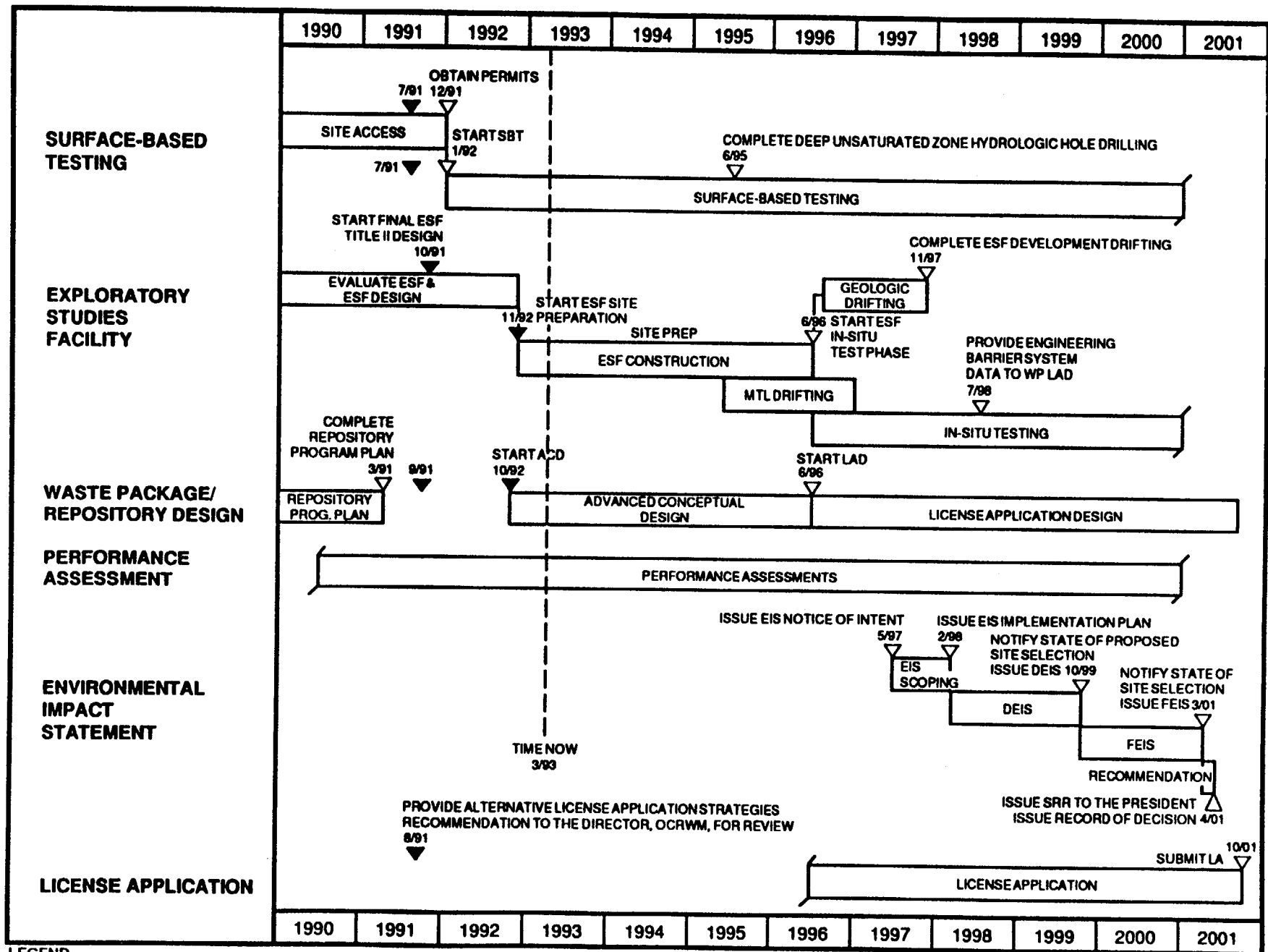
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Table 3-1. Summary Milestones <sup>a</sup>

Milestone	Baseline Date	Actual Date
<b><u>Surface-Based Testing</u></b>		
Obtain Permits	12/91	7/91
Start New Surface-Based Testing	1/92	7/91
Complete Deep Unsaturated Zone Hydrologic Hole Drilling	6/95	
<b><u>ESF</u></b>		
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	
<b><u>Waste Package/Repository Design</u></b>		
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	
<b><u>Environmental Impact Statement</u></b>		
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	3/01	
Issue Record of Decision	4/01	
Issue Site Recommendation Report to the President	4/01	
<b><u>License Application</u></b>		
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	

<sup>a</sup>Table shows approved Program Schedule Baseline and actual completion dates as of March 31, 1993

**Figure 3-1. Site Characterization Summary Schedule**



LEGEND

- ▽ PROGRAM COST AND SCHEDULE BASELINE MILESTONE
- ▼ ACTUAL START/COMPLETION DATE

Site Characterization Summary Schedule

SUMMSCHED.0525-4-93

Figure 3-1.

## PROGRESS REPORT #8

### 4. EPILOGUE

This section provides a brief summary of key events that occurred after the close of the reporting period on March 31, 1993.

#### 4.1 EXPERT JUDGMENT WORKSHOP REPORT (SECTION 1.4.2 AND TABLE 2-1, COMMENTS 3 AND 7)

The final report of the Expert Judgment Workshop (held in Albuquerque, New Mexico, November 18-20, 1992) was distributed on April 30, 1993. The report, "Recommendations to U.S. Department of Energy (DOE) Management Resulting from DOE's Workshop on the Use of Expert Judgment in Decision-Making," (DOE, 1993f) included six recommendations to DOE management together with a technical summary of the meeting.

#### 4.2 EARLY SITE SUITABILITY EVALUATION REPORT (SECTION 2.1.3.1)

The response to the three NRC comments and two questions on the ESSE document was issued in June, 1993. In addition to a response to the NRC, a response package was prepared for comments received from all affected units of local government, the State of Nevada, and the U.S. Department of the Interior.

#### 4.3 EXCAVATION OF STARTER TUNNEL (NORTH RAMP) (SECTIONS 2.1.2 & 2.1.2.2)

Excavation of the Starter Tunnel began in April 1993. As of mid-June, the pilot drift and the first two slashes (See Figure 2-3) had progressed 34 m (111 ft). Current expectation is to have the tunnel excavated to a full-face at 68 m (223 ft) by September 1993.

#### 4.4 RESPONSE TO NUCLEAR WASTE TECHNICAL REVIEW BOARD'S SPECIAL REPORT TO CONGRESS (EXECUTIVE SUMMARY)

On May 13, 1993, DOE submitted a response (DOE, 1993g) to the NWTRB "Special Report to Congress and the Secretary of Energy," (NWTRB, 1993).

## PROGRESS REPORT #8

### ACRONYMS AND ABBREVIATIONS

ACD	Advanced Conceptual Design
ACNW	Advisory Committee on Nuclear Waste
AFM	atomic force microscopy
AGU	American Geophysical Union
AML	areal mass loading
ANL	Argonne National Laboratory
AO	Annotated Outline
AP	Administrative Procedure
APD	areal power density
ASTM	American Society for Testing and Materials
ATM	Approved Testing Material
BLM	U.S. Bureau of Land Management
BWR	Boiling Water Reactor
CCB	Change Control Board
CCDF	complementary cumulative distribution function
CCSD	Clark County School District
CES	Center for Environmental Studies, University of Nevada, Reno
CHL	Calico Hills level
CNWRA	Center for Nuclear Waste Regulatory Analysis
CRWMS	Civilian Radioactive Waste Management System
CRWMS M&O	Civilian Radioactive Waste Management System Management and Operating Contractor
CTE	coefficient of thermal expansion
DHLW	defense high-level waste
DNA	Defense Nuclear Agency
DOE	U.S. Department of Energy
DRI	Desert Research Institute
EBDRD	Engineered Barrier Design Requirements Document
EBS	engineered barrier system
ECM	equivalent continuum model
EP	Experiment Procedure
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
ESF	Exploratory Studies Facility
ESFAS	Exploratory Studies Facility Alternatives Study: Final Report
ESFDRD	Exploratory Studies Facility Design Requirements Document
ESSE	Early Site Suitability Evaluation
FY	fiscal year
GIS	Geographic Information System
GIT	Geophysics Integration Team
GMS	Geotechnical Modeling System
GOES	Geostationary Operational Environmental Satellite



## PROGRESS REPORT #8

### ACRONYMS AND ABBREVIATIONS (Continued)

GSA	Geological Society of America
GSLIB	Geostatistical Software Library and User's Guide
GUI	Graphical User Interface
HRF	Hydrologic Research Facility
IDAS	Integrated Data Acquisition System
IEA	Institutional and External Affairs
IHLRWM	International High-Level Radioactive Waste Management
IITS	Items Important to Safety
IITWI	Items Important to Waste Isolation
ISR	Institute for Standards Research
ITE	Integrated Test Evaluation
ITPRP	Interlaboratory Testing Program for Rock Properties
LA	License Application
LBL	Lawrence Berkeley Laboratory
LBT	Large Block Test
LLNL	Lawrence Livermore National Laboratory
Los Alamos	Los Alamos National Laboratory
MCC	Materials Characterization Center
MGDS	Mined Geologic Disposal System
MGDSRD	Mined Geologic Disposal System Requirements Document
MPC	multipurpose canister
MTA	Main Test Area
NAGRA	Swiss National Cooperative Society for the Storage of Radioactive Wastes
NARG	Natural Analogue Review Group
NAS	National Academy of Sciences
NATM	New Austrian Tunneling Method
NER	New England Research, Inc.
NFE	Near-Field Environment
NMR	Nuclear Magnetic Resonance
NPDES	National Pollutant Discharge Elimination System
NRC	U.S. Nuclear Regulatory Commission
NRG	North Ramp Geologic
NTS	Nevada Test Site
NWPA	Nuclear Waste Policy Act
NWTRB	Nuclear Waste Technical Review Board
OCRWM	Office of Civilian Radioactive Waste Management
OFF	"oldest fuel first"
PA	performance assessment
PADB	Performance Assessment Data Base
PAS	Photo Acoustic Spectroscopy
PET	potential evapotranspiration
PI	Principal Investigator

## PROGRESS REPORT #8

### ACRONYMS AND ABBREVIATIONS (Continued)

PNL	Pacific Northwest Laboratory
PR	Progress Report
PRMS	precipitation-runoff modeling system
PTn	Paintbrush nonwelded
PWR	Pressurized Water Reactor
QA	quality assurance
QAL	Quality Activities List
QARD	Quality Assurance Requirements Document
REEC <sub>o</sub>	Reynolds Electrical and Engineering Co.
RFP	Request for Proposal
RIP	Repository Integration Program
RSN	Raytheon Services Nevada
SBT	surface-based testing
SCA	Site Characterization Analysis
SCP	Site Characterization Plan
SCPB	Site Characterization Program Baseline
SCP-CDR	Site Characterization Plan-Conceptual Design Report
SCRF	Stanford (University) Center for Reservoir Forecasting
SD	Geostatistical/Systematic Drilling Program
SEM	Scanning Electron Microscope
SGBSN	Southern Great Basin Seismic Network
SIMS	secondary ion mass spectroscopy
SIP	Scientific Investigation Plan
SMF	Sample Management Facility
SNF	spent nuclear fuel
SNL	Sandia National Laboratories
SRG	South Ramp Geologic
SZ	saturated zone
TBM	tunnel boring machine
TCP	thermocouple psychrometer
TDR	time domain reflectometry
TEM	Transmission Electron microscope
TGA	thermogravimetric analysis
TL	thermoluminescence
T&MSS	Technical and Management Support Services
TP	Technical Procedure
TSA	Total-System Analyzer
TSL	Topopah Spring level
TSPA	Total System Performance Assessment
TSw	Topopah Spring welded
UNR	University of Nevada, Reno
UNRSL	University of Nevada, Reno Seismological Laboratory

## PROGRESS REPORT #8

### ACRONYMS AND ABBREVIATIONS (Continued)

USBR	U.S. Bureau of Reclamation
USGS	U.S. Geological Survey
UZ	unsaturated zone
VSP	vertical seismic profiling
WIPP	Waste Isolation Pilot Plant
WP	Waste package
XRD	x-ray diffraction
YFF	"youngest fuel first"
YMIM	Yucca Mountain Integrating Model
YMIO	Yucca Mountain Information Office
YMP	Yucca Mountain Site Characterization Project
YMPO	Yucca Mountain Site Characterization Project Office
YMQAD	Yucca Mountain Quality Assurance Division

## PROGRESS REPORT #8

### NOMENCLATURE

#### Metric (SI) Units

°C	degree Celsius
cc	cubic centimeters (cm <sup>3</sup> )
cm	centimeter (= 10 <sup>-2</sup> m or 2.54 inches)
d	day
g	gram (= 0.3527 ounce)
h	hour
ha	hectare (=2.48 acres)
Hz	hertz (cycles per second)
K	degree kelvin
kg	kilogram (= 10 <sup>3</sup> grams or 2.2046 pounds)
km	kilometer (= 10 <sup>3</sup> m or 0.6213 mile)
L	liter (= 0.2641 gallon)
m	meter (= 3.2808 feet)
mg	milligram (= 10 <sup>-3</sup> g)
mL	milliliter (= 10 <sup>-3</sup> L)
mm	millimeter (= 10 <sup>-3</sup> m)
µm	micrometer (= 10 <sup>-6</sup> m)
nm	nanometer (= 10 <sup>-9</sup> 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

#### Elements and their Isotopes

#### Isotope(s) (if used in text)

Ac	actinium	
Al	aluminum	
Am	americium	
Ar	argon	<sup>39,40</sup> Ar
B	boron	
Br	bromine	
Ca	calcium	
C	carbon	<sup>12,13,14</sup> C

# PROGRESS REPORT #8

## NOMENCLATURE (Continued)

<u>Elements and their Isotopes</u>		<u>Isotope(s)</u> (if used in text)
Cs	cesium	
Cl	chlorine	<sup>35,36,37</sup> Cl
F	fluorine	
Fe	iron	
Gd	gadolinium	
H	hydrogen	<sup>2</sup> H (deuterium) <sup>3</sup> H (tritium)
I	iodine	<sup>129</sup> I
K	potassium	
Li	lithium	
Mg	magnesium	
Mn	manganese	
N	nitrogen	
Ni	nickel	
Np	neptunium	<sup>237</sup> Np
O	oxygen	<sup>16, 17, 18</sup> O
P	phosphorous	
Pb	lead	
Pu	plutonium	
Rb	rubidium	
S	sulfur	
Si	silicon	
Sr	strontium	
Tc	technetium	<sup>99</sup> Tc
Th	thorium	<sup>232</sup> Th
U	uranium	<sup>232,235,238</sup> U

## Chemical Compounds

CaCO <sub>3</sub>	calcium carbonate (calcite)
CO <sub>2</sub>	carbon dioxide
HNO <sub>3</sub>	nitric acid
NaCl	sodium chloride
SF <sub>6</sub>	sulfur hexafluoride
SiOH	silicon hydroxide (silanol)
UO <sub>2</sub>	uranium dioxide (other oxidation states of uranium include: U <sub>3</sub> O <sub>7</sub> , U <sub>3</sub> O <sub>8</sub> , and U <sub>4</sub> O <sub>9</sub> )

# PROGRESS REPORT #8

## NOMENCLATURE (Continued)

### Other (non-SI) Scientific/Engineering Terms and Units

bar	pressure
cu. yd	cubic yard
ft	foot
gpm	gallons per minute
$h_{dz}$	dry-out zone thickness
in	inch
$K_b$	bulk permeability
$K_d$	batch distribution coefficient
ka	kiloannum (thousand years ago)
Ma	megannum (million years ago)
mi	mile
mil	1/1000th of an inch
$\underline{M}$	molarity
$\underline{N}$	normality
pH	negative log of hydrogen ion concentration (acidity/alkalinity)
ppb	parts per billion
ppm	parts per million
psi	pounds per square inch
t	time
$t_{bp}$	boiling period at the center of the repository
$T_{peak}$	peak average temperature at the repository center
$t_{peak}$	time to peak temperature
$\Delta T_{max}$	maximum temperature rise
yr	year

## PROGRESS REPORT #8

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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

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