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Nuclear Waste Policy Act (Section 113)

Progress Report on the Scientific Investigation Program for the Nevada Yucca Mountain Site

October 1, 1991 - March 31, 1992

Number 6

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

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NOTE TO READERS:

In accordance with section 113(b)(3) of the Nuclear Waste Policy Act of 1982, as amended (NWPA), the Department has prepared the sixth report in a series of reports on the progress of site characterization at the Yucca Mountain candidate site. The document is entitled "Site Characterization Progress Report: Yucca Mountain, Nevada" and covers the period from October 1, 1991, through March 31, 1992.

The civilian radioactive waste management (OCRWM) program is pleased to report that significant progress was made during the reporting period with the issuance of a water appropriation permit by the State of Nevada. This permit allows pumping of water for dust suppression, site preparation, and drilling for the next 10 years for surface-based testing and Exploratory Studies Facility (ESF) activities. This has allowed OCRWM to implement a comprehensive surface-based testing program including extensive drilling, trenching, and mapping at the site.

In addition, OCRWM received approval from DOE's Energy Systems Acquisition Advisory Board to start comprehensive surface-based testing and to initiate Title II design for the ESF. The U.S. Nuclear Regulatory Commission determined that the DOE and DOE participant quality assurance programs are acceptable for implementation of site characterization activities and other quality related activities.

The Department will continue to issue progress reports covering 6-month periods, as specified in the NWPA.

Sincerely,

John W. Bartlett

John W. Bartlett, Director
Office of Civilian Radioactive
Waste Management

PROGRESS REPORT #6

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PROGRESS REPORT #6

EXECUTIVE SUMMARY

In accordance with the requirements of section 113(b)(3) of the Nuclear Waste Policy Act (NWPA) and 10 CFR 60.18(g), the U.S. Department of Energy (DOE) has prepared this report on the progress of site characterization activities at Yucca Mountain, Nevada, for the period October 1, 1991, through March 31, 1992. This report is the sixth in a series of reports that are issued at intervals of approximately six months during site characterization. Also included in this report are activities such as public outreach and international programs that are not officially part of site characterization. Information on these activities is provided in order to fully integrate all aspects of the Yucca Mountain studies.

The Office of Civilian Radioactive Waste Management (OCRWM) program made significant progress in the reporting period with the issuance of a Water Appropriation Permit by the State of Nevada on March 2, 1992, for Well J-13, located on the Nevada Test Site (NTS). The permit allows the pumping of water for dust suppression, site preparation, and drilling for the next ten (10) years for surface-based testing and Exploratory Studies Facility (ESF) activities.

On March 2, 1992, the U.S. Nuclear Regulatory Commission (NRC) lifted Site Characterization Analysis (SCA) Objection 2. In lifting the objection, the DOE and DOE participant Quality Assurance (QA) programs were determined by the NRC staff to be acceptable QA programs for implementation of site characterization activities and other quality related activities.

On December 30, 1991, OCRWM received approval from DOE's Energy Systems Acquisition Advisory Board (ESAAB) and Under Secretary to start comprehensive surface-based testing and to initiate Title II Design for the ESF. Current ESF Title II Design Activities are related to the completion of design activities and review of Design Package 1A, which includes north portal surface preparation, tunnel boring machine (TBM) launching chamber, and electrical and water distribution. Design Package 1A has undergone a 50% complete management review, and is currently undergoing a 50% complete independent technical review. Revisions to the drawings, analyses, and specifications will be prepared to appropriately address reviewer comments.

Neutron-access drilling at the northeastern edge of the potential repository block continued. Seven boreholes (USW UZN-55, USW UZN-54, USW UZN-37, USW UZN-11, USW UZN-36, USW UZN-17, USW UZN-15) were completed during this reporting period. Present day infiltration processes and net infiltration rates will be evaluated from these boreholes.

An Early Site Suitability Evaluation (ESSE) study, which had been recommended by the Nuclear Waste Technical Review Board (NWTRB), was completed during this reporting period. The evaluation was coordinated by the Technical and Management Support Services (T&MSS) contractor, and consisted of experts from many of DOE's participants and the T&MSS contractor. The purpose of the evaluation was to provide an early assessment of the Yucca Mountain site and to provide recommendations to DOE management on the suitability or unsuitability of the proposed Yucca Mountain site. The evaluation was conducted according to DOE's General Siting Guidelines in 10 CFR Part 960. An

independent Peer Review Panel, selected for their technical qualifications and independence from DOE OCRWM and the Yucca Mountain Site Characterization Project (YMP), evaluated the ESSE draft report containing the analyses, conclusions, and recommendations of the ESSE team. The review was completed in November 1991. All comments of the Peer Review Panel were resolved by the ESSE Core Team and the ESSE Report was appropriately modified. The final ESSE Report and Report of the ESSE Peer Review Panel were submitted to the DOE and released for public review and comment on February 21, 1992. A Director's Forum has been scheduled by DOE for May 7, 1992, in Chicago, Illinois, to provide an opportunity for representatives of affected governments and Indian Tribes, interested parties, and the public to discuss policy, strategy, and plans for site evaluation with DOE representatives.

An initial effort for a Total System Performance Assessment (TSPA) of the Yucca Mountain site, involving an analysis of both expected and unexpected conditions, was concluded. The first report in a series of iterative TSPAs was completed and submitted to the Yucca Mountain Site Characterization Project Office (YMPO) on March 31, 1992. The current TSPA addressed the issues of human intrusion, basaltic volcanism, tectonism, and groundwater and gaseous flow. The modeling capabilities of the YMP participants and their ability to generate complementary cumulative distribution functions (CCDFs) were tested during this TSPA.

In order to integrate and evaluate the results and recommendations from studies (e.g., ESSE), performance assessments, and other sources, the YMPO has initiated an Integrated Test Evaluation (ITE) task. The purpose of the ITE is to develop recommendations regarding changes in work scope or prioritization in baseline plans for site characterization for YMPO consideration. The primary criterion for prioritization is the earliest possible detection of unsuitable conditions for a potential repository at the Yucca Mountain site. An ITE Management Plan has been drafted and was submitted to YMPO for review.

DOE OCRWM held a workshop in October 1991 to discuss the draft Mission Plan Amendment (MPA) (DOE, 1991a), issued in September 1991, with interested parties, affected governments, and the public. Thirty-eight (38) parties submitted written comments to the document by the end of the comment period, which closed on November 8, 1991. Approximately 700 individual comments were identified by DOE, for which responses were provided. The draft MPA was revised to address the comments as appropriate and the revised MPA is currently under DOE Concurrence Review. A Comment-Response Document for the MPA is also under Concurrence Review by DOE.

A preliminary draft of an annotated outline (AO) for license application was developed by the Civilian Radioactive Waste Management System Management and Operating (CRWMS M&O) contractor for DOE. The purpose of the AO is to provide the NRC with DOE's understanding and interpretation of the regulatory requirements, and allow the NRC to recognize those areas where DOE requires guidance as a potential applicant under 10 CFR Part 60. It is intended to facilitate active exchanges for the identification, clarification, and resolution of issues in a timely manner so as to allow DOE time to prepare a license application, if the site were found suitable. The AO is planned to be an evolving document, to be updated as information and data from site characterization and performance assessment become available.

Public outreach continues to be an integral component of DOE's effort in introducing site characterization and nuclear waste disposal concepts to the public. Numerous tours of Yucca Mountain were conducted for the public and other interested parties. Workshops and presentations on programmatic and technical project overviews were provided by YMP staff members at the Yucca Mountain Information Office. In addition, an OCRWM exhibit, entitled "Managing the Nation's Nuclear Waste," was displayed at numerous fairs and meetings. YMP Public Update Meetings were held in Nevada with participation by the State of Nevada. Substantive interactions with the NRC and oversight organizations, such as the NWTRB and the NRC's Advisory Committee on Nuclear Waste (ACNW), continued.

The OCRWM international program continued to work in cooperation with a number of countries and international organizations to share advances in technology, science, and public education in nuclear waste disposal. Cooperative testing efforts with Switzerland and Canada involving borehole logging technology development, studies of fracture rock hydrology, and borehole calibration were initiated. Natural analogue studies of sites in Australia, Africa, Canada, and New Zealand continued as a significant component of the international program. Final reports for the International Stripa Project are being completed, as well as preparations for a symposium presenting results from this project.

PROGRESS REPORT #6

1.0 INTRODUCTION

1.1 PURPOSE AND SCOPE

In accordance with the requirements of section 113(b)(3) of the NWPA and 10 CFR 60.18(g), DOE has prepared this report on the progress of site characterization activities at Yucca Mountain, Nevada, for the period October 1, 1991, through March 31, 1992. This report is the sixth in a series of reports that are issued at intervals of approximately six months during site characterization.

DOE's plans for site characterization are described in the Site Characterization Plan (SCP) for the Yucca Mountain site (DOE, 1988a). The SCP has been reviewed by the NRC, State of Nevada, affected units of local government, other interested parties, and the public. Responses to 4,615 comments by these parties and others have been issued. More detailed information on plans for site characterization is being presented in Study Plans for the various site characterization studies and their component activities.

The Site Characterization Progress Report (PR) presents brief summaries of the status of site characterization activities and cites the technical reports and research products that provide more detailed information on the activities. The report provides highlights of work started during the reporting period, work in progress, and work completed and documented during the reporting period. In addition, the report is the vehicle for the discussion of changes to DOE's site characterization program resulting from ongoing collection and evaluation of site information; the development of repository and waste-package designs; the results of performance assessments; and any changes that occur in response to external comments.

The information in the PR is conveyed in a convenient summary form to be used for information purposes only. It is not the mechanism for controlling and documenting technical or policy changes in schedules or the testing program, but does identify decision points reached and modifications to schedules where appropriate. Such changes are documented through DOE change-control procedures.

The PR consists of two main sections: (1) an introductory section, and (2) a section on the status of site characterization activities, which follows the format of SCP Chapter 8. An appendix (Section 3.0) containing the current summary schedule for the repository program is included. A list of acronyms is also provided at the back of this report.

The 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

The Yucca Mountain site has not been selected for a repository. Rather, it has been designated by the U.S. Congress as a candidate site to be

characterized. DOE is conducting a program of detailed investigations and suitability evaluations at the Yucca Mountain site to determine whether it is suitable for development as a high-level radioactive nuclear waste repository. The plans, activities, and results of this program are reviewed by the State of Nevada, NRC, NWTRB, and other external organizations.

If the site is found to be suitable and is recommended for development by the President and approved by Congress, then DOE is required to demonstrate to the NRC that the site and potential repository system meet the applicable regulations governing licensing. If, during the course of scientific investigations, information supports a finding that the Yucca Mountain candidate site is unsuitable, DOE will stop all work at the site, and will notify Congress, and the Governor and legislature of the State of Nevada, in accordance with the provisions of the NWPA.

Site characterization is defined in the NWPA as "...activities, whether in the laboratory or in the field, undertaken to establish the geologic condition and the ranges of the parameters of a candidate site relevant to the location of a repository...." Its purposes are to obtain the information needed to determine whether the Yucca Mountain site is suitable for development as a repository; to acquire data necessary to develop optimum designs for a potential repository and waste package; to conduct the quantitative evaluations and performance assessments needed to determine site suitability; and to demonstrate that a repository at the Yucca Mountain site will comply with the NRC's requirements for licensing.

The activities planned for site characterization consist of surface-based studies, underground studies conducted in an ESF, laboratory tests, modeling and analysis. The performance assessments will evaluate: (1) whether a potential repository can be constructed and operated at the site without adversely affecting the health and safety of the public during repository operations, and (2) whether the waste emplaced in a potential repository will remain isolated from the human environment for thousands of years.

Surface-based characterization studies at Yucca Mountain have been in progress since May 1986, when the site was approved for characterization. These studies have 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; and geologic mapping. Limited expanded surface-based activities were continued during the reporting period, as detailed in Section 2.2 of this report. The duration of each testing activity is based on the nature of the work to be performed, and the type and amount of information to be obtained by the activity.

According to the current program schedule (see the Appendix, 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 will be initiated and, as part of this program, selected surface-based and underground tests will be continued beyond the site characterization phase if the site is found to be suitable. Appropriate new tests and monitoring would also be initiated and continued during repository construction and waste emplacement until such time as there is adequate confidence that the potential

repository is performing as expected and the NRC issues a license amendment to permanently close the repository.

1.2.1 Site Characterization

Chapter 2 of this report describes in detail the accomplishments of the site characterization program during the reporting period. Figures 1.1 and 1.2 show the locations where the activities are being performed.

The OCRWM program made significant progress in the reporting period with the issuance of a Water Appropriation Permit by the State of Nevada on March 2, 1992, for Well J-13, located on the NTS. This permit will allow the pumping of up to 94.83 acre-feet of water per year for ten (10) years for surface-based site testing and ESF site preparation. Until the permit was issued, it was necessary for water to be hauled approximately 50 miles from an available source west of Yucca Mountain.

The permit also includes implementation of the monitoring plan developed with the National Park Service (NPS) for the groundwater levels and spring flows in the Yucca Mountain region of southern Nevada and California. Further regulations will be instituted should monitoring identify unmitigable impacts on existing water rights. Drilling of monitoring Well JF-3 was completed during the reporting period. An eight and five-eighths inch casing was run to a depth of 1147 feet and a two and seven-eighths inch steel tube was inserted to a depth of 1290 feet.

In addition, the Floodplain Assessment and Statement of Findings for the surface-based testing was published in the Federal Register on October 1, 1991, as required under Executive Order 11988, Flood Plain Management. The findings concluded that there would be no significant impacts on floodplains as a result of the surface testing.

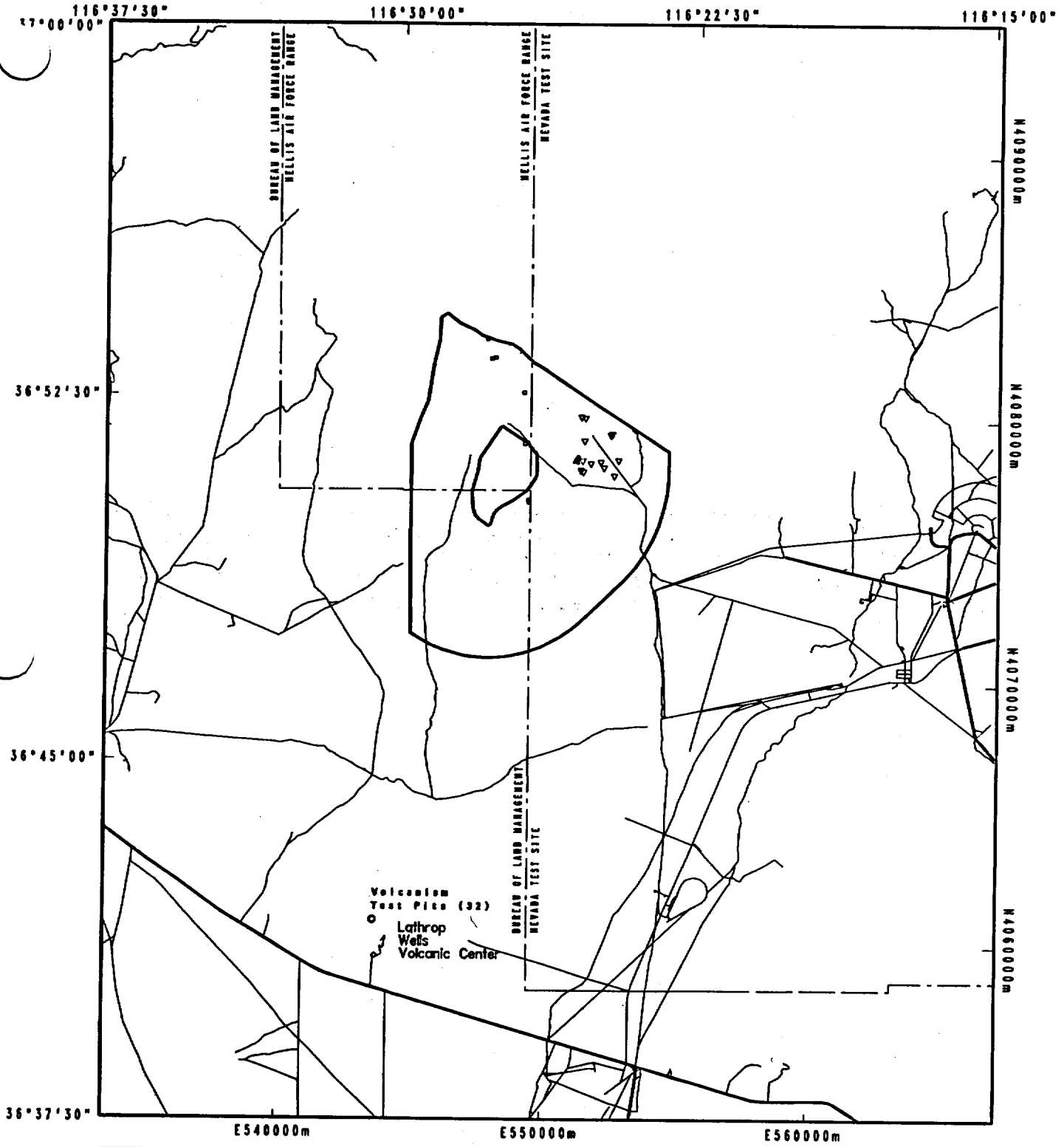
An Air Registration Certificate for the LM-300 drill rig was granted by the State of Nevada on November 4, 1991. Quarterly reports on air quality monitoring results will be submitted to the Nevada Department of Environmental Protection once the drill rig is operating on the site. The LM-300 drill rig was relocated from Area 6 of the NTS to the Yucca Mountain site in preparation for drilling hole UZ-16.

Other environmental activities included an application for a Free-Use Permit for extraction of sand and gravel from Fortymile Wash which was submitted to the U.S. Bureau of Land Management (BLM) on January 28, 1992. In addition, a permit modification application for the underground injection control permit was submitted to the Nevada Department of Conservation and Natural Resources on December 12, 1991, and is currently under review.

Approval was received from DOE's ESAAB and Under Secretary to start comprehensive surface-based testing and to initiate Title II Design for the ESF on December 30, 1991. ESF Title II Design is divided into ten (10) separate packages. Current ESF Title II Design Activities (Design Package 1A) are for surface disturbing activities in relation to the north ramp portal site and access roads. Design Package 1A, which encompasses the north portal site preparation and surface facilities, includes the preparation of 25 design

Figure 1.1. Site Characterization activities undertaken during the reporting period in the Yucca Mountain area including the Lathrop Wells volcanic center. "Circular" areas enclosed by black lines on Yucca Mountain define the following: large area = boundary of the accessible environment; small area = potential repository block. Large area is the approximate location shown in Figure 1.2.

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT



N

MILES

KILOMETERS

CONTOUR INTERVAL 200 FEET

NEW ACTIVITIES THIS REPORT

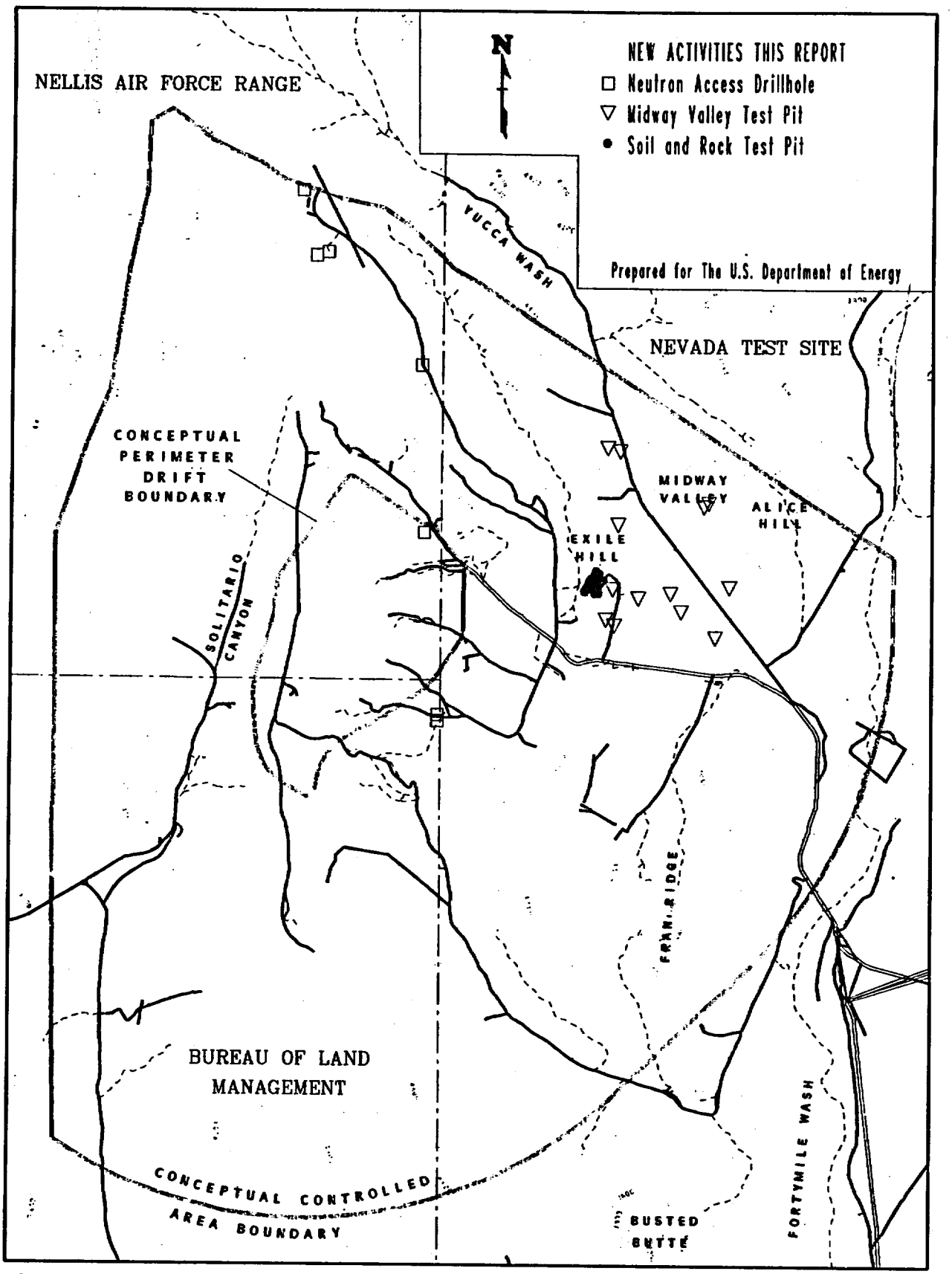
- Neutron Access Drillhole
- Midway Valley Test Pit
- Soil and Rock Test Pit
- Volcanism Test Pits

Prepared for the U.S. Department of Energy

EG&G YMP-92-160.0

Figure 1.2. Site Characterization activities undertaken during the reporting period in the area of the Yucca Mountain site accessible environment. Conceptual Controlled Area Boundary = boundary of the accessible environment; Conceptual Perimeter Drift Boundary = potential repository block.

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT



drawings, 12 design analyses/calculations, and 74 design specifications. These drawings, analyses, and specifications are complete and have been reviewed (50% Design Review). Core Hole NRG-1 will provide geologic foundation information to the north portal design. The Site Manager approved the preparation activities for this drill pad and access near the north portal. Excavation was initiated on March 11, 1992.

Neutron-access drilling at the northeastern edge of the potential repository block continued. Seven boreholes, USW UZN-55, USW UZN-54, USW UZN-37, USW UZN-11, USW UZN-36, USW UZN-17, and USW UZN-15, were completed during this reporting period. The boreholes will help characterize present day infiltration processes and net infiltration rates.

On March 2, 1992, the NRC issued a letter (Bernero to Bartlett) lifting SCA Objection 2. Specifically, the NRC staff evaluations of the DOE and DOE participant QA programs have determined that these QA programs are acceptable for implementation of site characterization activities and other quality related activities for the YMP, with no exceptions.

On November 26, 1991, DOE transmitted a request, with attached documentation, to the NRC to lift SCA Objection 1 on Design Control. DOE has worked hard to close SCA Objection 1 in order to be ready to initiate ESF Title II design.

The ESSE study was completed during this reporting period by a team of experts from many of DOE's participants and the T&MSS contractor. The purpose of the evaluation was to provide an early assessment of the suitability of the proposed Yucca Mountain site according to DOE's General Siting Guidelines in 10 CFR Part 960. A review by an independent Peer Review Panel of the ESSE draft report containing the analyses, conclusions, and recommendations of the ESSE team was completed in November 1991. The peer review panel was selected for their technical qualifications and independence from DOE OCRWM and the YMP. The ESSE Peer Review Panel evaluated the ESSE Report for adequacy of the information presented, for the approach used in the analyses, and to determine whether the report presents an objective and technically defensible view of the suitability of the Yucca Mountain site with regard to 10 CFR Part 960. All comments of the Peer Review Panel were resolved by the ESSE team and the ESSE Report was appropriately modified. The final ESSE Report (Younker et al., 1992a) and report of the Peer Review Panel (Younker et al., 1992b) was submitted to DOE and released for public review and comment on February 21, 1992. DOE has scheduled a Director's Forum on May 7, 1992, in Chicago, Illinois, to provide an opportunity for representatives of affected governments and Indian Tribes, interested parties, and the public to discuss policy, strategy, and plans for site evaluation with DOE representatives.

An ITE task was initiated under the auspices of the YMPO Test and Evaluation Plan (T&EP) (DOE, 1990a). The purpose of the ITE task is to integrate results from previous studies with information from other sources to develop recommendations to the YMPO about changes in work scope or prioritization that should be considered in baseline plans for site characterization. The primary criterion for prioritizing studies is the earliest possible detection of unsuitable conditions for a repository at the Yucca Mountain site. The study will also focus on "testing" currently planned for fiscal year 1993 (FY 1993). The recent studies [e.g., ESSE (Younker et

al., 1992a), Test Prioritization Task (TPT) (Mattson et al., 1991), Calico Hills Risk/Benefit Analysis (CHRBA) (DOE, 1991b), and the ESF Alternatives Study (ESFAS) (Dennis, 1991)] provided recommendations about specific actions DOE should consider based on repository system performance or the suitability of the site, but did not evaluate changes needed in the baseline site characterization plans from an integrated perspective. A draft ITE Management Plan was prepared and submitted to YMPO for review. The plan is currently under review by YMPO.

Performance assessment activities continued in support of site characterization, and in support of ESF and repository interface design studies. Performance assessment model development and experimental studies in support of model validation continued. A TSPA for the Yucca Mountain site continued, involving the analysis of both expected and unexpected conditions. The first report in a series of iterative TSPAs was completed and submitted to the YMPO on March 31, 1992. This TSPA tested the modeling capabilities of the YMP participants, as well as their ability to generate CCDFs which could be compared against the existing regulatory requirements. The next iteration of TSPA is expected to serve a particular program need and clearly interface with site characterization and design needs.

Public outreach continues to be instrumental in introducing site characterization and nuclear waste disposal concepts to the public. Fifty-two tours of Yucca Mountain were conducted for approximately 4,300 members of the public and other interested parties such as senior staff of the General Accounting Office, ABC news, staff members of United Kingdom Nirex, and American Nuclear Energy Council members. Numerous programmatic and technical project workshops and presentations were provided by YMP staff members at the Yucca Mountain Information Office. YMP Public Update Meetings were held in Las Vegas, Beatty, and Reno, Nevada, with participation by the State of Nevada. These meetings were attended by a total of approximately 700 people. The meetings were structured to allow the public to have an opportunity to interact with YMP staff.

There were substantive interactions with the NRC, including informal technical exchanges on various topics, such as the AO, Issue Resolution, Waste Form, Thermal Loads, and Air/Vapor Movements due to Thermal Gradients. In addition, there were interactions with the NWTRB on assorted topics, including Seismic Vulnerabilities, OCRWM Budget Allocation, Borehole Sealing and Backfilling, and Engineered Barrier Systems (EBS). Interactions with the ACNW included working groups on dating of volcanic features, seismic and faulting investigations for a geologic repository, and a systems analysis approach to reviewing the overall high-level waste program. A YMP overview on regulatory requirements, site characterization activities, and Performance Assessment was presented to the National Academy of Sciences (NAS) Separations Technology & Transmutation Systems Study panel.

1.2.2 Programmatic developments in support of site characterization

DOE OCRWM issued a Draft MPA (DOE, 1991a) in September 1991. The Draft MPA describes the CRWM program to manage and dispose of the nation's spent fuels and high-level radioactive waste in a manner that protects the health and safety of the public and of workers, and the quality of the environment.

DOE provided 10,000 copies of the document to Federal agencies, States, Indian Tribes, and units of local governments, the utilities, the National Association of Regulatory Utility Commissioners, other interested parties, and the public, for review and comment. In October 1991, a workshop was held to discuss the document with interested parties, affected governments, and the public. By the end of the comment period, which closed on November 8, 1991, 38 parties had submitted written comments. DOE identified approximately 700 individual comments for which responses were provided. The draft MPA was revised to address the comments as appropriate. A Comment-Response Document for the MPA and the revised MPA are currently in DOE Concurrence Review.

In support of the YMP, the M&O is developing a Mined Geologic Disposal System (MGDS) AO for a potential license application. The AO is planned to be an evolving document, to be updated as information and data from site characterization and performance assessment become available. A preliminary draft of the AO has been issued and is under DOE review.

DOE is developing an Issue Resolution Process. This process is an effort directed at receiving guidance and comment from the NRC staff regarding definition and interpretation of regulatory terms, the acceptability of methodologies for site characterization, and the adequacy and sufficiency of site characterization planning, acquired data and analyses within the context of the requirements of 10 CFR Part 60. The Issue Resolution Steering Group identified eight (8) issues to consider (Erosion, Origins of calcite-silica deposits, Probability and effects of Basaltic volcanism, Seismic hazard evaluation, EBS boundary, Disturbed zone boundary, Substantially complete containment, and Groundwater travel time) and working groups have been established to develop topical and technical reports on these issues. Erosion and origins of calcite-silica deposits are two issues that have been identified for near-term resolution. The erosion working group prepared a detailed outline of a topical report to identify acceptable methodology and data requirements for erosion. This report is currently in concurrence review. A completed detailed outline is expected to be available for presentation to the NRC by the end of April 1992. Evaluation of data, and preparation of action plans and outlines for topical reports are in progress by the working groups for the remaining topics.

The Environmental Protection Agency (EPA) is currently proposing to repromulgate 40 CFR Part 191, the EPA standard for management and disposal of high-level and transuranic waste. In a December 20, 1991, meeting between high level EPA and DOE management, DOE offered to provide technical assistance to EPA in developing a technical basis for repromulgation. Among the various tasks being conducted as part of this assistance, the OCRWM is assisting EPA in the development of alternative approaches to the human intrusion and C-14 issues in 40 CFR Part 191. DOE will provide example regulatory language illustrating how the proposed revision might be incorporated into the standard. Technical and regulatory justification for the proposed revision and details of the technical analysis that supports the proposed revision will also be provided by DOE. The proposed rule is expected to be published in the Federal Register during the latter part of 1992. In addition, the EPA Science Advisory Board (SAB) is expected to review the issue of potential release of gaseous C-14 from a potential repository located in an unsaturated zone (UZ). The SAB report is not expected to be completed until the fall of 1992.

PROGRESS REPORT #6

The OCRWM international program continued to work in cooperation with a number of countries and international organizations to share advances in technology, science, and public education in nuclear waste disposal. Work was initiated by OCRWM program participants on the various tasks under the cooperative testing agreements signed with Canada and Switzerland in September 1991. These efforts involve field and laboratory testing, instrumentation development and testing, modeling efforts on the performance of components of the natural and engineered barriers, performance assessment model verification work and natural analogue studies. The cooperative testing with Switzerland includes work involving borehole logging technology development and studies of fractured rock hydrology being performed in the unique Grimsel Pass underground laboratory. Cooperative work with Canada is making use of unique Canadian facilities such as a borehole calibration laboratory.

Discussions have also continued with technical staff and management of the Swedish waste disposal program for the purpose of further developing technical work scopes for possible OCRWM participation in the Swedish Hard Rock Laboratory (HRL) being constructed at the Aspo location in Sweden. If the OCRWM program participates in the HRL, a multiyear project agreement will be established.

International natural analogue studies continued to be a significant component of the OCRWM international program. The program continued to evaluate the benefits of participating in new phases of natural analogue studies of sites in Australia (the Alligator River Project), Africa (the Oklo mine in Gabon), Canada (the Cigar Lake deposits), and New Zealand.

Final reports from the International Stripa Project are being completed and close-out activities are in progress along with planning for a final symposium presenting results from the project. The OCRWM program is continuing to evaluate participation in cooperative activities with Spain, France, and the Commission of European Communities.

2.0 STATUS OF SITE CHARACTERIZATION

2.1 PREPARATORY ACTIVITIES

2.1.1 Quality Assurance program

The OCRWM Office of Quality Assurance (OQA), Yucca Mountain Quality Assurance Division (YMQAD) has begun implementation of a limited scope audit program. A minimum of three audits per participant are performed in each FY period. Audits are divided into three categories to provide a comprehensive review of related criteria. The implementation of limited scope audits allows for timely follow-up on identified problems and increases auditees ability to resolve identified problems.

During the reporting period, YMQAD conducted one full scope and 12 limited scope audits. The full scope audit was of the YMPO. Limited scope audits were conducted of Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL) (2), Raytheon Services of Nevada (RSN) (2), Reynolds Electrical and Engineering Company, Inc. (REECo) (2); Sandia National Laboratories (SNL), T&MSS, U.S. Geological Survey (USGS), and the YMPO. The audits evaluated the participants QA programs for compliance to OCRWM requirements and effectiveness of program implementation. It was determined by the respective audit teams that the participants are implementing effective QA programs. Corrective actions for minor areas of weakness identified during the audits has been initiated.

YMQAD conducted four surveillances of YMPO and T&MSS. The surveillances were conducted to evaluate specific site characterization related activities and as follow-up to verify corrective actions taken to close open deficiencies. It was determined that YMPO and T&MSS are implementing effective QA programs and that corrective actions have been taken to close open items.

The NRC lifted SCA Objection 2 (letter dated March 2, 1992, Bernero to Bartlett) relating to the lack of an acceptable OCRWM QA program. The NRC lifted SCA Objection 2 based on the information stated in the August 21, 1991, letter from Shelor to Linehan and subsequent analysis. Through these actions, the NRC has determined that all organizations participating in the site characterization activities have developed and are implementing a QA program that meets NRC requirements. The NRC staff will continue to monitor implementation through future audits and surveillances.

Throughout the reporting period, work continued on consolidation of procedures between DOE/Headquarters (DOE/HQ) and YMPO. During this period, ten procedures were issued and/or revised.

To ensure that the NRC is kept informed of the status of OCRWM's QA program, ongoing bimonthly QA meetings continue to be held with the NRC. These meetings provide a forum for the NRC, DOE, Edison Electric Institute (EEI), State of Nevada, and local governments to identify QA issues and participate in the resolution of these issues. These meetings provide information on the status, development, and progress for QA-related actions.

2.1.2 Exploratory Studies Facility design and construction

Requirements Documents for the ESF were revised to conform to a two-ramp configuration of the ESF, as recommended by the ESFAS. Plans for the surface and sub-surface site characterization activities were re-started on October 1, 1991. ESAAB acceptance of the Title I, Design Summary Report for the ESF Draft, Revision 1, was transmitted to the YMPO on December 30, 1991. Title II Design, on portions of the first phase of the ESF, consisting of site preparation, north portal pad area, high-wall, portal and starter tunnel, preliminary facilities, and utilities (water, electric, and sanitary systems) were initiated on October 1, 1991. A 50% management review of this Title II effort began on March 2, 1992, and an independent technical review was started on March 30, 1992. Comments from these two reviews are being incorporated into the continuing design work. Ninety percent (90%) design reviews are expected to be conducted in July 1992.

The revised ESF Title I Design proposes as many as four TBMs for the excavation of the ESF. Ventilation requirements in the sub-surface areas and these TBM loads require the procurement of a third, new 138 kV power transmission line from Nevada Power Company, in Las Vegas, to the NTS. A Conceptual Design Report for modifications to the existing NTS electric system is being prepared. It is expected to be completed on April 1, 1992. Initial power line procurement meetings with Nevada Power Company are underway.

2.1.3 OCRWM initiatives in surface-based and underground testing

2.1.3.1 Early Site Suitability Evaluation (ESSE)

The ESSE effort is a contractor evaluation of the technical suitability of Yucca Mountain, Nevada, as a potential site for a mined geologic repository for the permanent disposal of high-level radioactive waste. In late 1990, the Director of OCRWM had requested that this study be undertaken early in the site characterization of the Yucca Mountain site. The ESSE effort was assigned to the T&MSS contractor to allow a necessary element of independence to the evaluation. The report was completed and issued in January 1992 (Younker et al., 1992a).

The purpose of the ESSE was to determine if there is evidence of features or conditions that would render the Yucca Mountain site unsuitable for repository development. After analysis, the ESSE team was requested to provide recommendations and current status to the DOE on the suitability of the site. This is the second such evaluation for the Yucca Mountain site; a preliminary site suitability evaluation was completed as part of the site selection process, and its findings are reported in the Environmental Assessment (EA) (DOE, 1986). That evaluation, like the present one, was conducted according to DOE's General Siting Guidelines of Title 10, Part 960 of the Code of Federal Regulations (10 CFR Part 960).

In the judgment of the team conducting this evaluation, the presently available evidence continues to support the findings of the EA that the site is suitable for site characterization. This evaluation, however, found that additional information is needed in specific areas before a final

recommendation can be made regarding the suitability of the site for repository development.

The 14-member team that conducted this study was composed of technical personnel having expertise in each of the areas covered by the Siting Guidelines. The team included representatives from those organizations that are participating with the DOE in characterizing and evaluating the Yucca Mountain site. The team members, in turn, drew on expertise both from within and outside their organizations in completing this evaluation.

To ensure that the evaluation was technically sound and logically consistent, the ESSE Report underwent two formal reviews. The first review was performed by YMP technical personnel who were not involved in preparing the ESSE Report and its site suitability evaluations. The second review was conducted by a panel of 14 experts (university faculty members and private consultants) who have had minimal previous involvement with the geologic repository program. The report was then revised based on comments and recommendations received from reviewers, and these revisions were subsequently reviewed and accepted by the reviewers. The comments of the outside peer review and the associated responses are provided in a companion document to the ESSE Report (Younker et al., 1992b).

The ESSE contractor report and the peer review report were completed in January 1992 and OCRWM released the reports for a 90-day public review and comment period on February 21, 1992. The ESSE and the site evaluation process will be the subject of an OCRWM Director's Forum in May 1992. When the public comment period closes, the Director will consider comments received and points of discussion raised at the Forum to determine what actions should follow with respect to future plans for site evaluation.

2.1.3.2 Integrated Test Evaluation (ITE)

Scoping for the ITE effort began in January 1992. The purpose of the ITE study is to integrate results from previous studies with information derived from other sources to develop recommendations to the YMPO about changes in work scope or the prioritization of activities for site characterization. The primary criterion for prioritizing studies is the earliest possible detection of unsuitable conditions for a repository at the Yucca Mountain site. The study will also focus on "testing" currently planned for FY 1993. Recent studies [e.g., ESSE (Younker et al., 1992a), TPT (Mattson et al., 1991), CHRBA (DOE, 1991b), and the ESFAS (Dennis, 1991)] provided recommendations about specific actions the DOE should consider, based on repository system performance or the suitability of the site, but did not evaluate changes needed in the baseline site characterization plan from an integrated perspective.

The Evaluation Team consists of staff from the CRWMS M&O contractor, T&MSS, SNL, LANL, LLNL, and the USGS. Oversight and management for the work is provided by the YMPO.

Planning was established as follows: the effort is targeted to begin in early April 1992 with approval of the management plan. The matrix development, assessment, and analysis are currently scheduled to be completed

by mid-June 1992. Documentation of the results are scheduled to be completed at the end of July 1992, including a formal YMPO briefing, and a QMP-06-04 review of the report by mid-September 1992.

2.1.4 Permits

2.1.4.1 Compliance with federal environmental requirements

YMPO has obtained all of the necessary permits and clearances issued by Federal agencies to allow initiation of site characterization activities. A Corps of Engineers Section 404 Permit has been obtained. The DOE has obtained one Free Use Permit and continues to consult with the BLM for a second permit for the excavation of sand and gravel. Consultations have also continued with Native American tribes and bands, as specified in the Programmatic Agreement with the Advisory Council on Historic Preservation.

YMPO implemented a groundwater monitoring program in agreement with the NPS. The program serves as an early warning system to detect potential impacts before they occur in Amargosa Valley, Devil's Hole, and Death Valley National Monument. A new observation well (JF-3) was constructed in support of this program. The first report was sent to the NPS in early March 1992.

2.1.4.2 Compliance with state environmental requirements

Following decisions by the U.S. Court of Appeals and U.S. District Court, the State of Nevada continues to process DOE's permit applications. Over the past six months, Nevada has issued an air quality registration certificate for the greater than 500 horse power engine on the LM-300 drill rig, a water appropriation permit for Well J-13, and waivers from having to obtain an appropriation permit for Well JF-3 and borehole UZ-16, where no water is taken for a beneficial use. The underground injection control permit, issued for C-well hydrologic tests, is being modified by the State to include approval to inject tracers in 50 additional boreholes.

YMPO has submitted to the State of Nevada two air quality monitoring reports in compliance with the permit for land disturbance issued in June 1991, and two quarterly and one annual report in compliance with the permit for underground injection issued in July 1991. The YMP will continue to work closely with the Nevada regulatory agencies to satisfy permit conditions in a timely fashion.

2.1.5 Land acquisition

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

Fourteen participant requests to initiate site characterization activity were processed during the period. Ten of these requests have been completed and access authorization granted. The remaining four have been partially

completed. These four requests are awaiting the results of the following actions: two rights-of-way applications to the Barstow Resource Area BLM office for surface water monitoring stations; two rights-of-way applications to the Barstow Resource Area BLM office for seismic stations; four rights-of-way applications to the Stateline Resource Area BLM office for seismic stations; four rights-of-way applications to the Tonopah Resource Area BLM office for seismic stations; two request letters to the Nellis Air Force Base Range for seismic stations; and a permit request to Clark County, Nevada, for a seismic station.

2.1.6 Public outreach

Office of Institutional and External Affairs (OIEA) staff coordinated YMP Update Meetings in Las Vegas, November 18; Beatty, November 19; and Reno, November 21, 1991. A new format which proved to be successful was initiated for YMPO Update Meetings. A total of about 700 people attended the three meetings in November 1991.

OIEA staff coordinated seven Open House/Tours of the Yucca Mountain area, which were attended by approximately 1,650 guests. An additional 45 special group tours were also held with a total of 2,666 participants. These special tours consisted of 13 VIP tours, 13 private group tours, 6 educational tours for schools, and 7 media tours.

OIEA staff prepared briefing packages, handled logistics, and accompanied YMP staff to approximately 116 speaking engagements. These presentations were made to technical groups as well as students and the general public. Over 5000 individuals were reached.

OIEA staff hosted 45 tours at the Yucca Mountain Information Office, located in Las Vegas, with a total of 2177 visitors (this includes the monthly Open House/Tours). An additional 2137 adults and students visited the Las Vegas and Beatty offices.

YMPO Educational program was greatly expanded during this reporting period. An Educational Coordinator was hired and various events were developed, coordinated, and implemented successfully. Among the events were three Girl Scout Geology Merit Badge Workshops, three monthly Lecture Series presentations, a Boy Scout Atomic Energy Merit Badge Workshop, school field trips and tours, and a Chamber of Commerce Youth Leadership tour and presentation.

OIEA handled logistics and staffing for 22 exhibits during this period. These exhibits ranged from public to technical and educational. Exhibits were also shown at the three Public Update Meetings in November 1991. A total audience of 5,750 was reached.

Interactions continued with the Nevada League of Cities, Nevada Association of County Organizations, educational and business communities, and other key groups. The County Representative program has proved to be quite successful and relations with the affected counties has continued to be proactive.

As part of pioneering an entirely new YMP information product line (exhibits, brochures, fact sheets, etc.), OIEA coordinated YMP scientific research with specific public outreach goals. OIEA has completed a three-stage approval cycle at DOE/HQ for these products, and interactions connected with the approval cycle are ongoing.

OIEA coordinated the opening of the new Pahrump Information Office and hired staff for this effort. Preliminary design and development of exhibits, and educational and support equipment for the new information office also took place in this reporting period. Final development and an Open House are now planned for April 1992.

2.1.7 Interactions with NRC and oversight organizations

During the reporting period, YMPO committed a significant level of effort in support of briefings, technical exchanges, and meetings with the NWTRB, NRC, and other YMP oversight groups. The YMPO participated in seven meetings with the NWTRB: (1) NWTRB Full Board meeting on evaluation of ranges of thermal loading for high-level waste disposal on October 8-10, 1991; (2) NWTRB/Swedish Nuclear Fuel (SKN) meeting on the EBS on November 2-3, 1991; (3) NWTRB Structural Geology and Geoengineering (SG&G) panel on borehole sealing and backfilling on November 12-13, 1991; (4) YMPO participation in a DOE/HQ lead meeting with the NWTRB Full Board (Winter Meeting) on budget allocations, program priorities, the CRWMS M&O transition plan, and surface-based testing activities on January 7-8, 1992; (5) NWTRB SG&G panel on seismic vulnerabilities on January 22-23, 1992; (6) NWTRB meeting on the EBS on February 10-11, 1992; and (7) YMPO participation on a DOE/HQ lead meeting with the NWTRB Transportation and Systems (T&S) panel, focusing on system safety and human factors, transportation-related facility studies, and MRS conceptual design on March 10-11, 1992.

The YMPO also participated in ten interactions with the NRC. Interactions conducted over the reporting period included (1) an NRC meeting on final procedural agreements on October 28, 1991; (2) an NRC QA meeting with DOE and the State of Nevada on November 14, 1991; (3) an NRC regulatory strategy meeting on November 20, 1991; (4) an NRC interactions scheduling meeting on November 20, 1991; (5) an NRC meeting regarding status of the high-level waste program on December 17, 1991; (6) an NRC management meeting discussing the scope, purpose, and limits of NRC's consideration of DOE's AOs for the Geologic Repository and MRS facility, as well as NRC's review of topical reports and Study Plans on February 6, 1992; (7) an NRC QA meeting with DOE and the State of Nevada on February 18, 1992; (8) an NRC technical exchange on spent fuel on February 25-26, 1992; (9) an NRC technical exchange on thermal loading on March 17, 1992; and (10) an NRC technical exchange on air and vapor movement in the unsaturated zone due to thermal gradients on March 18, 1992.

In addition, there were several YMP site visits by NRC representatives, including John J. Linehan on December 13, 1991; Chairman Selin, Greg Cook, John Gilray, George Pangborn, and Paul Prestholt on January 13, 1992; and Philip Justus and Keith McConnell on January 24, 1992.

YMPO either attended or participated in eight meetings and working groups with the ACNW. All meetings were held in Bethesda, Maryland, and include: (1) an ACNW working group on computer modeling and performance assessment capabilities in the high and low-level waste management programs on October 16-17, 1991; (2) an ACNW 36th meeting, discussing the NRC staff's computer modeling and performance assessment capabilities with respect to high and low-level waste disposal strategies on October 18, 1991; (3) an ACNW working group on geologic dating on November 19, 1991; (4) an ACNW 37th meeting on Quaternary dating methods to be used in the assessment of volcanic features at Yucca Mountain on November 20-21, 1991; (5) an ACNW working group on seismic and faulting issues on December 17, 1991; (6) an ACNW 38th meeting on seismic issues on December 18-19, 1991; (7) an ACNW working group on a systems analysis review of the overall high-level waste program on February 19, 1992; (8) an ACNW 40th meeting concerning systems analysis and EPA's high-level waste standards on February 20-21, 1992. The 39th ACNW meeting on systems analysis of the high-level waste program was held January 15-17, 1992, and was attended and reported by a YMPO subcontractor representative.

The YMPO participated in a workshop sponsored by the Electric Power Research Institute (EPRI) on February 4-6, 1992, to review changes proposed for the EPA standard, 40 CFR Part 191. YMPO staff also attended EPRI workshops on November 14-15, 1991, and March 4-6, 1992, to discuss earthquakes and tectonics as they relate to performance assessment.

2.1.8 Comments on the technical program

The NWPA, section 113(a), requires DOE to receive and fully consider comments on the SCP. Recommendations by the NWTRB contained in their semiannual reports to Congress are treated as comments on the SCP and site characterization program. DOE's responses to the NWTRB recommendations are published in each subsequent semiannual report to Congress.

DOE remains cognizant of the open items that remain from the NRC's SCA (NRC, 1989). DOE has worked hard to close SCA Objection 1 in order to be ready to initiate Title II design. Objection 1 pertained to deficiencies that NRC believed existed in DOE's design control process for the ESF. In addition, Objection 1 pertained to the lack of demonstration that the identified test durations will permit all tests to be conducted without interference. The DOE provided initial documentation that DOE had resolved the NRC's concerns regarding the ESF design control process in a letter dated November 26, 1991. In a subsequent letter dated March 3, 1992, DOE supplied to the NRC additional documentation to close SCA Objection 1, comments 12, 16, 34, 35, 57, 72, 127, 128, 130, 132, and questions 28 and 61 (see Table 2.1). DOE will continue to address specific concerns related to test durations, etc., during ESF Title II Design. The documentation contained in the January 29, 1992, letter showed how the DOE's ESFAS (Dennis, 1991) and CHRBA (DOE, 1991b) explicitly addressed the SCA objections, comments, and questions that remained open after the NRC had evaluated the DOE's initial responses to SCA comments. In a letter to NRC dated December 16, 1991, DOE provided further expanation and clarification about planned mapping scales for surface fault maps. This was an open-item in SCA question 1 that DOE now believes is

TABLE 2.1 STATUS AND POSSIBLE MEANS TO ADDRESS NRC OPEN ITEMS ORIGINATING FROM NRC REVIEW OF DOE RESPONSES TO THE SCA; ASTERISKS SHOW OPEN-ITEM CONSIDERED CLOSED BY DOE.

#KEY TO POSSIBLE/PROPOSED METHOD OF RESOLUTION:

1. Acquisition of new site data is needed for resolution.
2. Concern addressed through ESFAS or new ESF design configuration.
3. Concern addressed through CHRBA.
4. Concern addressed through either (1) test prioritization task, or (2) development and implementation of site suitability methodology.
5. Concern addressed by implementation of YMP plan, Study Plan/activity or other design studies in current technical baseline.
6. Meeting with regulatory or oversight group (i.e., NRC or NWTRB).
7. Qualification/implementation of approved DOE and participant QA programs.
8. Development/implementation of design control plans and procedures.
9. Concern addressed by implementation of the Test and Evaluation Plan and associated test planning packages.
10. Concern addressed in development of performance assessment planning documents, or implementation of iterative performance assessments.
11. DOE has sent documentation with respect to resolving the NRC's Objection 1.

PR = Site Characterization Progress Reports

TABLE 2.1 STATUS AND POSSIBLE MEANS TO ADDRESS NRC OPEN ITEMS ORIGINATING FROM NRC REVIEW OF DOE RESPONSES TO THE SCA; ASTERISKS SHOW OPEN-ITEM CONSIDERED CLOSED BY DOE.

SCA OPEN ITEM		SUMMARY OF OPEN ITEM	RESOLUTION STATUS# (see codes, page 2-8)
OBJECTION	*1	Adequacy of Title I Design Control Process	-
COMMENT	1	Systematic, iterative approach to a license application	1, 4, 5, 9, 10
	2	Confidence in performance allocation goals	1, 4, 5, 9, 10
	3	Reliance on expert judgment to supply licensing information	1, 4, 5
	4	Rationale for testing needs; integration of testing with design and performance assessment	1, 4, 5, 11, PRs
	5	Interpretation of "substantially complete containment"	6
	6	Adequacy of alternative conceptual models	1, 4, 5
	7	Use of expert judgment vs. peer review	6
	8	Alternative tectonic models	-
	9	Use of expert judgment	1, 4, 5
	10	Assessment of significance of site hydrologic characteristics	4, 5, 10
	11	Thermal effects of waste emplacement in hydrologic environment	5, 10, PRs
	*12	Porous flow in Calico Hills Unit	-
	15	Solitario Canyon fault	-
	*16	Characteristics of Calico Hills hydrologic properties	-
	18	Initial modeling studies are not supported by planned activities	1, 4, 5, 10
	19	Saturated Zone work is not adequate for flow path hydrologic bound, flow direction, determination	1
	20	Potentiometric surface is not adequately defined	1, 5
	21	TC-99 and I-129 are not included to characterize groundwater flow and nuclide background concentrations	5
	22	Hydrochemical samples	5
	24	Standard solubility approaches are not adequate for thermodynamic properties of zeolites	1, 5
	25	Waste package degradation products and interactions between radionuclides on sorption	5

TABLE 2.1 STATUS AND POSSIBLE MEANS TO ADDRESS NRC OPEN ITEMS ORIGINATING FROM NRC REVIEW OF DOE RESPONSES TO THE SCA; ASTERISKS SHOW OPEN-ITEM CONSIDERED CLOSED BY DOE.

SCA OPEN ITEM		SUMMARY OF OPEN ITEM	RESOLUTION STATUS* (see codes, page 2-8)
COMMENT	31	Some parameters for speciation, kinetics, and matrix diffusion are not planned	5
	32	Integration of geophysics and discussion is not included	5
	33	Engineering rock characteristics are not integrated into three-dimensional models	5
	*34	Integration of drilling program	-
	*35	Adequacy of lithological, structural, and drifting activities to characterize the site	-
	36	Adequacy of location of perimeter drift and the concentration of faults	2, 11
	42	Adequacy of evaluation of escarpment retreat	5
	43	Adequacy of numerical goals in erosion, postclosure tectonics, and preclosure tectonics performance assessment tables	9, 10
	45	Volcanic rate calculations independent of underlying volcanic-tectonic processes	1, 5
	47	Relationship of postclosure tectonics to the waste package and EBS requirements	5
	48	Use of fault slip rates on the repository facilities are not conservative	1, 5
	49	Investigations on basaltic volcanism will fail to meet overall system performance	5, 9, 10
	51	Adequacy of geophysics to determine deep and shallow crustal features ...	5, geophysics "White Paper"
	52	Use of geophysics in evaluating basaltic volcanism	5
	53	Adequacy of natural resource assessment; consideration of ore deposition models	5
	55	Adequacy of geostatistical approach to geomechanical and thermal properties	1, 4, 5
	56	Validation of models for mechanical and thermal properties	5, 9
	*57	Design verification does not consider alternate methods of excavation	-

TABLE 2.1 STATUS AND POSSIBLE MEANS TO ADDRESS NRC OPEN ITEMS ORIGINATING FROM NRC REVIEW OF DOE RESPONSES TO THE SCA; ASTERISKS SHOW OPEN-ITEM CONSIDERED CLOSED BY DOE.

SCA OPEN ITEM		SUMMARY OF OPEN ITEM	RESOLUTION STATUS* (see codes, page 2-8)
COMMENT	59	Preclosure tectonics activities to be performed and timing of activities	4
	60	Adequacy of preclosure design and performance goals and characterization parameters	1, 5, 9
	61	Assumption that future faulting will follow previous faulting	5
	62	Use of standoff distances in preclosure tectonics for surface facilities	5
	63	Use of pre-existing and unavailable information for the preclosure tectonics program and the surface facilities	-
	64	Adequacy of study of faults for design and performance	2, 6
	66	Release via a single event (10,000 year cumulative slip earthquake)	5
	68	Adequacy of treatment on detachment faulting affects	5
	69	Synthesis of data on the northwest trending of faulting	2, 5
	71	Adequacy of technologies in assessing faulting for construction, operation, and closure	2, 3, 4, 5
	*72	Adequacy of seal program	-
	73	Adequacy of required backfill hydraulic conductivity	1, 10
	74	Adequacy of seal testing	1, 2, 5
	75	Definition of and inconsistent use of "geologic setting"	6
	77	Adequacy of consideration of retrieval operations	2
	79	Adequacy of waste package corrosion tests for the repository	1, 5, 11
	80	Performance goals consistent with interpretation and intent of "substantially complete containment".	6
	81	Adequacy of program in stress corrosion cracking behavior of waste package	1, 5
	82	Adequacy of waste package performance at licensing	1, 2, 5, 11
	84	Adequacy of issue resolution strategy for the EBS and waste package	1, 5, 6, 10

TABLE 2.1 STATUS AND POSSIBLE MEANS TO ADDRESS NRC OPEN ITEMS ORIGINATING FROM NRC REVIEW OF DOE RESPONSES TO THE SCA; ASTERISKS SHOW OPEN-ITEM CONSIDERED CLOSED BY DOE.

SCA OPEN ITEM		SUMMARY OF OPEN ITEM	RESOLUTION STATUS* (see codes, page 2-8)
COMMENT	85	Accounting of temporal changes in state of stress due to corrosion of container	5, 10
	86	Adequacy of degradation models of copper-based alloys	5
	87	Adequacy of affect of the contact of dissimilar metals causing corrosion	5
	88	Assumption of reduced uncertainties because of the unsaturated zone	1, 5, 10
	89	Effect of introduction of materials that affect performance of waste package and glass	1, 5, 8, 10, 11
	90	Consideration of varying oxygen fugacity on corrosion of waste package	1, 5, 10
	91	Consideration of alternate canisters for reduction of C-14 releases	10
	95	Adequacy of logic to screen and develop release scenarios	1, 5, 10
	96	Adequacy of the use of K_d for modeling heterogeneous medium	5
	98	Appropriateness of weighting CCDFs by expert judgment	10
	99	Quantification of all release modes ..	10
	100	Adequacy of consideration of faulty release scenarios	10
	101	Adequacy of SCP equation 8.3.5.13.21	10
	102	Adequacy of Ross sequences in comparison to the hydrologic flow model	10
	103	Ross sequences addressing anticipated conditions and not scenarios	10
	104	Ross sequences address spent fuel and not a vitrified waste form	10
	105	Rationale for elimination of scenarios	1, 5, 6, 10
	106	Missing coupling term for calculation of liquid phase radionuclide transport	10
	108	Appropriate use of expected partial performance measure.....	10

TABLE 2.1 STATUS AND POSSIBLE MEANS TO ADDRESS NRC OPEN ITEMS ORIGINATING FROM NRC REVIEW OF DOE RESPONSES TO THE SCA; ASTERISKS SHOW OPEN-ITEM CONSIDERED CLOSED BY DOE.

SCA OPEN ITEM		SUMMARY OF OPEN ITEM	RESOLUTION STATUS* (see codes, page 2-8)
COMMENT	109	Adequacy of treatment of coupling time between matrix and fracture flow in hypothesis testing tables ...	10
	110	Adequacy of dealing with human intrusion in the CCDF	10
	112	Adequate discussion of state variables as constants or random variables	10
	113	Consistency of definition of CCDF and the unit step function	10
	115	Adequacy of expanding of CCDF in terms of scenario classes	10
	116	Individual exposures via potable water may need to be expanded	6
	117	Individual exposure rates of C-14 may need to consider advective and diffusive flow rates	1, 5, 10
	118	Conduct of long term in situ laboratory waste package activities	1, 2, 5, 10, 11
	119	Adequacy of performance confirmation testing (10 CFR Part 60)	1, 2, 5, 10, 11
	120	Model and computer code validation studies	10
	121	Adequacy of seismic design of ESF	5, 6, 11
	122	Demonstration and acceptability of the dry coring method	PRs
	123	Assessment of effects of ventilation on the ESF	2, 5, 8, 11
	*127	Design Acceptability Analysis	-
	*128	Design Acceptability Analysis	-
	*130	Design Acceptability Analysis	-
	*132	Design Acceptability Analysis	-
QUESTION	1	Integration of mapping efforts	5
	3	Area of repository development	2, PRs
	5	Adequacy of vertical boreholes for evaluation of faults and fractures	2
	8	Rock properties: level of detail and uncertainty in 3D model	10
	9	Systematic drilling program: adequacy of sampling same specimens for rock properties	5
	12	Rationale for exclusion of lunar crater basaltic field as analogue ...	5

TABLE 2.1 STATUS AND POSSIBLE MEANS TO ADDRESS NRC OPEN ITEMS ORIGINATING FROM NRC REVIEW OF DOE RESPONSES TO THE SCA; ASTERISKS SHOW OPEN-ITEM CONSIDERED CLOSED BY DOE.

SCA OPEN ITEM		SUMMARY OF OPEN ITEM	RESOLUTION STATUS* (see codes, page 2-8)
QUESTION	14	Natural resources: adequacy of evaluation of previous mining and drilling leases on the site	5
	15	Resource exploration and mineral resource potential	5
	17	Rock properties: activities to investigate affects on thermal and mechanical properties	5, 11
	20	Discussion on vertical or horizontal emplacement	PRs
	21	Parameters for radiation shielding properties of the host rock	5
	22	Parameters related to repository construction and operation	5, 10
	23	Computer code verification and validation	7
	25	Heterogeneous air flow characteristics for seal program	5
	*28	ESF penetration of Calico Hills and impact on Issue 4.4	-
	30	Water quality as related to waste package design	5
	31	Integrity of spent fuel cladding	1, 5, 10
	32	Container "similarity" for borosilicate glass waste vs. spent fuel .	5
	33	Emplacement hole drainage concerns ...	1, 5, 10
	34	Meaning of undetected defective closures	10
	35	Acceptance criteria for helium leak tests	6, 10
	36	Contact of canisters with corrosive elements during shipping and handling	1, 5
	37	Basis for 10cm of free fall for canister and contents	5
	38	Basis for 1mm of thinning of canister due to impact or handling ..	1, 5, 10
	39	Definition of "unusual process history" of canister	1, 5, 10
	40	Basis for factor of 2 on borehole liner in comparison to container material .	1, 5, 10
	41	Consideration of 10 CFR 60.132 (a) in resolution of 2.4	1, 5
	42	Assumption of stability of vertical emplacement hole	5

TABLE 2.1 STATUS AND POSSIBLE MEANS TO ADDRESS NRC OPEN ITEMS ORIGINATING FROM NRC REVIEW OF DOE RESPONSES TO THE SCA; ASTERISKS SHOW OPEN-ITEM CONSIDERED CLOSED BY DOE.

SCA OPEN ITEM		SUMMARY OF OPEN ITEM	RESOLUTION STATUS* (see codes, page 2-8)
QUESTION	44	Basis for assumed numbers of breached assemblies or canisters	5
	45	Investigation of particulate source terms, retention factors, and plate-out of waste package during accident conditions	1, 5
	46	Basis for stricter containment of long half-life isotopes	6
	47	Assumption on breaches of waste containers	6
	49	Effects of low temperature oxidation on containers	1, 5, 10
	51	Design and research criteria for accepting waste from INEL and Hanford	5, 9
	53	Specification of cooling rate of the glass waste	Waste Acceptance Committee and Materials Steering Committee
	55	Interference at the ESF by water storage tanks, septic field, and waste water lagoon	8, 11
	56	Basis for 5cm of fault displacement in waste package environment	-
	57	Effects of drilling multipurpose boreholes	8
	58	Flexibility of ESF to accommodate in situ testing of waste package	11
	59	Basis for length of in situ thermal tests	2, 9, 11
	*61	Accommodation of design changes during ESF construction	-
	62	Basis for 500 ft of separation of ESF from waste emplacement and 30m of separation from ESF and waste emplacement panel	11

closed. Open items will be addressed by DOE as site characterization proceeds and when information has evolved such that these concerns can be addressed.

NRC informed DOE that the entire OCRWM QA program was unconditionally accepted in a letter dated December 20, 1991. In a letter dated March 2, 1992, the NRC informed DOE that it was lifting SCA Objection 2. Objection 2 pertained to the lack of an acceptable QA program for the Civilian Radioactive Waste Management program.

2.1.8.1 Comments on SCP Study Plans

DOE and the NRC follow protocol established for Study Plan acceptance in an agreement resulting from a December 15, 1988, meeting. The NRC notifies the DOE within three months of receipt of a Study Plan if there are objections to starting the work defined by the plan. The NRC also provides detailed technical comments on specific Study Plans at their discretion. To date, 40 comments have been received on nine Study Plans. The State of Nevada receives controlled copies of all approved Study Plans at the time they are sent to the NRC. The State has submitted 58 comments on eight Study Plans. The response to comments on individual Study Plans by either the State or NRC is discussed under the applicable sections in Chapter 2.2.

2.1.9 Site Characterization Program Baseline (SCPB)

Revision 2 of the SCPB was issued in October 1991 to document revised plans for testing in SCP Section 8.3.1.14. These changes were largely administrative in nature and consolidated all of the anticipated studies under Investigation 8.3.1.14 into one Study Plan (8.3.1.14.2, Soils and Rock Properties). In Revision 3 of the SCPB, changes to the objectives of Activities 1 and 4 in Study Plan 8.3.1.2.1.4 (Regional Hydrologic Synthesis and Modeling) and Activity 4 in Study Plan 8.3.1.2.3.2 (Characterization of the Saturated-Zone Hydrochemistry) were documented. Revision 3 also reflected the addition of three drill holes to Study Plan 8.3.1.2.3.1 (Regional Ground-water Flow System). These drill holes will provide data on the large hydraulic gradient northwest of Yucca Mountain. Revision 4 of the SCPB was issued in March 1992 to incorporate changes in the objectives of Activities 1 and 3 in Study Plan 8.3.1.2.3.2 (Characterization of the Upper Saturated-Zone Hydrochemistry).

All revisions of the SCPB are controlled. The SCPB identifies the DOE's baselined site characterization program and provides the means to demonstrate traceability of changes in the site characterization studies. Both the NRC and the State of Nevada maintain controlled copies of the SCPB.

2.1.10 Performance assessment

TSPA continued the process laid out in the SCP: detailed identification of events and processes that will need to be modeled for licensing, the development of a total-system model of gas-phase releases, and the production of a total-system analysis that draws on detailed calculations to construct the CCDFs needed for evaluating compliance with regulations. This

total-system analysis describes probabilistically both the expected behavior of a potential repository system and the unexpected, disruptive phenomena that may occur.

The initial TSPA analyses were completed for the four elements of this assessment: groundwater flow, gas flow, human intrusion, and basaltic volcanism. The nominal-flow case includes representations of both fracture and matrix flow. Studies of groundwater flow and transport include representations of both the unsaturated and the saturated zones. This exercise differed from the Performance Assessment Calculational Exercise-1990 (PACE-90) (a demonstration of computational capabilities, identification of critical processes and elements, and demonstration of the ability of participants to work together) and analyses associated with ESSE (see Section 2.1.3.1) in that these simulations were stochastic, the set of phenomena modeled was expanded, the results of the analyses were used to calculate dose, the calculations were run out to the accessible environment, and a larger number of radionuclides were included in a more complex source term. Goals of this exercise were to demonstrate the capability to abstract data and calculational results from complex analyses for use in higher level calculations and to develop a tool to be used eventually in understanding sensitive parameters and processes.

Work was completed on a two-dimensional numerical analysis of the Yucca Mountain region extending from drillholes USW H-5 to UE25a. Offset along the Ghost Dance fault was included. NORIA-SP was used to generate a time-dependent flow field. Results show that water infiltrating through the upper boundary tends to saturate regions immediately upstream of the fault and also at the down-dip boundary. However, only a moderate amount of lateral flow was computed as a result of the difference in the geologic unit conductivities and the discontinuity along the fault.

The following reports were published in support of the TSPA analyses noted above: "Simplified Radionuclide Source Term for Total-System Performance Assessment" (Wilson, 1991) and "Numerical Studies of Rock-Gas Flow in Yucca Mountain" (Ross et al., 1991).

The results of numerical simulations of tectonohydrologic coupling resulting from typical Basin and Range earthquakes were reported in the paper "Potential for Water-Table Excursions Induced by Seismic Events at Yucca Mountain, Nevada" (Carrigan et al., 1991). The simulations show that only very small water table excursions, on the order of two to three meters, are likely to occur in response to pore pressure fields induced by typical Basin and Range earthquakes.

2.1.11 Transition to the CRWMS Management and Operating (M&O) contractor

CRWMS M&O contractor activities included completing training requirements to perform quality affecting work, assuming system engineering and integration duties, and implementing the initial phases of the M&O Transition Plan.

The training requirements were successfully completed, and culminated in a successful Readiness Review in December 1991. A detailed concept of the operation plan for overall integration activities also was developed and

implemented. The Transition Plan was finalized and consisted of three major categories of activities:

1. The M&O performing as a YMP participant, by transitioning into the areas of ESF planning, waste package planning, performance assessment, and repository planning.

2. The M&O assisting the YMPO in its conduct of overall YMP activities, including technical, financial, and regulatory support areas such as managing the technical baselines of the ESF, site, and repository; controlling schedule and cost performance; satisfying regulatory and institutional requirements; and managing YMP records.

3. The M&O transitioning into a range of efforts which includes providing management support to the YMPO. These tasks also include planning the ESF, surface-based testing, integrating YMP efforts, defining and controlling interfaces, directing technical activities of DOE associated contractors and reviewing efforts of YMP participants.

Efforts for these three major activities were initiated. In addition, the workload elements below were specifically transferred to the M&O as part of the three major activities:

- Systems
- Continue reference information base (RIB) Development
- Edit and Distribute the Automated Technical Data Tracking System Catalog
- Systems Performance Assessment
- Evaluate Waste Package

Progress in the above areas is described below where applicable to site characterization activities.

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 groundwater flow system characterization and modeling for both the unsaturated and saturated zones (SCP Section 8.3.1.2).

- Geochemistry - investigates and models rock chemistry and mineralogy, groundwater 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).

- 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 groundwater 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 what potential impacts these installations and operations might have 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 unsaturated zone 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

Study Plan 8.3.1.2.1.1 received NRC acceptance on October 21, 1991. YMPO received ten comments from the State of Nevada on December 10, 1991, which were forwarded to the USGS for response on December 20, 1991.

Activity 8.3.1.2.1.1.1 - Precipitation and meteorological monitoring. Monitoring of the Yucca Mountain precipitation storage-gage network continued. The network consists of 104 collection gages of three types: plastic wedges, 4-inch diameter canisters, and 8-inch diameter, National Weather Service standard, metal rain gages. Some wedges have been replaced with the 4-inch gages while some sites have both a wedge and a 4-inch gage. This allows direct comparison of the two types of gages. The network will be expanded further to include gages at the newly drilled neutron access holes. The past six-month period has been unusually wet, especially in 1992. Since October 1, 1991, there have been at least 15 Pacific storms with precipitation affecting the Yucca Mountain region. The areal average precipitation at the collection gage network from these 15 storms was over 8 inches. Since January 1, 1992, the areal average was over 6.5 inches. The annual average precipitation (AAP) for Yucca Mountain is about 6 inches and the AAP in Jackass Flats is 5.1 inches.

Weather station and tipping bucket rain gage data collection and archival continued. The Sierra-Misco rain gages at the five weather stations were laboratory calibrated. The Qualimetrics heated precipitation gages at the five weather stations will undergo laboratory calibration soon. The first Qualimetrics gage has been set up to begin laboratory calibration. An additional 20 tipping-bucket rain gages will be added to Study Areas 1 and 2 as defined in Study Plan 8.3.1.2.1.1.

The collection of regional precipitation and evaporation pan data continued. The data are used in regional geostatistical analyses of precipitation patterns and to determine major storm affects in southern Nevada, southwest California, and the Yucca Mountain region.

Local and regional storm data were analyzed using multivariate geostatistics to evaluate spatial and seasonal variability during FY 1991. The precipitation data base was expanded to include both historical and active stations with sufficient lengths of record for calculating the AAP. Values of AAP will be used in a comparative analysis of annual totals by calculating relative deficit and excess precipitation for each station, which ultimately will be useful in the characterization of weather patterns and climatic trends. Work is in progress to use elevation data, lightning strike data, and possibly cloud cover data in an attempt to improve mapping accuracies using multivariate geostatistics.

Radio telemetry capability was added to three weather stations (station numbers 1, 2, 3) and two additional tipping bucket rain gages (Fran Ridge and G3). This enables the remote downloading of data to the Hydrologic Research Facility (HRF). Data continue to be recorded on cassettes as a backup measure. Seven sites can now be remotely downloaded.

Receipt of Geostationary Orbital Environmental Satellite (GOES) satellite data continued. Data are downloaded via earth station link with GOES-West every three hours. Data consist primarily of infrared pictures of most of North America. This information is valuable in determining the origin, development, and movement of storms affecting the southwest U.S. and the Yucca Mountain region.

Lightning strike data were collected from thunderstorm activity in the Yucca Mountain region. Little lightning activity occurred during the winter storms. However, the storm of March 30, 1992, produced widespread lightning across southern Nevada, and pea-sized hail near Yucca Mountain and golf ball-sized hail in Henderson and Las Vegas were reported. Lightning activity was moderate in Jackass Flats near the HRF, with no strikes documented on Yucca Mountain. Video time-lapse photography of the weather over Yucca Mountain continued. This information is valuable in determining the development, location, and movement of storms that directly affect the mountain. Visual information can be studied along with satellite, lightning, and precipitation data to add to the overall understanding of the region's meteorology. This information will help determine the extent (if any) to which Yucca Mountain has an orographic effect on cloud/storm development.

2.2.1.2 Study 8.3.1.2.1.2 - Characterization of runoff and streamflow

Activity 8.3.1.2.1.2.1 - Surface-water runoff monitoring. Monitoring activities continued at 9 continuous-recording stream gages, 13 peak-flow sites, and 21 storage-type precipitation gages. An additional continuous-recording gage was installed during October 1991 on the Amargosa River at Tecopa, California, as part of planned expansion of the regional surface-water network. ALERT telemetry systems, which will allow for real-time notification of flow, were installed in 3 gauges located within the upper Fortymile Wash drainage basin and in the new Tecopa gage. Levels were run at selected network sites to check staff plate settings against established reference marks and to document stream-channel, cross-section and slope characteristics. The planned data report on surface-water and precipitation data collected during water years 1983-85 was submitted for final typing. Compilation of the 1986-92 records continued.

Intermittent regional storms during the period January 1 to March 31, 1992, brought record precipitation into the Southern Nevada Region with over 5 inches reported for the Las Vegas Valley and over 6.5 inches reported for Yucca Mountain. Average annual precipitation is about 4 inches for the Las Vegas Valley and about 6 inches for Yucca Mountain. Although runoff was generally minor in most cases, streamflow which occurred in Fortymile Wash near the Narrows gage in February 1992 was the first flow at that point in Fortymile Wash since 1984. Direct and indirect measurements of stream-flow were made and documented at several of the regional network sites.

Activity 8.3.1.2.1.2.2 - Transport of debris by severe runoff. Field reconnaissance of erosional and depositional features related to severe runoff were conducted at a number of localities in the Yucca Mountain area. Aerial photographs, Landsat TM image data, and digital terrain models are currently being evaluated in terms of their availability and suitability to this study. Sites affected by severe runoff due to historic weather events will be

selected from field and aerial reconnaissance for subsequent site-specific analysis to determine if any relationships exist between debris transport processes and those terrain factors that control their location and geographic extent. To date, field reconnaissance activities have focused on examining sites of the 1984 and 1990 severe runoff events. Areas under investigation include the upper, middle, and lower Amargosa River and Fortymile Wash, Las Vegas Wash and its major tributaries (e.g., Duck Creek and Flamingo Wash), and debris flow sites such as Copper Canyon, Ophir Creek, Postosi Mountain, and Jake's Point. Investigative activities have included examinations of (1) past and present fluvial deposits, (2) drainage features associated with drainage outlets and tributary systems, (3) processes of alluvial fan formation, and (4) development of modern-day floodplains and the influence of severe runoff. Jake's Point, a tributary area of Fortymile Wash that was subjected to severe runoff in 1984, is currently under investigation using a photogrammetric technique to determine the quantity (volume) of debris that was eroded from this upland ridge and deposited in the valley below.

In southern Nevada, debris transport was especially intense in response to severe March 1992 weather. These storms produced intense precipitation, hail, and flooding in the southern Las Vegas valley and resulted in near bank-full conditions along Duck Creek and Flamingo Wash, and within distributary networks on the alluvial fans that surround the valley. Data for these severe runoff events (e.g., discharge rates, and the maximum velocity and erosive power of these streams) are still being collected. It is anticipated that these data will provide further insight into the processes of debris movement by severe runoff.

2.2.1.3 Study 8.3.1.2.1.3 - Characterization of the regional ground-water flow system

Study Plan 8.3.1.2.1.3 received NRC acceptance October 4, 1991.

Activity 8.3.1.2.1.3.1 - Assessment of the regional hydrologic data needs in the saturated zone. This activity is mostly completed as discussed in Study Plan 8.3.1.2.1.3. Data prioritization and uncertainty are discussed at length in the activity description within the Study Plan.

Activity 8.3.1.2.1.3.2 - Regional potentiometric-level distribution and hydrogeologic framework studies. Cuttings were collected during the construction of two wildcat oil-test wells in the Amargosa Desert in October 1991. The first drill hole was completed to a total depth of 5,020 feet. Cuttings from the drilling fluid were collected, washed, and bagged by YMP personnel. A second hole was constructed to a depth of 1,466 feet and was abandoned as a result of lost-circulation problems.

Log data from mining-company drill holes constructed in the Amargosa Desert were compiled in a uniform format, plotted, and described. Field reconnaissance was performed to find additional mining company drill holes constructed in the Funeral Mountains and Greenwater Range. Several drill holes were visited that had either collapsed or were too shallow to use. Water levels were obtained from about 23 observation wells in the subregional groundwater flow system.

Tables were compiled, showing June 1991 well status, to be used to develop a monitoring network that will provide spatial coverage and act as a partial check on data being collected as part of environmental monitoring. A draft version of a water-level data report was completed, containing approximately 540 water-level measurements.

A small-diameter jack pump (similar to a windmill-style pump) was successfully tested in a well in the Amargosa Desert. The test, which was conducted in a shallow depth to water area, was cut short when the water level dropped below the pump intake. Future testing will be conducted in areas where the water level is several hundred feet below land surface. When the pump is fully operational, water samples can be obtained from an open well by two people in a matter of hours.

Activity 8.3.1.2.1.3.3 - Fortymile Wash recharge study. Hydrogeologic data in the Fortymile Wash area were compiled by reviewing reports containing location, land surface elevation, well depth, water level, and geologic data for UE-29a#1, UE-29a#2, UE-29 UZN#91, UE-25 UZN#92, UE-25 WT#15, UE-25 WT#13, J-13, and J-12. A reference list of the data sources was made for future use.

Channel geometry data on Fortymile Wash, Topopah Wash, and the Amargosa River were analyzed with previously published regional channel geometry-discharge relationships. Preliminary runs with an Agricultural Research Service computer model were made to investigate mean flow values and recharge in the Yucca Mountain area.

The Merced River, California stream flow time series (1916-90), was analyzed using nonlinear dynamics methods chaos theory. The abstract "Still No Evidence of Chaos in Western U.S. Streamflow" (Savard, 1991) was published and a poster presented at the 1991 Fall American Geophysical Union (AGU) meeting. The abstract "Looking for Chaos in Streamflow with Discharge-Derivative Data" (Savard) was accepted by the AGU for presentation at the 1992 Spring meeting special session, "Predictability of Climatic and Hydrologic Systems: Insights from Nonlinear Dynamics."

Precipitation-streamflow-recharge events were documented during the reporting period. Photographs of streamflow were made to help document the events.

Activity staff assisted in setting up a flume and ten-turn potentiometer to measure water levels in the flume at well JF-3. The flume was used to measure pump discharge during aquifer sampling. Similar techniques using a flume may be incorporated for other aquifer tests discharging into Fortymile Wash. The ten-turn potentiometer will also be used to monitor water levels in infiltration tanks during infiltration testing.

Activity 8.3.1.2.1.3.4 - Evapotranspiration studies. YMP staff met with staff from Desert Research Institute, Reno, and the Australian Government, to discuss methods for estimating evapotranspiration in arid environments.

Text and illustrations to USGS Water-Supply Paper 2377 entitled "Geohydrology and Evapotranspiration at Franklin Lake Playa, Inyo County, California" (Czarnecki) were revised per USGS final editorial review. Two reports were written describing the deployment of a multilevel sampler at

Franklin Lake Playa, Inyo County California, and submitted for editorial and technical reviews. One paper "Does Localized Recharge Occur at a Discharge Area Within the Ground-Water Flow System of Yucca Mountain, Nevada?" (Czarnecki) will be published in the proceedings of Waste Management '92. The other, "A Hint of Recharge at Franklin Lake Playa, Inyo County, California," (Czarnecki) will appear in the proceedings of the 7th International Conference on Water-Rock Interactions.

2.2.1.4 Study 8.3.1.2.1.4 - Regional hydrologic system synthesis and modeling

Study Plan 8.3.1.2.1.4 was approved by DOE and was sent to the NRC on January 15, 1992.

Activity 8.3.1.2.1.4.1 - Conceptualization of regional hydrologic flow models. Conceptualization of regional flow models was completed.

Activity 8.3.1.2.1.4.2 - Subregional two-dimensional areal hydrologic modeling. A saturated-zone groundwater travel time workshop was organized and held in Tucson, Arizona, and attended by about 50 YMP personnel. NRC representatives were also present. A paper entitled "Factors Affecting Ground-Water Flow Direction and Magnitude at Yucca Mountain" was presented (Czarnecki). A wrap-up discussion was held at the end of the two-day meeting. A meeting of YMPO's Hydrology Integration Task members was held afterward to coordinate the preparation of a summary paper of the meeting. A proposal was prepared and revised for performing additional testing in drill-hole USW G-2 and other holes. Testing will include additional geophysical logging, flow surveying, and pumping to obtain hydrochemical samples from well G-2.

Activity 8.3.1.2.1.4.3 - Subregional two-dimensional 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. Staff continued to evaluate ARC/INFO and MODFLOW, a USGS groundwater flow model, interfaces and hardware and software that may be used for three-dimensional modeling. They also continued development of concepts and requirements necessary for initial three-dimensional model runs.

2.2.1.5 Study 8.3.1.2.2.1 - Characterization of unsaturated-zone infiltration

Activity 8.3.1.2.2.1.1 - Characterization of hydrologic properties of surficial materials. Over 800 rock samples have been collected for laboratory analysis from several surface outcrop transects. Transects were located in order to investigate the spatial relationships between physical properties of the rock (e.g., bulk density, grain density, and porosity) within the various units over Yucca Mountain. Sixty-eight representative transect samples were selected for more detailed hydrologic measurements including saturated hydraulic conductivity, water retention, and imbibition. Transects include a horizontal transect along the west side of Yucca Crest in the nonwelded shardy base of the Tiva Canyon Member to look at horizontal variability within one unit; two horizontal transects, one approximately two miles along the crest to look at the upper cliff micro-unit of the Tiva Canyon and another

approximately one mile along the west side of the ridge to examine the vitric caprock of the Topopah Spring Member, a very low porosity unit; a vertical transect extending from the Solitario Canyon fault to the top of the ridge at UZ-6s; another transect extending from the base of the Calico Hills to the Tiva Canyon caprock located at the north end of Yucca Mountain, generally referred to as the Prow; a transect sampling the Calico Hills unit west of the Prow; a transect sampling the upper Tiva Canyon exposed in Pagany Wash; and a transect sampling from the base of the Topopah Spring through the lower Tiva Canyon located at Busted Butte. Measurements of hydrologic properties on one-inch diameter drilled plugs have been completed on most of these samples and indicate strong deterministic trends that reflect emplacement and cooling history of the volcanic units. A paper entitled "Deterministic Geologic Processes and Stochastic Modeling" (Rautman and Flint) was prepared for presentation at the International High Level Radioactive Waste Management (IHLRWM) Conference in Las Vegas in April 1992.

Activity 8.3.1.2.2.1.2 - Evaluation of natural infiltration. A small scale deterministic model was initiated using the data from six boreholes in a cross section in Pagany Wash (USW UZN-4 through USW UZN-9). This model was originally planned as a one-dimensional exercise using the TOUGH code, but when mass balance calculations indicated lateral flow, it was expanded to two-dimensional. VS2DT, a two-dimensional finite difference algorithm, was modified to allow for irregularly shaped mesh boundaries, operator selection of moisture characteristic functions, different input and output formats and redimensioning. The purpose of this model is fourfold: 1) to obtain indirect information on the hydrologic and physical parameters for alluvium; 2) to simulate flow for future climate scenarios for the purpose of analyzing the probability distribution of natural infiltration; 3) to conduct sensitivity analysis of model parameters to help determine required accuracies for the characterization of parameters [saturated hydraulic conductivity, porosity, functional relations, water content, anisotropy, storativity, adsorption (clay content and type), thermal conductivity, and surface resistance]; and 4) to assist in development of the large scale deterministic model. Preliminary simulations were done with 1984 neutron logging data collected before and following a runoff event which had no associated rainfall data or evapotranspiration data. A paper entitled "Inverse Solution Applied to One-Dimensional Infiltration at an Arid Site Using an Integral Finite-Difference Model" (Hevesi et al., 1991) provided the preliminary results in a presentation at the Soil Science Society of America (SSSA) meeting in Denver.

The drilling of neutron access boreholes continued with boreholes located in/or on WT-2 Wash (N-54 and N-55), Wren Wash (N-37), Mile High Mesa (N-11), and Bleach Bone Ridge (N-15, N-17 and N-36). N-54, 55 and 37 were drilled approximately 250 ft in order to penetrate the nonwelded and bedded units and encounter the top of the Topopah Spring unit. N-11 was drilled in the area of Yucca Mountain with the most rainfall. The remaining three holes provide coverage of the Pagany Wash watershed, an analogue to the potential repository area under wetter climatic conditions, and all penetrate into Tiva Canyon welded tuff. Locations were selected for the remaining neutron holes scheduled to be drilled in FY 1992.

The analysis of borehole neutron logging and core data from the newly drilled boreholes was started. Development of a field calibration equation

for actual in situ volumetric water content was initiated. This equation will utilize a transfer function to associate it with the neutron calibration tanks to detect any drift that may occur in the instruments over time. Neutron logging was conducted daily during the drilling of N-55 and N-54 to ensure that changes in formation water content due to drilling, as well as formation equilibration times, were documented. This was done in order to assess the appropriate measured formation water content to relate to the core samples collected during drilling to assure an accurate calibration. During the drilling of N-55 circumstances required the withdrawal of the casing which enabled the use of the neutron log in the uncased portion of the borehole. This will contribute to an uncased borehole calibration. The N-55 borehole was also logged with a TV camera when it was uncased, which provided information on the voids behind the casing, explained some of the variabilities noticed in cased borehole neutron logs, and will help to improve the calibration equation. A preliminary equation has produced a correlation between volumetric water of core and neutron counts of r^2 equal to 0.92. The development of an uncased calibration for the neutron probe has allowed for the analysis of open hole profiles in existing boreholes (UZ-7, UZ-4 and UZ-5). Profiles in N-55, N-54 and UZ-7 (upwash of N-55 and N-54) are very similar. Differences in the profiles are supportive of the concept of increased infiltration into tuff under shallower alluvium which occurs on the sideslope and upwash in the channel. The analysis of the other 74 boreholes will be continued when the new calibration equation is finalized.

Neutron-logging profiles in Pagany Wash following heavy precipitation during February 1992 showed significant increase in water content to a depth of 1 meter. This pulse has continued to percolate downward. Data from N-91 and N-92 in Fortymile Canyon indicated that water penetrated to approximately 3 meters and then stopped moving downward, suggesting an impermeable layer or preferential flow undetectable by the neutron probe. The development of conceptual models was discussed in a paper entitled "Using a Conceptual Model to Evaluate the Methodology Required to Determine Net Infiltration at an Arid Site" (Flint et al., 1991), which was presented at the SSSA meeting in Denver.

The installation of an automated class A evaporation pan at a field site in Jackass Flats was completed. A field site instrument station includes a tipping bucket rain gage, totalizing anemometer, and thermistors for measuring water and air temperature. Laboratory testing of the prototype time domain reflectometry (TDR) system was completed. Field testing continued at the field site in Jackass Flats where the evaporation pan is located.

Samples from N-55 core have been identified to produce a data-set representing tritium (H^3) concentration approximately every 5 feet throughout the borehole. Tritium sample size requirements and handling methodology have been determined and arrangements have been made with the USGS geochemistry group to conduct the analysis.

In order to develop a field calibration for the cross-hole gamma probe, parallel access tubes have been installed at a field site in Jackass Flats. The access tubes were installed using a newly developed procedure that utilizes a portable pneumatic jack-leg drill so as to cause minimum surface disturbance. Laboratory calibration was initiated, and a preliminary test of instrument operation and sensitivity was completed.

Two shallow unsaturated zone in situ monitoring sites have been identified where there are closely spaced boreholes. The casing could be removed from one borehole and the borehole instrumented to monitor pressure, temperature, and water potential, while the other borehole is maintained for neutron logging. This would allow a comparison of two different methods of monitoring natural infiltration. The locations are in Split Wash and Wren Wash where both sets of boreholes are about 5-10 feet apart. Monitoring instrumentation will include peltier thermocouple psychrometers, thermistors and pressure transducers.

Activity 8.3.1.2.2.1.3 - Evaluation of artificial infiltration. Several sites for the artificial infiltration studies have been selected for early construction. Sites selected include 12 ponding sites, 6 small plot rainfall simulation sites, and 6 large plot rainfall simulation sites. This represents the various infiltration-runoff units, sideslope, ridgetop and alluvium (channel and terrace) and will provide suitable data for characterization of artificial infiltration.

The prototype infiltrometer study was resumed. An evaluation of the soil sampling methodology for the gravelly, rocky soils at Yucca Mountain was started. Some laboratory work will be required before a full field scale sampling program can be developed. New information regarding calculated solutions for well permeameters was obtained and is being evaluated for applicability. The GUELPH well permeameter has been loaned to SNL where it will be compared with a prototype model of another infiltrometer.

2.2.1.6 Study 8.3.1.2.2.2 - Water movement test

Comments on the Study Plan were received from the NRC and State of Nevada and addressed by the Principal Investigator. Responses were sent to the YMPO on October 17, 1991.

Activity 8.3.1.2.2.2.1 - Chloride and chlorine-36 measurements of percolation at Yucca Mountain. Sample collection was coordinated with field activities of other site characterization studies. The following samples were collected during this period: (1) 76 surface-soil samples along the Perimeter Drift Boundary to assess variability in meteoric chlorine/bromine (Cl/Br) ratios; (2) 77 samples (to depths of 3 m) from pits in Midway Valley to estimate present-day infiltration rates using chlorine-36/chlorine ($^{36}Cl/Cl$) analysis; (3) 16 deep-soil samples from 8 pits in Midway Valley to establish a data base on the spatial variability of the meteoric $^{36}Cl/Cl$ ratio; and (4) 250 ream-cutting samples from 7 neutron-access boreholes to be analyzed for $^{36}Cl/Cl$ and Cl/Br. These investigations will determine depths to which bomb-pulse ^{36}Cl has moved and correlate this with the lithology, assess the extent to which bomb-pulse ^{36}Cl signals correlate to those of H_3, evaluate the variability in the meteoric $^{36}Cl/Cl$ ratio, and evaluate the proposal to use Cl/Br ratios in rock samples to correct the $^{36}Cl/Cl$ ratios for the effect of dilution by rock chloride.

2.2.1.7 Study 8.3.1.2.2.3 - Characterization of percolation in the unsaturated zone--surface-based study

Study Plan 8.3.1.2.2.3 received NRC acceptance on March 26, 1992.

Activity 8.3.1.2.2.3.1 - Matrix hydrologic properties testing. A technical procedure for preserving, handling, and analyzing core samples from Yucca Mountain drill holes was approved and implemented. The procedure covers the measurement or calculation of gravimetric water content of rock samples. It also addresses the methodology for saturating and drying samples to measure bulk density, grain density, and porosity. Core samples from the first new neutron access borehole were processed using this procedure.

Prototype testing was nearing completion on several laboratory techniques. The water retention measurements using the submersible pressurized outflow cell (SPOC) are in the final experimental stages. The cell itself has been redesigned and tested several times to improve the weight, pressure strength, and sealing mechanism for the capillary barrier. Experiments have also been carried out using small load cells to detect the change in the weight of the device as water is expelled or imbibed. A number of difficulties with load cell temperature and air current instability were overcome by placing the apparatus inside a temperature-controlled chamber. A large, walk-in environmental chamber is currently being obtained for production-scale analysis using multiple SPOC devices. A paper discussing the preliminary SPOC system, "Use of Submersible Pressurized Outflow Cells in Characterization of Hydrologic Properties of Volcanic Rock Samples" (Flint and Flint, 1991a), was presented at the SSSA meeting in Denver. A specialized ultracentrifuge is being procured to allow usage of a new steady-state method for the determination of water retention curves and unsaturated hydraulic conductivities on low permeability rock samples. The procedure uses a precision, controllable infusion pump to create steady state flow through the sample while maintaining a constant partial water saturation, allowing unsaturated hydraulic conductivity to be determined. This is a notoriously difficult measurement to make on low flow rocks using the traditional Hassler experiment with high gas/water entry pressure capillary barriers and precision-controlled pressures. The centrifuge method shows great promise for obtaining unsaturated hydraulic conductivity data from Yucca Mountain cores.

Several new pieces of equipment have been obtained for the HRF. A helium pycnometer, which measures grain density and volume, using a Boyle's Law gas expansion method, was procured to make automatic measurements on individual samples and has undergone extensive evaluation to determine methodology and accuracy. A chilled-mirror psychrometer is being used to determine water potential. The instrument provides calibrated data by employing a Peltier-cooled mirror to detect the dewpoint and an infrared sensor to measure temperature. Calibrations are being run with supersaturated solutions of various salts which have known, standard potentials to assess the accuracy and repeatability of the device. Apparatus for impregnating the pores of tight rock samples with dyed epoxy plastic has been designed and constructed. This equipment will be used to prepare rock chips for thin-sectioning. Image analysis and video equipment are being procured for the petrographic microscope to allow detailed, quantitative analyses to be run on the pore geometry and flowpath morphology of the Yucca Mountain unsaturated-zone tuffs.

An abstract entitled "Laboratory Analysis of Porosity and Permeability in Unsaturated Tuffs at Yucca Mountain, Nevada" (Soeder et al., 1991) was presented at the Geological Society of America (GSA) Annual Meeting in San Diego, California on October 22, 1991. Another abstract entitled "Effects of Sample Handling and Measurement Methodology on the Determination of Porosity in Volcanic Rock Samples" (Soeder et al., 1991) was presented at the American Statistical Association/CSA/SSSA Annual Meeting in Denver.

Activity 8.3.1.2.2.3.2 - Site vertical borehole studies. Three 40-foot deep boreholes, located adjacent to the HRF building, were instrumented during the reporting period. Each of the three boreholes is configured with 4 instrument stations located at depths of 10, 20, 30, and 40 feet. Sensors are read every 2.5 hours. Backup sensors at each station are scanned periodically to corroborate readings of the primary sensors. Boreholes #1 and #2, which were instrumented in October 1991, have equilibrated. Borehole #3 was instrumented in late February 1992. Data quality is excellent. Psychrometers are resolving water potential changes to better than 0.05 bars, pressure transducers are recording pressure changes that are on the order of 5 pascals, and thermistors are detecting temperature changes that are on the order of ±0.0005°C. Initial results indicate that atmospheric loading (i.e. barometric pumping) is active to depths of at least 40 feet, and that the equilibration process is driven primarily by convective mass transfer caused by barometric pressure changes. Secondary pressure changes, caused by semidiural heating and cooling of the atmosphere, are also detectable to depths of at least 40 feet. These secondary pressure pulses, which are superimposed on the barometric pressure wave, also cause minor fluctuations in measured water potentials. The correlation of pressure changes with water potential changes is 1 to 1. Primary sensors in boreholes #1 and #2 have been excited at a frequency that is equivalent to one year of operation at the planned cycling frequency for sensors that will be used in the deep UZ monitoring program at Yucca Mountain. No degradation in sensor accuracy has been observed.

A final downhole instrument station apparatus (DISA) design was established in conjunction with the instrumentation of HRF borehole #3. Engineering drawings for the DISA have been completed. Construction of the first gas sampling apparatus was completed. Software for running this system has been written. The primary transfer standards, two-pressure humidity generator, that will be used to maintain calibration of the chilled mirror used in the gas sampling apparatus, is complete and has been shipped to the NTS. Testing and debugging of the system will be conducted during the second half of FY 1992.

Plans and preparations for drilling and instrumenting borehole UZ-16 (VSP-2) were initiated during the reporting period. A criteria letter was prepared in November 1991. RSN is completing the final draft of the work package for this drilling and testing program. Drilling is scheduled to begin mid-May 1992, pending approval of the gas tracer injection permit. Final preparations are under way for stemming this borehole with a 1,700-foot string of 3-component, oriented geophones. Vertical seismic profiling (VSP) field surveys are scheduled to begin in early FY 1993.

The local data acquisition system (DAS) currently being used to scan and record data collected from the HRF boreholes will be converted over to the Integrated Data Acquisition System (IDAS) in May 1992. This conversion

represents the first stage of bringing the IDAS on-line. The HRF borehole monitoring program will be used as a prototype platform to evaluate and debug IDAS. The optical disk (WORM drives) system for the IDAS data archiving is scheduled to become operational in June/July 1992. The microwave data communications problem still has not been resolved. An alternative to the narrow band, line-of-sight, 23 GHZ system is being investigated. An off-the-shelf, wide-band, 900 to 960 MHZ system looks very promising, provided the YMP can secure an FCC license to operate in this band width at the test site. An application for this license is being processed by RSN.

The contract for construction of the first insulated instrument shelter for use in the deep UZ borehole monitoring program was awarded in February 1992. This shelter is scheduled for delivery to the NTS in August 1992.

Data for the two-dimensional physical fault model and the two-dimensional imbricate fault model of Yucca Mountain have been collected and are being processed on the Florida State University Cray computer. Two of the four test holes for field VSP surveys at Bergen Park, Colorado, have been drilled. Cross-hole tomography data will be collected at these sites.

Test results from air injection testing at the Apache Leap Test Site (ALTS) near Superior, Arizona, showed more variability in the pressure transducers than expected. To eliminate this variability, an experiment in operating the transducers in current mode is being conducted at the HRF. It is hoped that current operation will provide more consistency in their operation. Final analysis of air permeability testing in 8-inch holes at the ALTS was completed. Several possible flow models were tested and permeabilities from drawdown and recovery tests were in good agreement. The results have been compiled for inclusion in a future report on ALTS testing.

The U.S. Bureau of Reclamation (USBR) has received the packers to be used in the 12.25-inch packer assembly. The hose reel, winch, and hydraulic system for assembly of the support trailer have been received and completion of a field-ready 12.25-inch air injection testing system is scheduled for June 1992.

The Sierra calibration bench was selected for installation at the HRF for calibration of project mass-flow controllers and meters. This system will allow immediate calibration and operation checks of the gas flow monitoring equipment.

Three papers (abstracts) were presented and published during the period: "The Use of Forward- and Back-Scattered P-, S- and Converted Waves in Cross-Borehole Imaging" (Balch et al., 1991); "Prototype Instrumentation in G-Tunnel Underground Facility in Support of Site Characterization of Unsaturated Zone Percolation at Yucca Mountain, Nye County, Nevada" (Kume et al., 1991); and "Thermodynamic Processes of Liquid and Vapor Movement in Rainier Mesa, G-Tunnel Underground Facility, NTS, Nevada" (Rousseau et al., 1991).

Rig modifications were completed on the LM-300 by the manufacturer. The rig was delivered to the NTS in December 1991. It has been undergoing a checkout process by REECo which includes the assembly of parts that had to be removed for transportation and certification of the diesel engines. UZ-16

will be the first hole for the LM-300. This hole is scheduled to begin the middle of May 1992.

Testing of core bits (both diamond and PDC) and reamer bits continues at the Colorado School of Mines. Information as to the best cutter configuration and cutter size is being developed in relation to the type and hardness of rock sample being cut. This information has already been transferred to field tests of PDC bits that have shown promise of durability during neutron hole drilling. Continued information exchange between field and laboratory results has given the YMP a start toward finding tools that can be used for surface-based testing at Yucca Mountain.

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.

2.2.1.8 Study 8.3.1.2.2.4 - Characterization of Yucca Mountain percolation in the unsaturated zone—ESF study

The NRC has deferred their review of Study Plan 8.3.1.2.2.4 (Activities 4, 5, 7, 8, and 9) until DOE has evaluated the need to revise the plan for consistency with current ESF plans.

Activity 8.3.1.2.2.4.1 - Intact-fracture test in the Exploratory Studies Facility. Laboratory procedures continued to be developed and tested for the determination of fluid-flow and chemical transport properties in discrete fractures. Staff provided support for prototype testing related to the Percolation Tests in the ESF, Activity 8.3.1.2.2.4.2. Support included completion of the block enclosure and electrical feed-throughs for instrumentation, programming for thermocouple psychrometer data collection, preparation of water (adjustment of constituents and tracers) for the test, construction of pressure transducer tensiometers, and numerous other tasks. Start of this prototype test is scheduled for November 1992.

Development of the Moire projection method for fracture profile characterization progressed. The high-resolution imaging equipment was installed and the equipment is being evaluated. The use of transform analyses for replicating the topographical surfaces appears to be the best technique to use. Fast-Fourier transform (FFT) analysis continues to produce high resolutions and accuracies (approximately 4 micrometers) with processing times of approximately 2 to 4 minutes. Up to 9 frames can be spliced together using a combination of joining and rotating the frames to obtain three-dimensional plots of surfaces.

Cosine transforms are being investigated and presently yield quicker plots because the data are in a spatial domain as opposed to a frequency domain as used in the FFT method. High resolutions have been obtained but the accuracy has not been compared to the FFT technique.

Two papers were submitted to the USGS Reports Section for processing: "Implementation and Use of an Automated Projection Moire Experimental Set-up" (Cardenas-Garcia et al.) and "Projection Moire as a Tool for the Automated Determination of Surface Topography" (Cardenas-Garcia et al.)

Activity 8.3.1.2.2.4.2 - Percolation tests in the Exploratory Studies Facility. Hydrologic testing on a large (54.3 cm long by 47.5 cm wide by 80.6 cm tall) block of fractured, welded tuff from the Tiva Canyon columnar unit commenced in late October 1991 at the Denver Federal Center. The purpose of the experiment is to provide detailed qualitative and quantitative observations of liquid water and tracer movement through fractured, welded tuff subjected to periodic infiltration pulses and/or constant head boundary conditions. A sand layer approximately 10 cm thick was placed on top of the block to mimic the hydraulic interactions between fractured welded tuff and either a more porous and permeable nonwelded tuff, or alluvium. The block is enclosed in Plexiglas to minimize water evaporation.

The block has been drilled with eighteen half-inch diameter boreholes, each of which contains a thermocouple psychrometer to monitor changes in water potential during the course of the experiment. The psychrometers will be replaced with tensiometer transducer systems as each station becomes sufficiently wet. Two tensiometer-transducer systems are currently being used to monitor matric potential in the upper sand layer. Moisture measurements are being augmented by ten resistivity probes that straddle the trace of a dominant fracture, and with six TDR probes located along opposing sides of the block.

Hydrologic properties of the sand and welded tuff matrix have been or are in the process of being determined. Pneumatic testing of the block from the small diameter boreholes prior to the onset of hydraulic testing provided estimates of the transmissivities of selected fractures and gave an indication of fracture interconnectedness. Initial hydraulic testing has involved saturating the overlying sand layer and monitoring the redistribution of water from the sand into the block. Water with a chemical composition similar to that of the unsaturated zone at Yucca Mountain was sprayed onto the sand at a known rate until water had begun to pond on the sand. Two slugs of water, distinguished from each other by the addition of bromide and iodide tracers, have been added thus far.

To date these experiments have suggested that in some cases an overlying porous material can be quite saturated and yet water movement into the fractures of the underlying welded tuff is negligible because the water is held under a tension that is too great to permit its entry into the fractures. Qualitative visual comparisons of water movement following the addition of the first and second pulses have also indicated that, as expected, water moved much farther down the fractures following the second pulse because initial matric potential gradients from the fractures into the matrix were diminished by the addition of the first pulse.

A data management system has been developed for all data that are being produced in the laboratory. The data are being stored on optical disks for permanent protection and storage.

Activity 8.3.1.2.2.4.3 - Bulk permeability test in the Exploratory Studies Facility. Measurements of permeability, porosity, bulk density, and grain density of four samples taken from the large block that is being tested in the ponding test (Activity 8.3.1.2.2.4.2) were completed by the HRF personnel.

Activity 8.3.1.2.2.4.4 - Radial borehole tests in the Exploratory Studies Facility. Test data from air injection testing at ALTS near Superior, Arizona, have been completely reduced to engineering units. Final analysis of the data is 60% complete. Analysis of the injection zone shows that in the early test period the flow is radial but soon shifts to a leaky-radial flow model. Analysis of the monitoring zones show spherical flow. This suggests that the geometry of the flow system is dependent on both scale and time, and that the testing scale selected was very appropriate. Tests conducted in fractured zones showed no well-bore storage influences while those conducted in nonfractured zones show large well-bore storage effects. Steady-state analysis found excellent correlation between injection rate and pressure squared differences.

The possibility of using the Sea Mist borehole lining and sampling system in radial borehole monitoring holes is being investigated. The system has the potential to eliminate short-circuiting in air injection testing.

Activities 8.3.1.2.2.4.5-10 had no progress during the reporting period; these are out-year activities.

2.2.1.9 Study 8.3.1.2.2.5 - Diffusion tests in the Exploratory Studies Facility

A revision to the Study Plan which incorporates DOE/HQ and YMPO comments was submitted to the YMPO for review on June 11, 1991. Comment resolutions were verified by YMPO on January 24, 1992.

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 on October 7, 1991. One general concern in NRC's acceptance letter regarding gas-flow modeling was forwarded to the USGS for a response on December 2, 1991.

Activity 8.3.1.2.2.6.1 - Gaseous-Phase circulation study. Analyses of data from gas samples collected in March 1991 were completed. A new sample tracking system has been developed. Additionally, gas standards for gas chromatograph calibration are being purchased.

Prototype thermal infrared (IR) surveys were conducted at Yucca Mountain and its vicinity in December 1991. These surveys were conducted to test the feasibility of using thermal IR surveys to locate fractures that exhaust air due to topographic effects. The surveys were conducted at Yucca Crest, at an exposed outcrop on Dead Yucca Ridge, and at Point-of-Rocks ridge. The surveys indicated false positive readings were generated by overhanging ledges and loose boulders. Point-of-Rocks ridge, an area of known blowing fractures, was chosen to provide comparative data from false positive readings and actual blowing fractures. This prototype work indicates that aerial IR surveys would not be useful in detecting blowing fractures at Yucca Mountain. However, a

stationary thermal imager that is focused on one area for a long duration might detect blowing fractures on very cold nights.

2.2.1.11 Study 8.3.1.2.2.7 - Hydrochemical characterization of the unsaturated zone

Activity 8.3.1.2.2.7.1 - Gaseous-phase chemical investigations. Rock-gas samples from USW UZ-1 from 1983 through 1991 were collected and analyzed for gas compositions and isotopic data. From 1983 through 1987, each station in the borehole (15 stations from surface to 1200-foot depth) were sampled twice a year, and from 1988 to present, they were sampled only once a year because of the decreased variability in the data from year to year. These data have been compiled and plotted. A report entitled "Gaseous-Phase Isotopic and Chemical-Composition Data from Test Hole USW UZ-1, Yucca Mountain, Nevada" (Yang et al.) is being prepared.

The design of batch and column tracer gas-sorption tests has been completed. The batch tests utilize a glass manifold with specially designed flasks. The sample is placed inside the flask, pumped to vacuum, and injected with the desired tracer gas. Analysis of samples is by gas chromatograph. The column tests utilize a glass column connected to Teflon tubing. The tubing forms a closed system that flows through an analyzer appropriate for the gas of study. A pump provides a continuous flow of the gas through the system. Gas-sorption tests were performed on both borehole stemming materials and various tuff and bedded tuff materials. The stemming material currently undergoing tests is gypsum cement. Three size fractions were characterized for surface area and mineralogy. Tuff materials were Tiva Canyon, Yucca Mountain, Pah Canyon, and Topopah Spring Members.

The inflatable multi-packer system to be used in gas sampling for hydrochemistry investigations in the new borehole UZ-16 (12 inches in diameter) was fabricated by the USBR. The bladder was inflated to 35 psi (pounds per square inch) and the pressure drop after three days was only 0.5 psi. The packer seals against the borehole wall will be tested in the field when the borehole is completed. A gas chromatograph is to be installed inside the field mobile laboratory for on-site gas-composition analyses for the UZ-16 borehole. Detectors will include TCD (Thermal Conductivity Detector), FID (Flame Ionization Detector), and ECD (Electron Capture Detector) for measuring nitrogen (N), oxygen (O), argon (Ar), carbon dioxide (CO_2), methane, and sulfur hexafluoride (SF_6). The tracer gas, SF_6, concentration will be monitored in the drilling air inflow and outflow from the borehole.

Activity 8.3.1.2.2.7.2 - Aqueous-phase chemical investigations. Pore-water extraction of cores from UE-25, UZ#4, UZ#5, and USW UZ-6s are on-going. In addition to the intact cores, rock chips were also tested for pore-water extraction by compression. Preliminary results indicated that rock chips could also be squeezed by one-dimensional compression to obtain pore water, instead of using the high-speed centrifuge. However, prior to compression, nitrogen-gas purging through the compression cell to expel atmospheric air in the rock-chip spacings was required to avoid the contamination of pore water by atmospheric CO_2. A paper entitled "Flow and Transport Through Unsaturated Rock - Data from Two Test Holes, Yucca Mountain,

Nevada" (Yang) was approved for publication in the proceedings of the IHLRWM Conference to be held in Las Vegas in April 1992.

Chemical data on pore water from G-Tunnel and UZ#4 and UZ#5 core samples were reduced and compiled. A report entitled "A Preliminary Study of the Chemistry of Pore Water Extracted from Tuff by One-Dimensional Compression" (Peters et al.) was approved for publication in the Proceedings of the 7th International Symposium on Water-Rock Interaction.

A DX-100 Model Ion Chromatograph and automated acquisition system were tested to determine their feasibility for use in the field mobile laboratory. The unit was capable of analyzing anions and selected cations. It will be extremely helpful for quick analyses on perched water samples, if encountered, or spot checks on anion-tracer concentrations in the utility water used during the construction phases.

Tests were conducted to determine the relative efficiency of recovering pore water from welded tuff cores by continuous squeezing from 0 to 120 kilopounds per square inch (KSI) rather than maintaining constant pressure steps at 20, 40, 60, 80 and 100-KSI. The time required for compression was reduced by one-half when using the continuous increase in pressure method. Results appeared to be similar. A draft report entitled "Pore-Water Extraction from Unsaturated Tuff by Compression (I), Nevada Test Site" (Mower et al.) was prepared.

Two cores with similar moisture contents and degree of saturation, but with different fabric orientation (one parallel to the core axis and the other perpendicular to the core axis) were tested to determine if a particular rock-core fabric orientation is more favorable than another for water extraction. These cores were compressed in a one-dimensional compression cell and water-extraction efficiency was not significantly different between the two orientations.

Results of rubble-coring tests indicated that a surface-set-bit cored faster than an impregnated bit, but also wore out faster. The bit-penetration rate depended on fabric orientation in the welded rock; parallel to fabric was best, and the faster penetration rates were better for keeping the core cool. A moderate force applied to the drill was best for maximum penetration and minimum heat produced. Compressed air worked well for bit cooling and could be applied at the minimum pressure required to remove cuttings. The optimal rotational speed was about 250 RPM. Both Hydrostone and Sulfaset would produce minimum heat inside a rubble piece and both were appropriate as blocking materials for rubble. A draft report on rubble-coring tests was being prepared.

2.2.1.12 Study 8.3.1.2.2.8 - Fluid flow in unsaturated, fractured rock

Study Plan 8.3.1.2.2.8 was revised per YMPO review comments and resubmitted to the YMPO on November 26, 1991.

Activity 8.3.1.2.2.8.1 - Development of conceptual and numerical models of fluid flow in unsaturated, fractured rock. The flow module of computer program SFIT (Kool and Parker, 1987) was used to simulate a hypothetical

imbibition experiment into a column of soil with properties taken from the VS2D documentation. Results from this simulation were then treated as actual data and used as input to the parameter estimation module of SFIT. Various amounts of "data" from the simulated experiment were used to estimate the saturated hydraulic conductivity and van Genuchten parameters n and α. Since the characteristics of the soil were known, this permitted an investigation into the amount and types of data that would result in the most economical and accurate estimates of the soil properties from imbibition experiments. However, the flow model of SFIT does not seem capable of simulating flow problems involving hydraulic properties thought to be reasonable for tuffs. It will need to be modified before it can be applied to imbibition data collected on rocks from Yucca Mountain.

Estimation of rock unsaturated hydraulic properties by inverse methods will also require proper identification of the correct functional forms for these properties. An analysis was made of the relative permeability versus moisture content and moisture content versus matric potential data for sample 3p of Flint and Flint (1991b). The van Genuchten expression for the moisture retention curve fit the moisture content versus matric potential data quite well. However, estimates of effective hydraulic conductivity based on the related hydraulic conductivity function and parameters were poor predictors of the measured effective hydraulic conductivity, even when the exponent in the tortuosity term of the relative permeability function was allowed to vary.

A procedure has been developed to derive capillary pressure curves of volcanic tuffs from laboratory (or field) measurements of sorptivity and hydraulic conductivity, which are much easier properties to measure. This procedure avoids the necessity of time-consuming numerical simulations.

The flow behavior of a simple fracture network containing 5 large and 4 small fractures was simulated with the computer code TOUGH to examine the dependence of flow pathways and matric potential variability on average matric potential. The mesh for the simulation was created with the Fracture-Matrix Mesh Generator (FMMG) code.

Based on recently published hydrologic literature, a graph was prepared showing the minimum expected error in the calculated permeability that results from ignoring the Klinkenberg effect in the analysis of air-injection tests. The graph, which shows relative error as a function of injection pressure and absolute permeability, indicates that relative error increases with decreasing permeability and decreasing injection pressure.

The TOUGH simulator for unsaturated flow in fractured formations has been modified so that matrix imbibition from the fractures is computed analytically, thus allowing the simulation of larger scale problems, with higher spatial resolution. A paper describing this version of TOUGH, entitled "Semi-Analytical Treatment of Fracture/Matrix Flow in a Dual-Porosity Simulator" (Zimmerman and Bodvarsson) has been accepted for presentation at the IHLRWM Conference and publication in the conference proceedings. The paper "Permeability of a Fracture with Cylindrical Asperities" (Kumar et al., 1991) was published by Fluid Dynamics Research and Lawrence Berkeley Laboratory (LBL). Two additional reports were published as LBL reports, "The Capillary Hysteresis Model HYSTR-User's Guide" (Niemi and Bodvarsson, 1991)

and "Incorporation of the Capillary Hysteresis Model HYSTR into the Numerical Code TOUGH" (Niemi et al., 1991).

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.

2.2.1.13 Study 8.3.1.2.2.9 - Site unsaturated-zone modeling and synthesis

The YMPO review of Study Plan 8.3.1.2.2.9 was completed on February 27, 1992. Responses to the comments are being addressed by staff.

Activity 8.3.1.2.2.9.1 - Conceptualization of the unsaturated-zone hydrologic system. A review of recent modeling reports and existing data bases of Yucca Mountain for site scale modeling continues for the development of a coarse, three-dimensional model. Periodic modeling meetings attended by LBL and USGS modelers and hydrologists were held to facilitate the modeling and data needs for both the site characterization and performance assessment programs. The primary concern expressed at the meetings was the lack of sufficient data in some areas that makes it difficult to accurately develop a three-dimensional model grid. Most of the geological and hydrological data that were planned to be available at this time will not be available until the proposed test holes have been drilled and tested. More frequent modeling meetings between LBL and USGS investigators will be necessary to assist the modeling work being done under Activity 8.3.1.2.2.9.2 (Selection, Development, and Testing of Hydrologic Modeling Computer Codes) at LBL, for initiation of work planned under Activity 8.3.1.2.2.9.3 (Simulation of the Natural Hydrologic System) at LBL, as well as SNL and USGS performance assessment related modeling activities.

Activity 8.3.1.2.2.9.2 - Selection, development and testing of hydrologic modeling computer codes. Contour maps and isopach maps were prepared for the base of the Tiva Canyon, the Paintbrush and the Topopah Spring hydrogeologic units, as well as for the groundwater table in the area of the site-scale numerical model. These maps were needed to develop the three dimensional numerical grid, performed under Activity 8.3.1.2.2.9.3 (Simulation of the Natural Hydrologic System). The maps were reviewed by USGS staff to make sure they were consistent with the larger-scale depositional features of the volcanic tuffs. The maps and other geologic and hydrologic information were included in a technical paper, "Development of a Three-Dimensional Site-Scale Model for the Unsaturated Zone at Yucca Mountain, Nevada" (Wittwer et al.). The paper was accepted for publication in the proceedings of the IHLRWM Conference and emphasizes the development of the grid based on all available geological and hydrogeological data. Work has started on the compilation and review of technical papers and reports on unsaturated flow codes.

Activity 8.3.1.2.2.9.3 - Simulation of the natural hydrogeologic system. The areal grid and the nonuniform vertical grid of the site-scale model were designed and developed. The vertical grid takes into account the thickness variations of the hydrogeological units and the offsets along the Ghost Dance, Dune Wash, and Abandoned Wash faults. The hydrogeological units were subdivided into a constant number of sublayers of various thicknesses (three for Tiva Canyon, three for Paintbrush, six for Topopah, and six for Calico

Hills hydrogeological units) in order to keep continuity between the grid blocks.

Compilation and analysis of data from various USGS reports for the definition of the hydrogeological units of the site-scale model was performed. Results of the USGS geological investigations will be used to refine the three-dimensional grid. Simulations have started to check the three-dimensional grid. The work is currently centered on the control of the connections between the elements including a fault and its neighbors. A two-dimensional cross section has been chosen to test the effects of the numerical grid around the Ghost Dance fault. Simulations with small two-dimensional submodels have been started to evaluate the grid effects on the moisture flow. A paper, which will include the results concerning the resolutions of the discontinuities related to the hydrogeological units and the faults, is being prepared for a special issue of the Radioactive Waste Management and Nuclear Fuel Cycle.

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 UZ integration and synthesis. No progress during the reporting period; this is an out-year activity.

2.2.1.14 Study 8.3.1.2.3.1 - Characterization of the site saturated-zone ground-water flow system

Study Plan 8.3.1.2.3.1, Activities 1-6 and Activity 7, received NRC acceptance on December 6, 1991. Two general concerns in NRC's acceptance letter regarding test-to-test interference and relationship to other Study Plans were forwarded to the USGS for a response on January 8, 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 saturated zone at Yucca Mountain continued. Monthly water-level measurements were made in 14 wells and quarterly measurements were made in 4 wells. Hourly water-level data were collected from 20 zones in 12 wells; in several of these wells (maximum of 2 wells at a time), periods of continuous data also were collected. Fifty-nine transducer calibrations were performed and approximately 12 transducers were replaced. Two additional satellite data-collection platforms were installed to supplement the 6 platforms already in service. One existing platform was moved from one well to another. Pressures, as opposed to water levels, were monitored for some period in the lower zone of 3 wells (maximum of 2 wells at a time). Two recorders that should enable observation of seismically induced water-level changes were used. Water levels remained stable during the October 1991-March 1992 period.

A new type of transducer that appears to be more reliable and less prone to excursions was used to replace a number of the older types. This transducer, which has been tested for up to two years, is now being used in most wells. While several transducers were replaced during this six-month

period, the primary problem appeared to be water in the electrical connections and vent tube 25 feet above the water level. This problem is being actively investigated. Determining if apparent "water-level excursions" are real or instrument malfunction remained a major priority during this period. The excursions, which have occurred in the past in different wells at approximately the same time, last from a few hours up to several days. They generally occurred during periods of unsettled weather with low barometric pressure, rain and lightning. Satellite data-collection platforms that send near real-time data to a Prime computer in Denver were used to watch for the apparent excursions. Despite several periods when weather conditions were ideal for excursions, no wide-spread excursions occurred during this reporting period. This lends support to the theory that the excursions were primarily instrument problems associated with the older type of transducer.

The report entitled "Geohydrology of Rocks Penetrated by Test Well USW H-6, Yucca Mountain, Nye County, Nevada" (Craig and Reed, 1991) was published. The report entitled "Water Levels in Continuously Monitored Wells in the Yucca Mountain Area, Nevada, 1985-88" (Luckey et al.) was approved by DOE and the USGS director for publication. Draft reports on the 1989 continuous data and precision and accuracy of water-level measurements are nearing the end of the review cycle.

Water-level data for a period in mid-December was provided to the State of Nevada so they could investigate potential effects of three very-small earthquakes north of Yucca Mountain. The USGS examined the data and could determine no measurable effects of these earthquakes even though the effects of seismic events have been detected in the past.

Activity 8.3.1.2.3.1.3 - Analysis of single- and multiple-well hydraulic-stress tests. The c-hole complex hydrogeology report, "Preliminary Hydrogeologic Assessment of Boreholes UE-25c#1, UE-25c#2, and UE-25c#3, Yucca Mountain, Nye County, Nevada" (Geldon) was approved for publication by the USGS. Work on the draft of the Intraborehole Flow and Stress Test Report continued.

Monitoring strain-related pressure responses in wells due to atmospheric loading, earth tides, and seismic events, continued. Data for pneumatic diffusivity calculations (needed for analysis of barometric effects in uncased boreholes) were collected in wells UE-25c#2 and UE-25c#3. Monitoring of water level fluctuations (used in earth tide and atmospheric loading analyses) was conducted at wells USW H-4 and UE-25b#1. Seismic monitoring, for the hydraulic effects of earthquakes and UNEs (Underground Nuclear Explosions), was conducted at well USW H-4. Data will now be analyzed to obtain aquifer characteristics.

Dual-porosity analytical techniques were applied to previously obtained cross-hole test results from the c-holes and some aquifer characteristics were estimated from the analysis. Heat-pulse intraborehole flow surveys were conducted at the c-holes by the Borehole Geophysical Unit of the National Research Program of the USGS Water Resources Division. The intraborehole flow-rate values obtained were correlated with indications of fracture locations obtained from temperature and acoustic televiewer logs, to obtain a comprehensive picture of hydraulically conducting fractures in the c-holes.

This information will be used in the design of the cross-hole hydraulic and tracer tests.

Activity 8.3.1.2.3.1.4 - Multiple-well interference testing. The USBR completed the majority of the work of assembling the "monolithic test sections" for construction of two three-zone packer strings. These "test sections" consist of protective casing that houses the instruments for monitoring pressure and temperature changes and injection of tracers during hydraulic and tracer testing at the c-holes. Work on assembly of these "test sections" was done in parallel with laboratory functional tests of the packer system. The tests were successful in uncovering several minor problems that led to repairs of packer system components, and modification to the specifications for procuring additional components.

Preparations were finalized for conducting the cross-hole seismic tomography survey at the c-holes by LBL in June 1992. Results of the survey will be used in the design of the cross-hole and tracer tests.

Activity 8.3.1.2.3.1.5 - Testing of the c-hole site with conservative tracers. The present design of the tracer injection system may be overly complex and may be abandoned. Instead, a simpler design with injection of the tracer being accomplished through the already existing hydraulic extraction/ injection 2 7/8-inch pipe, may be adopted. The simpler design is preferable to avoid downhole complications. The switch in the design is still being examined to ascertain that no test objectives are compromised.

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. Analysis techniques for measuring the major dissolved cations in the lithium sorption batch experiments have been completed. The ion chromatography technique developed allows all cations of interest to be measured in a single run. Error statistics have been acquired on standard samples, so that an error analysis can be performed for the sorption experiments.

Background work on using fluorescent colloids as tracers in the c-well field tests has focused on finding a better analytical method for determining numbers and concentrations of synthetic colloids in groundwater samples. Flow cytometry shows promise as a better method, and arrangements have been made with the LANL flow cytometry resource to test the instrument's capabilities.

Progress in software development has been achieved for several applications. First, implementation baseline (the final baseline in the life cycle) has been submitted and reviewed for the SORBEQ application. Also, the Software Design Document has been written for the FRACNET application, and Software Requirements Specification have been written for two other applications, FEHMN (three-dimensional heat and mass transfer simulator) and GZSOLVE (linear equation solver).

A paper entitled "An Evaluation of Lithium Sorporation Isotherms and their Application to Groundwater Transport" (Newman et al., 1991) was

published. It reports batch adsorption and desorption equilibrium experiments to evaluate lithium sorption on crushed tuff in contact with groundwater. Sorption was determined to occur reversibly for solution concentration up to 150 mg/L. Equilibrium data are presented by evaluating the results using nonlinear sorption isotherm models. One-dimensional transport simulations indicated the importance of selecting the best sorption isotherm and suggested that column experiments may provide better isotherm information than batch data when the results are to be incorporated into a field-scale transport model.

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.

2.2.1.15 Study 8.3.1.2.3.2 - Characterization of the saturated-zone hydrochemistry

Comment resolution for YMPO's review of Study Plan 8.3.1.2.3.2 was verified and the Study Plan was accepted by the YMPO on March 11, 1992.

Activity 8.3.1.2.3.2.1 - Assessment of saturated-zone hydrochemical data availability and needs. Strontium (Sr) isotopic data for waters from and within the region of the NTS were compiled and installed in a preliminary spreadsheet data base. Unpublished potassium (K), uranium (U), and thorium (Th) data from selected cores and cuttings from Yucca Mountain were compiled for calculations of subsurface in situ production of selected radionuclides of interest to LANL and USGS investigators. It was determined that little NTS and vicinity hydrochemical data generated by USGS investigators in the course of geohydrologic support of the DOE Weapons Program have been stored in the USGS WATSTORE system. Electronic data records maintained by USGS staff in Las Vegas (current Weapons Program support) will be queried. Hard copies of historic NTS and vicinity data are being checked by USGS staff prior to entry, as appropriate, into a USGS data base.

Activity 8.3.1.2.3.2.2 - Hydrochemical characterization of water in the upper part of the saturated zone. The search for an alternative downhole sampling and data-collection system identified an additional U.S. manufacturer eager to design and build a system. As with previous identified potential suppliers, the requisite experience base is missing. This manufacturer, however will supply packers and sliding-port screens for borehole discretization packages, and a screen shifter to be incorporated in the downhole system. Estimated delivery of the system will be 9-12 months from order; this forecasts an earliest start date of early October 1993, for data collection and sampling at extant Yucca Mountain boreholes.

Samples were collected from boreholes J-12, J-13, JF-3, and UE-25 UZN#91 adjacent to Yucca Mountain. Samples were collected at all but one of the sites (N#91) under the aegis of USGS NTS environmental monitoring activities for the DOE Weapons Program.

Activity 8.3.1.2.3.2.3 - Regional hydrochemical tests and analyses. A meeting was scheduled for early April 1992 with NPS staff to plan reconnaissance of and data and sample collection at springs within the Death

Valley National Monument. This effort has been greatly facilitated by the NPS's high level of interest in the work.

No progress has been made relative to plans to obtain data and samples from DOE Environmental Restoration Program boreholes. The first borehole drilled was completed in such a fashion that only one of the zones designated for monitoring is currently accessible. Plans for this site and future sites are under discussion. A sample was obtained from Army Well 1 under the aegis of USGS environmental monitoring for the DOE Weapons Program.

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.

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, Site Saturated Zone Synthesis and Modeling, was revised per YMPO comments. The document was returned to the reviewers for their concurrence on March 31, 1992.

Activity 8.3.1.2.3.3.1 - Conceptualization of saturated-zone flow models within the boundaries of the accessible environment. USGS personnel conducted a 3-day field trip for the Fall 1991 GSA meeting on the regional hydrology related to Yucca Mountain. The field trip guide entitled "Hydrogeologic Overview and Field Trip of the Regional Ground-water Flow System in Relation to Yucca Mountain, Nevada" (Galloway et al., 1991) was published.

Work on the revised potentiometric water level map in the vicinity of Yucca Mountain continued. Corrections for fluid and density effects with depth were completed for water levels in wells to be presented on the map.

USGS investigators evaluated a variety of Geographic Information Systems (GIS) for performing three-dimensional geologic modeling, initially at the UE-25 c-well complex. It was determined that the LYNX system, Canada, would be the most applicable software because of its technical features (ability to represent faults), geostatistical capabilities and use elsewhere (SNL) in the YMP.

Activity 8.3.1.2.3.3.2 - Development of fracture network model. A new approach including new computer programs was developed by the LBL staff for interpreting fracture orientation and density data derived from boreholes so that 'true' in-situ distributions of such parameters can be estimated with less error. LBL staff constructed a heuristic conceptual model of the fracture system in the saturated zone at Yucca Mountain. It consists of hierarchically structured fracture system. Preliminary results of tracer transport simulation indicate that dispersion phenomena as a result of fracture intersections are highly irregular and quite different from those in porous media. A new pre-conditioning method for the hydrologic inversion algorithm was developed by LBL staff. It uses energy surface constructed by testing the sensitivity of the goodness of the match to the existence of each element. This method is based on the finding that the energy surface profile resembles the "real" mesh.

Fracture mapping locations, supporting the UE-25 c-well modeling, were permanently marked by USGS scientists in the Crater Flat Tuff outcrop, east of Little Skull Mountain. Initial mapping of fractures in the Crater Flat Tuff was performed in Raven Canyon, off Highway 95. To date, three 2x2 meter grid surveys and three areal surveys have been completed. Preliminary data from the outcrop east of Little Skull were presented at the Fall 1991 AGU meeting and are summarized in the published abstract, "Fractures in the Bullfrog Member of the Crater Flat Tuff East of Little Skull Mountain, Nye County, Nevada" (Ervin and Chornack, 1991).

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

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 is in review at the YMPO.

Activity 8.3.1.3.1.1.1 - Ground-water chemistry model. Two papers were prepared for the 7th International Water-Rock Symposium scheduled for July 1992: "Water-Rock Interactions and the pH Stability of Groundwaters from Yucca Mountain, Nevada" (Ebinger), which discusses the simulated pH stability of waters derived from Yucca Mountain in the presence and absence of different minerals, and "Precipitation of Calcite, Dolomite, Sepiolite, and Silica from Evaporated Carbonate and Tuffaceous Waters of Southern Nevada" (Vaniman et al.), which discusses the formation of sepiolite, calcite, and/or silica phases from the evaporation of waters from Yucca Mountain and surrounding areas.

2.2.2.2 Study 8.3.1.3.2.1 - Mineralogy, petrology, and chemistry of transport pathways

YMPO requested a revision to the Study Plan on October 24, 1991, in response to NRC comments. A proposed revision was submitted the YMPO on January 27, 1992.

Activity 8.3.1.3.2.1.1 - Petrologic stratigraphy of the Topopah Spring Member. In December 1991, certified software under LANL-YMP-SQAP, R0, for quantitative material determinations from x-ray diffraction (XRD) data became available. It was decided to resume XRD analysis as soon as samples become available from the new drill core.

Activity 8.3.1.3.2.1.2 - Mineral distributions between the host rock and the accessible environment. As with Activity 8.3.1.3.2.1.1, certified software became available for quantitative XRD, and the diffraction data backlog was significantly reduced. Quantitative mineralogy analyses on 90 samples were provided for Activity 8.3.1.3.4.1.1.

LANL staff continued studying five possible sites in the vicinity of Yucca Mountain as potential locations for a surface-based prototype test

facility. Analysis was done of lithologic, chemical, mineralogic, and modal-petrographic data from nonwelded vitric and zeolitic tuff outcrop samples from these sites. It was decided that when hydrologic-property data become available, they will be used to further refine site evaluation.

Twenty-nine samples of cuttings from drill hole USW H-5 (within the exploration block) were analyzed, using XRD to better define the transition from vitric to zeolitic tuff with depth and to constrain the thicknesses and locations of zeolitic zones. The results will also extend the current mineral-stratigraphic models and provide a basis for comparison with future SD drill holes. Staff began exploration of Fourier-Transform Infrared Microscopy as a method to study trace minerals. They also began investigating calcite compositions in core samples as a guide to late-stage precipitation in the unsaturated zone.

Activity 8.3.1.3.2.1.3 - Fracture mineralogy. Preparation began of a paper summarizing the results of manganese-oxide mineral studies. An abstract entitled "Fracture-Lining Manganese Oxide Minerals in Silicic Tuff at Yucca Mountain, Nevada" (Carlos et al., 1991) was presented at the annual GSA Conference in October 1991. Samples from drill cores in Crater Flat (VH-1 and VH-2) were compared with those at Yucca Mountain (USW G-1, G-2, GU-3, and UE-25b#1H).

2.2.2.3 Study 8.3.1.3.2.2 - History of mineralogic and geochemical alteration of Yucca Mountain

The Study Plan was approved by the YMPO on December 18, 1991, and was sent to the NRC on January 31, 1992.

Activity 8.3.1.3.2.2.1 - History of mineralogic and geochemical alteration of Yucca Mountain. A paper entitled "Determination of Paleogeothermal and Paleohydrologic Conditions in Silicic Tuffs from Illite/Smectite Mineralogy" (Bish, 1991) was presented at the Clay Mineral Society Annual Meeting, October 5-10, 1991. An abstract of this paper was published in the conference program. The paper discussed the paleogeothermal conditions in the Miocene silicic tuff sequence from Yucca Mountain. Illite/smectite mineralogy, potassium/argon (K/Ar) dating, and fluid inclusion analysis data were used to reconstruct the paleogeotherms for Yucca Mountain 11 Ma ago during hydrothermal alteration related to the Timber Mountain caldera. The paper reports relatively constant inferred paleotemperature in drill hole USW G-2 to ca. 3500 ft. depth, much deeper than the present static water level, suggests that either a rain-curtain effect existed and/or the rocks deeper than 3500 ft were relatively impermeable and were not affected by the regional groundwater flow.

A paper entitled "Calcite, Opal, Sepiolite, Ooids, Pellets, and Plant/Fungal Traces in Laminar-Fabric Fault Fillings at Yucca Mountain, Nevada" (Vaniman, 1991) was presented at the GSA Annual Meeting in October 1991. An abstract of this paper was published in the conference program. This paper discussed mineralogic and textural distinctions between pedogenic and non-pedogenic calcretes. Many of these distinctions reflect the much higher water-to-rock ratio of non-pedogenic calcretes, which are typically

associated with radial orifice structures, travertine terraces, and other features related to flowage.

A paper entitled "Natural Gels in the Yucca Mountain Area, Nevada, USA" (Levy, 1991) was presented at the European Materials Research Society 1991 Fall Meeting. An abstract of this paper was published in the conference program. The paper discusses the potential role of colloids in radionuclide transport, which is being investigated in part by a study of natural colloidal deposits in the rocks at Yucca Mountain, and that gels (colloids) at Yucca Mountain are associated with both diagenetic and hydrothermal alteration of volcanic glass, and the principal gel products in both environments are heulandite-clinoptilolite and silica. Considerable variation in the texture and crystallinity of these products was found, and Al-rich gel products (clays and zeolites) have attained a completely crystalline state, whereas much of the silica is only partly ordered.

A paper entitled "Preliminary Assessment of Clinoptilolite K/Ar Results from Yucca Mountain, Nevada: A Potential High-Level Radioactive Waste Repository Site" (WoldeGabriel et al.), was prepared for presentation at the 7th International Symposium on Water-Rock Interaction to be held in July 1992. This paper discusses studies of K/Ar isotopic systematics in clinoptilolite.

A paper entitled "Detections of Trace Amounts of Erionite Using X-ray Powder Diffraction: Erionite in Tuffs of Yucca Mountain, Nevada, and Central Turkey" (Bish and Chipera, 1991) was published. This paper discusses application of an x-ray-powder-diffraction technique to facilitate detection of erionite in tuffaceous rocks (to a lower limit of detection between 100 and 500 ppm) to Yucca Mountain tuffs. They found that erionite occurs sporadically in very small amounts, usually in fractures, and only in the altered zone directly above the lower vitrophyre of the Topopah Spring Member.

Studies of possible surface or near-surface hydrothermal alteration at Trench 14, Busted Butte, and Yucca Mountain progressed.

Activity 8.3.1.3.2.2.2 - Smectite, zeolite, manganese minerals, glass dehydration and transformation. A paper entitled "Rehydration Behavior of a Natural Analcime" (Chipera and Bish, 1991) was presented at the Clay Mineral Society Annual Meeting, October 5-10, 1991. The abstract of this paper was published in the conference proceedings. The paper discusses results of the rehydration behavior of natural analcime. Analcimes at room temperature would probably take years to reach their initial pre-hydration state and that with increasing temperature, the analcime structure expands to facilitate the entry of water molecules, leading to an increased rate of rehydration.

Long-term studies of the dehydration and rehydration of Topopah Spring vitrophyre glass have been completed.

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 activity.

2.2.2.5 Study 8.3.1.3.3.2 - Kinetics and thermodynamics of mineral evolution

No progress during the reporting period due to lack of funding.

2.2.2.6 Study 8.3.1.3.3.3 - Conceptual model of mineral evolution

No progress during the reporting period due to lack of funding.

2.2.2.7 Study 8.3.1.3.4.1 - Batch sorption studies

The Study Plan is being revised.

Activity 8.3.1.3.4.1.1 - Batch sorption measurements as a function of solid phase composition. Sorption studies continued, concentrating on the effects of crushing the rock samples on experimental determinations of sorption coefficients. X-ray diffraction (XRD) analyses of 90 samples have been received, and the results were studied. Determinations of the active surface areas of the crushed-rock samples using the BET method have been completed.

Activity 8.3.1.3.4.1.2 - Sorption as a function of sorbing element concentrations (isotherms). No progress during the reporting period because of emphasis on Activity 8.3.1.3.4.1.1.

Activity 8.3.1.3.4.1.3 - Sorption as a function of ground-water composition. Experiments to determine the effects on sorption of preconditioning tuff samples with groundwater chemistries more concentrated in calcium (Ca) and magnesium (Mg) have been completed and data analysis began.

Activity 8.3.1.3.4.1.4 - Sorption on particulates and colloids. No progress during the reporting period due to lack of funding.

Activity 8.3.1.3.4.1.5 - Statistical analysis of sorption data. A report was given on sorption experiments for neptunium (Np) on quartz and albite in simple electrolytes as a function of pH, equilibration time, concentration, and atmospheric composition. The newly acquired atomic-force microscope, which is used to obtain detailed images of substrates before and after sorption reactions and to characterize the textures of Yucca Mountain tuffs at the nanometer scale, was installed. Test images of a devitrified tuff, goethite, and hematite have been obtained.

2.2.2.8 Study 8.3.1.3.4.2 - Biological sorption and transport

YMPO completed verification of comment resolution for Study Plan 8.3.1.3.4.2 on December 7, 1991.

Experiments were completed to determine the effect of extracellular material on the agglomeration of clay colloids. Incorporation began of the results of these experiments into milestone reports.

As reported in the last PR, a siderophore produced by a microorganism isolated from Yucca Mountain forms a complex with Pu(IV). Significant progress has been made in characterizing this siderophore; its amino acid, carbon, nitrogen, and hydrogen content are known. Further characterization of this siderophore has been performed, using nuclear magnetic resonance (NMR) and Fourier-Transform infrared (FTIR) spectroscopy.

2.2.2.9 Study 8.3.1.3.4.3 - Development of sorption models

A talk entitled "The Minimum K_d Approach to the use of Sorption Coefficients in Performance Assessment" (Meijer) was presented at the Geochemistry Integration Meeting, December 4-5, 1991.

A paper entitled "A Sorption for the Derivation and Use of Sorption Coefficients in Performance Assessment Calculations for the Yucca Mountain Site" (Meijer) was prepared for the Proceedings of the DOE Yucca Mountain Site Characterization Project Radionuclide Adsorption Workshop at Los Alamos, September 11-12, 1990. This paper presented a strategy for quantifying the chemical interactions of radionuclides with the host rock at the proposed high-level waste repository located at Yucca Mountain, Nevada.

2.2.2.10 Study 8.3.1.3.5.1 - Dissolved species concentration limits

YMPO review comments on the Study Plan were received on November 8, 1991, and revision is in progress.

Activity 8.3.1.3.5.1.1 - Solubility measurements. New stock solutions of plutonium (Pu), Np, and americium/neodymium (Am/Nd) were prepared and were characterized for the UE-25p#1 water solubility determinations at 60°C. Filtration studies (to determine sorptive losses and preconditioning requirements) for all three radionuclides were completed, and solubility studies for the UE-25p#1 water at 60°C were initiated at pH 6, 7, and 8.5 for Np, Pu, and Am. For Np, steady-state has been reached at all three pH values, and UV/visible absorption spectrophotometry has been performed to determine the solution species. The three Pu solubility experiments have also reached steady-state, but the Am/Nd solubility experiments require additional work.

Staff continued preparing a paper entitled "Measured Solubilities and Speciations of Neptunium, Plutonium, and Americium in a Typical Groundwater (J-13) from the Yucca Mountain Region" (Nitsche et al.) for publication as an LA-series report.

A detailed technical procedure (DP) entitled "Mettler H6T Balance Operating and Calibration Procedure (TWS-LBL-DP-14, R0)" was in review. Two DPs, "Concentration Determination of Soluble Radionuclides from Data Provided by the Low Energy Gamma Counting System (TWS-LBL-DP-01, R0)" and "Operation and Calibration of Low Energy Gamma Counters (TWS-LBL-DP-02, R1)," were also being prepared.

Activity 8.3.1.3.5.1.2 - Speciation measurements. Thermodynamic studies of actinyl(VI) (e.g., plutonium dioxide (PuO_2^{2+})) speciation in complexing carbonate media using high-field Fourier-Transform NMR continued. Staff

investigated the possibility of using NMR as a unique species-specific tool for unraveling the stoichiometry and structure of actinides in carbonate solution.

The coding standards for Microsoft QuickBASIC were in software quality assurance plan (SQAP) review.

Photoacoustic spectrometer (PAS) software development has begun. A commercial wavelength calibration system for the PAS system, which is likely to save approximately one man-year of effort, has been located. A paper describing the development phase of the photoacoustic work was being prepared.

Experimental work on the PAS system continued to focus on the Pu(IV) carbonate systems. Speciation boundaries, as a function of both pH and total carbonate (i.e., combined bicarbonate and carbonate anions) concentration, were being mapped. The pH values studied ranged from 8 to over 11; total carbonate concentrations studied were between 0.01 and 1.0 M.

In collaboration with Study 8.3.1.3.6.1, studies of the solution speciation of Np(V) prior to and following contact (batch or column) with Yucca Mountain tuffs has begun.

Model complex studies continued with preparation of a report on hydrolysis studies of uranium tetrachloride (UCl4), which were completed in FY 1991. The report discusses the influence of carbonate and hydroxide complexation on the electronic spectra of the actinides.

Work was initiated, using a fresh stock solution of 242 Pu(IV), to produce single crystals of the several Pu(IV)-EDTA complexes that have been shown to exist. These species will be characterized using single-crystal XRD.

2.2.2.11 Study 8.3.1.3.5.2 - Colloid behavior

Activity 8.3.1.3.5.2.1 - Colloid formation characterization and stability. No progress during the reporting period due to lack of funding.

Activity 8.3.1.3.5.2.2 - Colloid modeling. No progress during the reporting period due to lack of funding.

2.2.2.12 Study 8.3.1.3.6.1 - Dynamic transport column experiments

The Study Plan is being revised to incorporate the YMPO review comments.

Activity 8.3.1.3.6.1.1 - Crushed tuff column experiments. In preparation for upcoming radionuclide transport experiments using Np, devitrified and zeolitic crushed-tuff columns were saturated, the flow rate in the columns was determined, and the columns were characterized using an H_3 solution.

Activity 8.3.1.3.6.1.2 - Mass transfer kinetics. No progress during the reporting period; this is an out-year activity.

Activity 8.3.1.3.6.1.3 - Unsaturated tuff columns. Staff completed design of a technique to study radionuclide transport through saturated solid-rock columns approximately six inches long by one inch in diameter; these columns are larger than those used previously in this activity. Columns of solid Calico Hills tuff have been prepared, and their characterization has begun.

A paper entitled "Radionuclide Migration Studies for Validating Sorption Data--Past, Present, and Future" (Triay) was prepared for the Proceedings of the DOE Yucca Mountain Site Characterization Project Radionuclide Adsorption Workshop at Los Alamos, September 11-12, 1990. This paper discussed experiments using crushed, intact, and fractured-tuff material that test the transport models used for scientifically predicting the effects of sorbing and nonsorbing radionuclides on a laboratory scale.

Activity 8.3.1.3.6.1.4 - Fractured tuff column studies. No progress during the reporting period; this is an out-year activity.

Activity 8.3.1.3.6.1.5 - Filtration. No progress during the reporting period; this is an out-year activity.

2.2.2.13 Study 8.3.1.3.6.2 - Diffusion

The Study Plan is being revised to incorporate YMPO review comments.

Activity 8.3.1.3.6.2.1 - Uptake of radionuclides on rock beakers in a saturated system. In preparation for static-diffusion experiments involving the uptake of radionuclides (Neptunium-237), intact tuff (rock beakers, diffusion cells, and tuff wafers fabricated from core received from the Sample Management Facility (SMF)) was saturated with water from the NTS well J-13. Preparation began of a paper on this subject.

Activity 8.3.1.3.6.2.2 - Diffusion through a saturated tuff slab. A DP entitled "Saturated Diffusion Cell Experiments" has been revised and approved.

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.

2.2.2.14 Study 8.3.1.3.7.1 - Retardation sensitivity analysis

The revised Study Plan incorporating YMPO review comments was provided to the YMPO on March 6, 1992.

Activity 8.3.1.3.7.1.1 - Analysis of physical/chemical processes affecting transport. Preliminary modeling continued, using the dual porosity/dual permeability model to calculate flow in unsaturated, fractured, porous media. Model tests were run to calculate flow in a discretely fractured medium that butts up against a fault zone.

Testing was initiated of the computer code FEHMN for accurate simulation of multiphase flow and fracture/matrix interaction.

Activity 8.3.1.3.7.1.2 - Geochemical/geophysical model of Yucca Mountain and integrated geochemical transport calculations. A paper was prepared entitled "Three-Dimensional Simulations of Radionuclide Transport at Yucca Mountain" (Birdsell et al.), which discusses the sensitivity of radionuclide transport to such factors as problem dimensionality, radionuclide species, recharge rate, sorption coefficient, dispersivity length scale, and source term.

Activity 8.3.1.3.7.1.3 - Transport models and related support. In coordination with Study 8.3.1.2.3.1, the Software Requirements Specification has been written for FEHMN (three-dimensional heat and mass transfer simulator) and GZSOLVE (a re-use component used by FEHMN, TRACRN, and FRACNET).

Work during this period has focused on preparing the computer code TRACRN (used to model flow and contaminant transport through porous media) for certification. The requirements phase was approved by the Configuration Control Board; the design phase neared completion and progress was made on the implementation phase, including documenting test runs of verification examples and preparing a user's manual.

2.2.2.15 Study 8.3.1.3.7.2 - Demonstration of applicability of laboratory data to repository transport calculations

The Study Plan was in preparation.

A talk entitled "The Use of Anthropogenic Analogues in Site Characterization for Low-Level Radioactive Waste Sites" (Springer, 1991) was presented at the U.S. Thirteenth Annual DOE Low-Level Waste Management Conference, November 19-21, 1991. The talk indicated how previous waste management experiences may be used in preparing for characterization of radioactive waste disposal sites.

Interaction between LANL and LBL continued with a discussion of an experimental design using a combination of borehole and alcove concepts to test radionuclide transport issues in the Calico Hills unit at Yucca Mountain. The objective is to evaluate the effectiveness of modeling using borehole data against characterization data obtained from mining the test block. Geophysical techniques will be used to assess response of the test zone.

2.2.2.16 Study 8.3.1.3.8.1 - Gaseous radionuclide transport calculations and measurements

No progress during the reporting period due to lack of funding.

2.2.3 Rock characteristics (SCP Section 8.3.1.4)

2.2.3.1 Study 8.3.1.4.1.1 - Development of an integrated drilling program

All related work is described with prototype drilling description (see Study 8.3.1.2.2.3).

2.2.3.2 Study 8.3.1.4.1.2 - Integration of geophysical activities

Progress is reported under the activities in which this work is being performed.

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 comment resolution process for Study Plan 8.3.1.4.2.1 was completed in January 1992 and the Principal Investigator completed revision of the Study Plan on February 3, 1992. The Study Plan was resubmitted to the DOE, has been through verification review, and awaits approval and transmittal to the NRC. A change request for the SCPB to conduct the geophysical surveys under Study Plan 8.3.1.4.2.1 rather than Study Plan 8.3.1.17.4.3 was submitted to the YMP Change Control Board (CCB).

Activity 8.3.1.4.2.1.1 - Surface and subsurface stratigraphic studies of the host rock and surrounding units. A paper entitled "Development of a Three-Dimensional Site-Scale Model for the Unsaturated Zone at Yucca Mountain, Nevada" (Wittwer et al.) was submitted to the 1992 IHLRWM Conference.

Investigation of Sr isotope variation in core samples from the high-silica rhyolite of the Topopah Spring Member of the Paintbrush Tuff suggest that the variation in Sr isotopes may be useful as a potential stratigraphic indicator within the unit. Sampling of cuttings from wells JF-3 and J-13 was initiated to investigate differences in Sr isotopic ratios between rocks and waters collected within the same stratigraphic unit.

Activity 8.3.1.4.2.1.2 - Surface-based geophysical surveys. Compilation and technical review of preexisting gravity and magnetic data from Fortymile Wash was completed, and a draft Open-File report entitled "Gravity and Magnetic Data of Fortymile Wash, Nevada Test Site, Nevada" (Ponce et al.) was submitted for internal USGS review. The report is primarily a data release but concludes that no significant vertical offset of geologic units underlies Fortymile Wash.

The design of the seismic profiles to be run across Yucca Mountain and along Yucca Wash was completed, and the announcement of the forthcoming request for contractor proposals was published. These plans integrate the concerns of the Geophysical Peer Review Panel.

A two-dimensional analysis of gravity profiles across Yucca Mountain relative to deep detachment faults was completed and will be included in the proposed USGS bulletin tentatively entitled "Status of Regional Geophysics at Yucca Mountain and Vicinity, Nevada and California." DOE concurrence was received on an USGS Open-File Report entitled "Geophysical Characterization of Mineral and Energy Resources at Yucca Mountain and Vicinity, Nevada" (Langenheim et al.).

Activity 8.3.1.4.2.1.3 - Borehole geophysical surveys. A paper entitled, "Physical Properties of Ash-Flow Tuff from Yucca Mountain, Nevada" (Nelson and Anderson) was accepted for publication by the Journal of Geophysical Research.

Evaluation of commercially available logging tools and methods used in comparison tests between two commercial logging companies in logging runs in USW G-2 was near completion, with anticipated release of the evaluation and associated recommendations as an Open-File Report tentatively entitled "Assessment of Geophysical Logs from Borehole USW G-2, with Recommendations for Future Logging at Yucca Mountain, Nevada" (Nelson and Schimschal).

Activities 8.3.1.4.2.1.4-6 had no progress during the reporting period because of lack of funding.

2.2.3.4 Study 8.3.1.4.2.2 - Characterization of the structural features within the site area

Verification of comment resolution for YMPO's review of Activities 3 and 5 of Study Plan 8.3.1.4.2.2 was completed February 10, 1992.

Activity 8.3.1.4.2.2.1 - Geologic mapping of zonal features in the Paintbrush Tuff. Structural analysis of exposed parts of the Ghost Dance fault zone in the vicinity of the potential repository block was initiated, with mapping based on a grid surveyed in January from benchmark locations. The grid will allow re-occupation of stations for mapping and analysis at different scales. Mapping is being done at 1" = 200' along the Ghost Dance fault zone. To date, 22 of approximately 61 grid areas have been mapped during several site visits.

Isotopic and geochemical analysis was initiated on samples collected from reference sections of altered and unaltered tuff exposures in the vicinity of Yucca Mountain. Staff supported the investigation of the Trench 14 calcite deposits. The capability to conduct Uranium-series dating in the isotope laboratory was developed during the reporting period. High-precision Sr isotopic analyses were being conducted on samples from southern Yucca Mountain that are interpreted to have never been below the water table. These studies will assess the degree of Sr modification caused by hydrothermal alteration.

Reconnaissance of structurally and stratigraphically complex areas near Yucca Mountain was underway, with preparation in place for detailed 1:12,000 mapping in the area west of Prow Pass.

YMP staff hosted three informal workshops; one described characterization activities, accomplishments, and plans to DOE staff, another brought together geologic investigators and the unsaturated zone modeling group to coordinate the geologic information needed by the modeling group, and the third considered the effectiveness of planned drillholes.

Activity 8.3.1.4.2.2.2 - Surface-fracture network studies. Fieldwork continued on mapping fracture outcrops, data have been obtained from more than 35 field localities. The bulk of the project activity involved analytical reduction of preexisting data sets. Verification and cataloging activities were completed on previous data sets. The design of the geotechnical data base (in conjunction with borehole evaluation, underground mapping and surface soil/rock characterization) was completed, so that participants will be able to use a single consistent data base for storage of information and extraction to a variety of statistical and modeling packages. The data base manager

program will be ORACLE, which is in place and which will have links to AUTOCAD. Other programs in place include FRACMAN (stochastic modeling system for planar discontinuities), SURFER (three-dimensional graphical contouring package), GRAPHER (two-dimensional x-y plotting for graphs), CLUSTRAN (statistics on a stereographic sphere), NWA STATPAK (statistical data manipulation) and GEOEAS (spatial statistical treatments) to be used in mapping, display, and statistical manipulation.

Activity 8.3.1.4.2.2.3 - Borehole evaluation of faults and fractures. Records from previous borehole televiewer surveys have been evaluated and cataloged, with appropriate QA verification. Review and modification of technical procedures was underway. Unprocessed preexisting data from drillhole USW G-4 were acquired and processing of data from boreholes USW G-4 and USW G-2 was begun.

Contact was made with representatives from COLOG Inc., Stanford University, CER Corporation, and Southwest Research Institute to establish a review of vendor techniques for acquisition and processing of borehole fracture data. This process will provide the benefits of currently expanding digital treatment of borehole televiewer data.

Activity 8.3.1.4.2.2.4 - Geologic mapping of the Exploratory Studies Facility. Scheduled elements of this activity have been deferred awaiting determination of the configuration of the ESF ramp design, including TBM size and design, number of concurrent headings, dimensions of underground openings, size of staff required to map headings, and other details. Field visits by YMP staff to the Fran Ridge prototype test pits were conducted to acquire estimates of size and excavation requirements for completing the test pits. These pits are being excavated to complete prototype testing of shaft mapping methods. The pit excavation will be integrated with pavement clearing for surface-fracture network mapping (Activity 8.3.1.4.2.2.2) in order to provide a three-dimensional data set in the area of the test pits.

YMP staff met with representatives from VAX/DEC regarding the upgrade of the MicroVax 2 platform to better drive the Kern DSR-11 analytical plotter. This activity joined surface fracture mapping in acquisition and verification of software packages (noted above in Activity 8.3.1.4.2.2.2) for treatment of underground mapping data.

YMP staff participated in a field workshop to examine the effectiveness of planned drillholes (Study 8.3.1.14.2.2) along the proposed alignments of the north and south ramp declines into the ESF. Tentative borehole locations were determined with respect to position of known or inferred structures, to rig access, and to the tentative location of ramp alignments. Participants in the workshop included USGS, USBR, YMPO/DOE, and other YMP personnel.

Activity 8.3.1.4.2.2.5 - Seismic tomography/vertical seismic profiling. Validation studies on computer programs that model seismic wave propagation through fractured rock (ANI90 and BEAM87) were underway and included testing with actual data from NTS Areas 2 and 10 to investigate three-dimensional fold anisotropy. The validation studies indicated that significant ray bending and focusing will occur in the top of the tuff section, producing a shadow zone from 200 to 400 m below the surface. Sensitivity studies for grid sizes were carried out. Data from Yucca Mountain holes will be used to test the system

in the potential repository environment. Planning is underway to coordinate VSP studies with the planned seismic reflection profile to calibrate the reflection work and test seismic imaging of the potential repository block by VSP methods.

A paper entitled "Practical Considerations for Tomographic Inversions" (Peterson) was submitted for internal review with the intention of submitting the paper to Geophysics for publication. Another paper entitled "High-Resolution Seismic Imaging for Characterizing Fractures in Potential Sites for Nuclear Waste Repositories" (Majer et al.) was submitted for presentation during the IHLRWM Conference in Las Vegas in April 1992.

2.2.3.5 Study 8.3.1.4.2.3 - Three-dimensional geologic model

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

2.2.3.6 Study 8.3.1.4.3.1 - Systematic acquisition of site-specific subsurface information

The Principal Investigator is revising Study Plan 8.3.1.4.3.1 based on YMPO review comments.

Activity 8.3.1.4.3.1.1 - Systematic drilling program. Results obtained during the previous period from the outcrop sampling scoping study have continued to provide insight into the spatial distribution of physical rock properties in unsaturated zone units at Yucca Mountain. This work is a collaborative effort by SNL and the USGS. An additional 150 samples at one- to two-meter spacings have been collected using a hand-held, gasoline-powered core drill from a new vertical transect through the entire Paintbrush Tuff interval north of Yucca Mountain, Nevada. Another 320 samples have been collected that form a two-dimensional grid covering the nonwelded interval between the Tiva Canyon and Topopah Spring Members. This interval has been identified by recent neutron-hole drilling (see Section 2.2.1.5) as of particular importance in understanding infiltration processes and unsaturated zone flow. A set of some 80 samples was obtained from existing drill holes through the SMF to provide examples of unsaturated zone materials not exposed in outcrop at Yucca Mountain.

Measurement of "framework" matrix properties on these outcrop samples, including porosity, bulk density, particle density, imbibition, sorptivity, and permeability, is providing important data on spatial variability and is reported in "Spatial Variability in Rock Matrix Properties from Surface Outcrop Sampling" (Istok et al., 1991) and "Microstratigraphic Units and Spatial Correlation of Hydrologic Properties in Tuff, Yucca Mountain, Nevada" (Rautman et al., 1991). A paper entitled "Deterministic Geologic Processes and Stochastic Modeling" (Rautman and Flint) was prepared for the IHLRWM Conference in Las Vegas in April 1992. It reports that in addition to the quantitative description of spatial variability, which represents a statistical property of the rock mass, the results of this scoping activity have documented the existence of numerous "deterministic" geologic features that affect the distribution of rock properties in space. Identification of these features, which have their origin in relatively well understood and

predictable geologic processes, has important implications for development of down-hole sampling patterns for site characterization drilling. Confirmatory identification and quantitative documentation of these same features in future drill holes at Yucca Mountain may require more closely spaced samples than originally planned for this study. However, the existence of these features, and their control of physical properties important to flow and transport, suggests that confidence in numerical geologic models used for performance assessment also may be greater than anticipated. Drilling and sampling plans for this study (and other site drilling studies) are being evaluated accordingly.

Development of the gas permeameter (in cooperation with SCP Subactivity 1.6.2.1.1, Development of a Theoretical Framework for Calculational Models) has progressed beyond the laboratory stage reported in PR 5. The device has been used successfully in the field on natural surfaces, in contrast to "smooth" sawn slabs. Reasonably repeatable permeability measurements have been obtained. However, logistics of successful operation in a production mode are not good, and other alternatives are being explored. Field measurements of permeability are believed important for scoping studies similar to the outcrop work described above. Specifically, many of the most porous and permeable units encountered at Yucca Mountain simply cannot be cored for laboratory measurement of any property; the rocks are too incompetent and disintegrate at the bit face. Because spatial variability of material properties in these particular units may have important consequences for performance, it appears critical to understand these units and to design the site characterization program to investigate them properly. Additional details of the field research program have been presented in "Field Research Program for Unsaturated Flow and Transport Experimentation" (Tidwell et al., 1992).

Separately, in "Laboratory Study of the Influence of Measurement Scale on Effective Media Property Estimates" (Tidwell et al., 1991), geostatistical evaluation of permeameter data obtained using the series of progressively larger orifice tips indicated that both the magnitude of the measurements and the continuity of these measurements is a function of tip size.

2.2.3.7 Study 8.3.1.4.3.2 - Three-dimensional rock characteristics models

The major portion of the modeling work to be conducted by this study is dependent upon site data to be obtained during site characterization. Thus, the majority of the study is considered an out-year activity, and the Study Plan is not being prepared at this time. Because of the unique nature of this activity, which is at the interface between site characterization and performance assessment, how the requirements for (site) Study Plans will be applied to this modeling (analysis) activity has not yet been completely determined.

Activity 8.3.1.4.3.2.1 - Development of three-dimensional models of rock characteristics at the repository site. A major new software package for three-dimensional geologic modeling has been purchased, received, and installed on two Sun SPARC-2 workstations at SNL. The Lynx Geotechnical Modeling System (GMS), from Lynx Geosystems, Inc., was acquired to remedy previously noted limitations of existing "two-and-a-half" dimensional modeling

software used at SNL. The Lynx GMS package is based on commercial mining software that is being modified by Lynx for more generalized environmental applications. The program has been acquired under a beta-test site agreement, under which SNL can make recommendations for improvements and additional capabilities that may prove useful in those areas. One upgrade has already been received following initial installation, and several more are expected prior to "finalization" of the first commercial version of the GMS.

The Lynx GMS package offers greatly enhanced, true three-dimensional modeling capabilities. A wide variety of geologic data, not just drill hole information, can be incorporated, displayed in its proper spatial position, and modeled using several different approaches. The geologist's on-screen interpretation can be checked for consistency in three dimensions (also on-screen) in any desired number of orientations to help avoid artifacts that may easily result from working with two-dimensional projections of three-dimensional volumes. A collection of geostatistical routines is being integrated into the modeling system to provide for analysis and interpolation of numerical rock properties. This subset of capabilities currently is quite mining oriented (i.e., ore grades), reflecting Lynx's historical background. SNL staff are exploring incorporating more advanced geostatistical methods into future releases of the Lynx GMS, which may be particularly useful in environmental applications. Some of these subroutines might be available from GSLIB, the geostatistical subroutine package obtained by SNL as a result of its participation in the Stanford Center for Reservoir Forecasting at Stanford University.

SNL staff (and one USGS investigator) have been trained on the Lynx system, but limited staff time due to funding restrictions and other priorities and a relatively steep learning curve for this complicated program have restricted actual use of the system. Construction of a very small model using existing data from drill holes USW H-4, USW UZ-7, and USW WT-2 confirmed staff expectations and enthusiasm regarding the GMS. Down-hole deviation survey data for existing drill holes at Yucca Mountain have been prepared and input into the system. Intercepts for major geologic units are being prepared for input, and USGS investigators working under Study 8.3.1.4.2.1 (Section 2.2.3.3, Characterization of Vertical and Lateral Distribution of Stratigraphic Units within the Site Area) have expressed interest in providing additional stratigraphic data and in collaborating on the development of more comprehensive models of Yucca Mountain. SNL staff and USGS personnel are also investigating converting digital geophysical well-log data to Lynx format. This is reported in "Geophysical Logs and Core Measurements from Forty Boreholes at Yucca Mountain, Nevada" (Nelson et al., 1991). Assuming the Lynx system does not balk internally at the large quantity of data involved, this data conversion would allow modelers to view the actual well logs in proper geographic and deviated position as they interpret geology and construct models of the site. Geophysical well logs frequently contain subtle information that supplements the more standard subdivision of rocks into "solid" stratigraphic units, which may also be viewed on-screen at the same time.

A paper entitled "Geologic Uncertainty in a Regulatory Environment: An Example from the Potential Yucca Mountain Nuclear Waste Repository Site" (Rautman and Treadway, 1991), describing the assessment of uncertainty in performance calculation results using advanced geostatistical simulation

techniques, has been published as part of a special journal volume on "Regulatory Geology and Regulatory Hydrology: Site and System Performance Evaluations in the Face of Uncertainty." The papers composing this special volume were in response to a call for such presentations by the NRC. A somewhat less site-specific discussion of advanced geostatistical techniques that are being used in this study, entitled "Advanced Geostatistical Methods Applied to the Yucca Mountain High-Level Nuclear Waste Program" (Rautman) will be presented at a special session on Advanced Methods in Engineering Geology at the 29th International Geological Congress in Kyoto, Japan, this summer.

The implications of recently documented "deterministic" geologic features that appear to control the distribution of physical rock properties important to performance assessment modeling of flow and transport (see discussion under Study 8.3.1.4.3.1 in PR section 2.2.3.6) have been summarized in a paper entitled "Deterministic Geologic Processes and Stochastic Modeling" (Rautman and Flint) that will be presented at the IHLRWM Conference in Las Vegas, Nevada.

2.2.4 Climate (SCP Section 8.3.1.5)

2.2.4.1 Study 8.3.1.5.1.1 - Characterization of modern regional climate

Activity 8.3.1.5.1.1.1 - Synoptic characterization of regional climate. Work conducted during the reporting period primarily involved technical planning. Evaluation of the needs of Terrestrial Paleoecology, however, suggest that this activity will require information on the stable isotope composition of precipitation. That information will provide the source and fractionation steps involved in the transport of water vapor from an ocean or other sources to southern Nevada. The isotope composition of modern rainfall may then be used to examine similar isotopes from various living trees in the region and thus calibrate cellulose stable isotopes and climate. Cellulose from packrat middens can then be used as a climate record.

2.2.4.2 Study 8.3.1.5.1.2 - Paleoclimate study: lake, playa, and marsh deposits

Study Plan 8.3.1.5.1.2 was sent to the NRC on December 6, 1991.

Activity 8.3.1.5.1.2.2 - Analysis of the stratigraphy-sedimentology of marsh, lacustrine, and playa deposits. Work focused on technical planning on the crucial issue of how much surface water was supported by past climate states. The present climate state, which originated about 10 to 12 thousand years ago, is likely to be at the dry end of effective moisture spectrum. Wetlands were relatively common in southern Nevada as recently as 14 thousand years ago and large deep lakes existed in all directions from Yucca Mountain until about 14 to 16 thousand years ago. Conversely, sites such as Kawich Playa has nearly a million year history of groundwater discharge, but that playa did not and has not experienced groundwater discharge for over 27 thousand years. These examples illustrate both the regional nature and strong spatial variance of climate. This study will focus on the evaluation of the history of surface water in the region over the past million years with a

strong emphasis on the last 200 thousand years using records from lake, playa, and marsh deposits.

2.2.4.3 Study 8.3.1.5.1.3 - Climatic implications of terrestrial paleoecology

Study Plan 8.3.1.5.1.3 was sent to the NRC on January 30, 1992.

Activity 8.3.1.5.1.3.1 - Analysis of packrat middens. Technical planning focused on the quantity of water in the natural system during past climate states. Primary records to be evaluated are pollen from aquatic sediments and plant macrofossils from packrat middens. Both records will provide direct evidence for the type of vegetation community that existed in the region and from that form a basis for estimating past precipitation. The cellulose extracted from woody plant material preserved in middens will provide a stable isotope record that may also be used to reconstruct climate.

2.2.4.4 Study 8.3.1.5.1.4 - Analysis of the paleoenvironmental history of the Yucca Mountain region

Study Plan 8.3.1.5.1.4 was accepted by the NRC on December 6, 1991. One general concern in NRC's acceptance letter regarding data qualification is under consideration by YMPO.

Activity 8.3.1.5.1.4.1 - Modeling of soil properties in the Yucca Mountain region. Studies in this activity have been prioritized and directed to the Calcite-Silica activity.

Activity 8.3.1.5.1.4.2 - Surficial deposits mapping of the Yucca Mountain area. Work in this activity emphasized identifying climate sensitive deposits on Yucca Mountain. Soil pits were constructed in Midway Valley to aid in the refinement of surficial stratigraphy at Yucca Mountain. The mapping study is in part intended to identify surficial carbonate deposits that can be analyzed isotopically to estimate past states of effective moisture.

Activity 8.3.1.5.1.4.3 - Eolian history of the Yucca Mountain region. The need for thermoluminescence age-dating was identified and steps were taken to obtain the ability to conduct such age-dating.

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.

2.2.4.6 Study 8.3.1.5.1.6 - Characterization of the future regional climate and environments

Comments on Study Plan 8.3.1.5.1.6 were received from the YMPO on January 30, 1992, and the strategy to resolve these comments was discussed with the appropriate YMPO points of contact.

Activity 8.3.1.5.1.6.2 - Regional climate modeling. A 3.5-year present-day climate simulation with the regional climate model MM4 driven by boundary conditions from a modified version of the general circulation model CCM was completed. The first step in the analysis of the output from this simulation was to compute 3-year seasonal averages of all CCM and MM4 model variables. Similar climatological averages based on meteorological measurements were calculated using the European Center for Medium Range Weather Forecasting global data base for tropospheric temperatures, wind, and water vapor and the high-resolution surface climatology for precipitation and surface temperature. The precipitation climatology of the MM4 was found to be superior to that of the CCM in every region of the western U.S. in all four seasons. A conference paper, "An Overview of the Yucca Mountain Global/ Regional Climate Modeling Program" (Sandoval et al.) will be presented in a poster session of the 1992 IHLRWM Conference at Las Vegas, Nevada, in April 1992.

The one-dimensional thermal lake model of Hostetler and Bartlein (1990) has been successfully coupled to the MM4. In this interactive two-way nesting, the lake model and the MM4 exchange information hourly. The MM4 passes surface layer atmospheric temperatures, winds, mixing ratios, and long- and short-wave radiation values to the lake model and the lake model calculates the temperatures profile of the lake and the surface evaporation rate. Test simulations over the Great Lakes region at a resolution of 60 km have shown that the model simulates surface temperatures, evaporation rates, and ice formation well. The coupled lake model will be used in simulations of paleoclimate conditions (Phase III) to provide lake surface temperatures and evaporation rates for Lakes Bonneville and Lahontan.

Test simulations have been conducted utilizing the split-explicit time integration option in MM4. The use of this time integration scheme will permit a 40 to 50 percent savings in computer time and thus will allow longer climate simulations with MM4. Initial problems in the implementation of this scheme have been alleviated by reducing the vertical diffusion coefficient. This scheme will be used in Phase II of the present-day climate simulations and in the paleoclimate simulations.

A paper summarizing the results of Phase I validation analysis has completed the SNL technical and management review.

2.2.4.7 Study 8.3.1.5.2.1 - Characterization of the Quaternary regional hydrology

Study Plan 8.3.1.5.2.1 was revised in response to YMPO review comments. The revised Study Plan was submitted to YMPO for verification on March 31, 1992. A change request for the SCPB to accomplish Activity 8.3.1.5.2.1.2 under Study Plan 8.3.1.2.2.7 is being prepared.

Activity 8.3.1.5.2.1.1 - Regional paleoflood evaluation. Data for the Yucca Mountain area, consisting of computer-generated digital landscape models, satellite images, and aerial photographs, are being compiled to assist in evaluating regional paleoflooding and the potential hazards of modern-day, high-magnitude floods and debris flows. Field and geomorphometric reconnaissances of the Yucca Mountain region (e.g., the upper and middle

reaches of the Amargosa River and Fortymile Wash) are being conducted to locate sites that may contain geomorphic evidence of the processes and products of regional paleoflooding relevant to the information needs of this activity. Candidate sites and/or site areas will be chosen for more detailed, site-specific investigation.

Activity 8.3.1.5.2.1.2 - Quaternary UZ hydrochemical analysis. A change request for the SCPB to accomplish Activity 8.3.1.5.2.1.2 under Study Plan 8.3.1.2.2.7 is being prepared.

Activity 8.3.1.5.2.1.3 - Evaluation of past discharge areas. Samples were collected in October 1991 from 16 playa sites in Nevada and 8 playa sites in California. All of the sites were sampled for ostracode fauna and analyzed for Sr isotope ratios.

In early March 1992, the aquatic microorganism collector was tested at well JF-3 which is 0.5 mile south of J-12 in Area 25, NTS. This well was pumped at 234 gallons per minute for 36 hours. For 22 hours, 20 gallons per minute were diverted through the aquatic microorganism collector. Although JF-3 was pumping about 10 percent air, which was probably introduced into the aquifer during well development with compressed air, the undisturbed aquifer may not have been oxygenated. Preliminary analyses of the nets in the field indicated that no organisms were present. Final analysis of the net contents will be completed in April 1992.

During late March 1992, samples were collected from two playas in Nevada, one in California and one in Arizona. Two springs and flowing wells were sampled in Nevada and two in California. One rock sample was collected from a past discharge site (dry-spring mound) in Nevada. Four samples of water from wells in California were collected for Sr isotopic ratios analysis.

A paper was presented and published entitled "Characterizing the Distribution of Pedogenic Carbonates using a Geographic Information System and a Carbonate Accumulation Program, Amargosa Desert, Nevada" (Faunt et al., 1991). Another paper was published, "Quaternary Spring Deposits at the Southern End of Crater Flat, Nye County, NV" (Taylor, 1991).

Activity 8.3.1.5.2.1.4 - Analog recharge studies. Two field trips were conducted to the study sites and preparation for the April 1992 field trip have been completed. Heavy snows in February 1992 caused by a subtropical Pacific storm increased the chance of runoff at Kawich Creek and significantly increased the snow pack in both analogue study areas. A field trip the week after the storms achieved good measurements of the effect of the precipitation.

Data from 1985 through 1990 have been reviewed and are being prepared for publication as a USGS report. Solar insolation data have not been verified due to the difficulty with verification of data from nearby weather stations. These data should be available from the National Climatic Data Center and Solar Energy Research Institute in April 1992. Annual summaries have been completed for the weather and hydrologic data except for the solar insolation data. Data are stored in a printed format and in a computer medium. A USGS automated data processing system, NWIS, has been used to facilitate computer storage of the data.

Leaves collected from the summer field work were dried, prepared for weighing, and statistical methods development started to determine the relationship between leaf weight and leaf area. Elevation, slope, and aspect data stored in ARC/INFO files have been moved to the Sun computer in preparation for the development of hydrologic response units (HRUs). Vegetation maps have been added to the topographical features in the ARC/INFO data base for HRU development.

Sample preparation for the chloride leaching tests was completed by the USGS Branch of Geochemistry in December 1991 and leaching started in January 1992. Three samples have been leached to date: (1) Rainier Mesa tuff, (2) Stewart Creek tuff, and (3) Kawich Creek tuff. Initial results indicate that chloride concentrations decrease rapidly after the initial leach.

The October 1991 and January 1992 quarterly precipitation samples from Organ Pipe Cactus National Monument and Oliver Knoll, Arizona, were collected and processed. The sonic anemometers and their associated electronics were demonstrated to function as specified. Problems with the data collection software encountered when the system was run on the computer were resolved. The long-term meteorologic instrumentation will be installed as soon as it can be calibrated and its instrumentation shelter finished.

The New Mexico Institute of Mining and Technology has completed about 20 ^{36}Cl dates on the three soil surfaces under consideration as calibration soils for the project and are beginning to analyze the hydrogen-2 (^{2}H) and oxygen-18 (^{18}O) contents of soil samples collected in May 1991.

Activity 8.3.1.5.2.1.5 - Studies of calcite and opaline silica vein deposits. Sr isotope studies continued on samples from Bare Mountain and the Striped Hills where preliminary data indicate that the bedrock substrates contribute little to the formation of associated secondary calcretes; on samples from the deepened part of Trench 14 and from site 199 (at the south end of Crater Flat); and of water samples from Wells J-12, J-13, and Army #1 that will generate high-quality baseline data for subsequent study of water from JF-3. Slight differences between these water samples and analyses of earlier collections suggest that isotopically distinct zones are yielding water in these wells.

Stable C and O, and Sr isotope studies continued on the occurrences of secondary calcite within Yucca Mountain. More samples were collected from existing drill core to augment the collection. Plans are underway to begin lead (Pb), samarium (Sm), and Nd isotope studies of the secondary calcites to provide additional information in determining the source of the fluids responsible for the calcite deposits.

Continued work on the secondary calcite samples from Yucca Mountain indicated that calcites in the unsaturated and saturated zones precipitated from distinctly different fluids. Delicate growth-banding of the unsaturated zone calcite, observed by cold cathode luminescence, indicates that this calcite may record a long history of deposition. Present efforts are focused on detailed studies of this banding, development of a stable and Sr isotope record of past variations in fluid composition, and extensive dating of this calcite by C-14 and U-series methods. It is anticipated that these data will produce a record of responses of the unsaturated zone hydrology to past

changes of climate at the Yucca Mountain site. Efforts have also been initiated to perform fluid inclusion studies of this calcite to look for evidence of past fluctuations of water table elevation.

Abstracts entitled "The $\delta^{13}C$ and $\delta^{18}O$ Values of Epigenetic Calcite within Yucca Mountain, Nevada: Paleohydrologic Implications" (Whelan and Stuckless, 1991); "Strontium Isotope Characterization of Ground-Water Flow Systems in Southern Nevada" (Peterman et al., 1991); "Lead Isotopes in the Carbonate-Silica Veins of Trench 14, Yucca Mountain, Nevada" (Zartman and Kwak, 1991); "A Model for the Formation of Pedogenic Carbonate Based on Strontium Isotope Data from Southwest Nevada" (Marshall and Mahan, 1991); and "Isotopic Evidence for a Per Descensum Origin for Hydrogenic Veins in Faults Near Yucca Mountain, Nevada" (Stuckless et al., 1991) were presented at the annual meeting of the GSA in San Diego, October 21-24, 1991, and are published in the abstract volume from the meeting.

Short papers entitled "Paleohydrologic Implications of the Stable Isotopic Composition of Secondary Calcite Within the Tertiary Volcanic Rocks of Yucca Mountain, Nevada" (Whelan and Stuckless) and "Strontium Isotope Geochemistry of Calcite Fracture Fillings in Deep Core, Yucca Mountain, Nevada" (Peterman et al.) will be presented at the IHLRWM Conference in Las Vegas in April 1992.

Short papers entitled "Isotopic Studies of Fracture Coatings at Yucca Mountain Nevada" (Marshall and Whelan) and "Strontium Isotope Characterization of the Ash Meadows Ground-Water System, Southern Nevada" (Peterman et al.) were submitted to the Water-Rock Interaction Conference to be held in Park City, Utah, in June 1992.

2.2.4.8 Study 8.3.1.5.2.2 - Characterization of future regional hydrology due to climate changes

Study Plan 8.3.1.5.2.2 was revised in response to YMPO review comments and is in comment resolution.

Activity 8.3.1.5.2.2.1 - Analysis of future surface hydrology due to climate changes. Hydrologic modeling hardware and operating system software needs were evaluated. The USGS Office of Surface Water was consulted for assistance with the availability of USGS-supported, surface-water runoff models that will be evaluated and potentially used in this activity. The technical documentation for all USGS-supported surface-water modeling software was ordered and catalogued. A number of available data sets and technical procedures for generating high-resolution watershed data needed for this activity were evaluated.

Activity 8.3.1.5.2.2.2 - Analysis of future UZ hydrology due to climate changes. A change request for the SCPB CCB was submitted to the YMPO proposing the elimination of this activity because the scope of work will be performed in 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 hydrologic characteristics of the Yucca Mountain saturated zone. Data conversion/input continued. Maps of surface water drainages, springs, faults, structural stresses, geology, calderas, structural zones, land cover, hydrologic basins, surficial geology, water chemistry and geologic cross-sections are nearing completion. Landsat remote sensing data are being obtained from the federal library for use in regional and vegetation mapping studies to be conducted in cooperation with Activity 8.3.1.5.2.1.3. Regional structural data (including faults, stresses, and anomalous drainages) were input to the GIS. Preliminary analyses including rose diagram plots and trend surface analyses have been conducted.

Three-dimensional hydrogeologic model development was started. Geologic cross sections and surface geology was entered into the GIS. Development of a conceptual model of regional hydraulic conditions was begun with 1) development of methods to quantify regional recharge/discharge, 2) delineation of hydrologic sub-basins, and 3) designation of hydrogeologic units. Plans for documenting data conversion were finalized. USGS staff decided to develop hypercard media similar to the USGS Arctic data base for indexing and cataloging activity data.

Work continued on the isotope diffusion model SNPDIF with modules added to allow the use of snow permeability in place of snow-pore radius. A paper summarizing the details of the work is in draft form.

2.2.5 Erosion (SCP Section 8.3.1.6)

2.2.5.1 Study 8.3.1.6.1.1 - Distribution and characteristics of present and past erosion

Work on Study Plan 8.3.1.6.1.1 has been deferred until the NRC has commented on the DOE proposal to consider erosion as a topic for issue resolution on the basis of the presently available data.

Activity 8.3.1.6.1.1.1 - Development of a geomorphic map of Yucca Mountain. Erosion has been selected by the YMP as one of the first topics to be considered for issue resolution during FY 1992. An annotated outline for the topical report on erosion was completed. A scoping study to determine volumetric analyses using photogrammetry was tested and appeared to be a valid method for determining short-term and long-term erosion rates at Yucca Mountain.

Photogrammetric data collection was completed and checked in the field to validate the digital terrain models (DTMs) at Jakes Point debris flow. Elevation differences between DTMs were used to calculate the volume of debris eroded from the hillslope during one rainstorm in 1984. An abstract entitled "Volumetric Analysis of Debris Eroded off a Hillslope near Yucca Mountain, Nevada, during a Single Precipitation Event" (Coe et al., 1991) was published. This scoping study, along with long-term erosion studies, will contribute to issue resolution of erosion at Yucca Mountain this fiscal year. This method may also be useful to determine debris-flow hazards in Activity 8.3.1.2.1.2.2.

Long-term erosion rates were calculated from relict, colluvial boulder deposits on Yucca Mountain (Harrington and Whitney, 1991). Long-term erosion rates vary from about 1-6 mm/1000 years on Yucca Mountain hillslopes. These data are the primary technical basis for the YMP issue resolution topical report on erosion.

2.2.6 Postclosure tectonics (SCP Section 8.3.1.8)

2.2.6.1 Study 8.3.1.8.1.1 - Probability of a volcanic eruption penetrating the repository

The Study Plan received NRC acceptance on October 5, 1991. Responses to August 8, 1991, comments from the State of Nevada are being held until NRC phase II review comments are received in order to coordinate the responses.

Activity 8.3.1.8.1.1.1 - Location and timing of volcanic events. No progress during the reporting period; funding for this activity begins in FY 1994.

Activity 8.3.1.8.1.1.2 - Evaluation of the structural controls of basaltic volcanic activity. Staff revised calculations of the probability of magmatic disruption using a range of structural models including the random model, the Crater Flat Volcanic Zone model, the Northeast-trending model, and the State of Nevada Chain model.

Digitized data for various magmatic disruption models were obtained from EG&G, using the Site GIS data system.

Activity 8.3.1.8.1.1.3 - Presence of magma bodies in the vicinity of the site. No progress during the reporting period due to lack of funding.

Activity 8.3.1.8.1.1.4 - Probability calculations and assessment. Preparation began on a paper entitled "Recurrence Models of Volcanic Events: Applications to Volcanic Risk Assessment" (Crowe et al.) for presentation at the IHLRWM Conference. Time distribution models for volcanic events were assessed, and a revised table of probability values for the recurrence rate of volcanic events for the Yucca Mountain region was developed.

2.2.6.2 Study 8.3.1.8.1.2 - Effects of a volcanic eruption penetrating the repository

The first draft of the Study Plan has been completed and is in LANL review.

Activity 8.3.1.8.1.2.1 - Effects of Strombolian eruptions. A strategy for calculating the probability of bounding the effects of magmatic disruption on a repository was developed. A paper entitled "Physical Processes and Effects of Magmatism in the Yucca Mountain Region" (Valentine et al.) was prepared, describing eruption modeling, subsurface effects of intrusion of basalt magma, and the dynamics of magmatic process. Samples were collected at the Paiute Ridge area of the eastern NTS to provide the first set of data for

these studies. Staff began initial modeling of basaltic magma chambers, exemplified by small sill intrusions, in the Paiute Ridge area of the NTS.

Activity 8.3.1.8.1.2.2 - Effects of hydrovolcanic eruptions. Staff began a study of the effects of emitted heat and volatiles on the waste inventory and isolation system of a potential repository.

2.2.6.3 Study 8.3.1.8.2.1 - Analysis of waste package rupture due to tectonic processes and events

A revision of Study Plan 8.3.1.8.2.1 in response to YMPO review comments was completed on December 10, 1991. A portion of the approach discussed in the Study Plan was presented to the NWTRB during a meeting on January 22-23, 1992.

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.

2.2.6.5 Study 8.3.1.8.3.2 - Analysis of the effect of tectonic processes and events on changes in water-table elevation

Study Plan 8.3.1.8.3.2 is in preparation.

Activity 8.3.1.8.3.2.5 - Effects of faulting on water-table elevation. A paper entitled "A Geologic Hypothesis for the Large Hydraulic Gradient under Yucca Mountain, Nevada" (Fridrich et al.) was submitted for internal USGS review March 18, 1992.

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.

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.

2.2.6.8 Study 8.3.1.8.5.1 - Characterization of volcanic features

Activity 8.3.1.8.5.1.1 - Volcanism drill holes. Basalt cuttings were obtained from a hole less than 400 feet deep at an aeromagnetic anomaly south of the town of Amargosa Valley and were submitted for $^{40}Ar/^{39}Ar$ dating.

Activity 8.3.1.8.5.1.2 - Geochronology studies. A paper entitled "The Lathrop Wells Volcanic Center: Status of Field and Geochronology Studies" (Crowe et al.) was prepared for the IHLRWM Conference in April 1992.

Staff gave a presentation to the ACNW on geochronology dating methods for young volcanic rocks and participated in the ACNW working group on geologic dating.

Statistical analyses of K-Ar and $^{40}Ar/^{39}Ar$ dating for the Lathrop Wells center was completed.

Initial paleomagnetic data were obtained for the Ql_6 and the buried lava sites at the Lathrop Wells center.

Activity 8.3.1.8.5.1.3 - Field geologic studies. Two phases of trenching studies at the Lathrop Wells volcanic center were completed, and the first trenching studies were undertaken at the Cima volcanic field.

The stratigraphy of the Lathrop Wells volcanic center was revised, using field data from the trenching studies and in-process data from geochemical studies.

Field studies were completed for a sequence of mesa-forming basaltic lava flows south of Black Mountain. These units overlie the tuff of Thirsty Canyon. Two samples were collected from the basaltic lavas and submitted for dating using the $^{40}Ar/^{39}Ar$ method.

Activity 8.3.1.8.5.1.4 - Geochemistry of scoria sequences. Geochemical and petrological data for the Crater Flat volcanic field were examined, and a paper on basalt cycles, entitled "Geochemical Evidence for Waning Magmatism and Polycyclic Volcanism at Crater Flat, Nevada" (Perry and Crowe), was prepared for the IHLRWM Conference in April 1992.

Petrology samples were collected from the 3.7 Ma basalt center, initiating a new phase of petrology and geochemical studies for these units.

Activity 8.3.1.8.5.1.5 - Geochemical cycles of basaltic volcanic fields. Geochemical data for the Crater Flat volcanic field were examined and were compared with other volcanic fields in the Basin and Range provinces and with Mauna Kea volcano in Hawaii.

2.2.6.9 Study 8.3.1.8.5.2 - Characterization of igneous intrusive features

A draft of Study Plan 8.3.1.8.5.2 is scheduled for completion and submittal for YMPO review during the second half of FY 1992.

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. Preparations were made for anticipated field work during the fall of 1992, that included calibration of equipment, selection of vendors for equipment calibration, reconfiguration of the truck-mounted temperature logging system, and planning for a new geologic borehole.

2.2.6.10 Study 8.3.1.8.5.3 - Investigation of folds in Miocene and younger rocks of the region

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

2.2.7 Human interference (SCP Section 8.3.1.9)

2.2.7.1 Study 8.3.1.9.2.1 - Natural resource assessment of Yucca Mountain, Nye County, Nevada

Study Plan 8.3.1.9.2.1 was revised in response to YMPO review comments and was submitted for verification of comment resolution on January 13, 1992.

Drill cuttings of Paleozoic carbonates were collected from a wildcat oil-test in Amargosa Desert in October 1991. A total depth of 5,020 feet was reached in the well. YMP staff was able to collect cuttings which were washed and bagged for examination. Unwashed samples were collected for conodont fossil analyses. Paleozoic-rock cuttings (dolomite) were first encountered at 1,960 feet below land surface and continued to the total depth of the drill hole. Preliminary analyses indicate that no conodonts were recovered from 2,960-3,060 feet below land surface, but conodonts were recovered at intervals of 4,150-4,210 and 4,210-4,255 feet. Conodont indices indicated that the host rock reached a temperature of at least 300°C.

2.2.7.2 Study 8.3.1.9.2.2 - Water resource assessment of Yucca Mountain, Nye County, Nevada

The Study Plan is in review at the NRC.

2.2.7.3 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.

2.2.7.4 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.

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 activity.

2.2.8.2 Study 8.3.1.12.1.2 - Plan for synthesis of Yucca Mountain Project meteorological monitoring

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

2.2.8.3 Study 8.3.1.12.2.1 - Meteorological data collection at the Yucca Mountain site

The Study Plan received NRC acceptance on November 12, 1991. A DOE audit of the Study Plan resulted in a Corrective Action Request (CAR) written to revise the document to comply with DOE/NRC format and content guidance. This revision was completed, and a draft was sent to the YMPO for technical review on March 31, 1992. Five comments received from the State of Nevada on December 2, 1991, were responded to by the DOE on February 13, 1992.

Meteorological and air quality data acquisition and processing continued through use of the Yucca Mountain meteorological monitoring network. The network consists of four "remote" sites that are instrumented with battery-powered meteorological monitoring systems. The sites include measurements of wind speed, wind direction, and temperature at the 10-meter level with the standard deviation of the horizontal wind direction (sigma-theta) calculated by the on-site data acquisition system and a tipping bucket precipitation gauge; one 60-meter tower that includes measurements of wind speed, wind direction, and temperature at the wind speed at the 10-meter level with the sigma theta calculation and a tipping bucket precipitation gauge; two of the site locations have high-volume air samplers to monitor particulate matter in the size fraction below 10 micrometers in nominal aerodynamic diameter (PM10), one of the sites includes a collocated sampler used for QA purposes; a gaseous air quality monitoring station is also established to monitor criteria pollutants.

Ambient Air Monitoring Data, as required by the State of Nevada Air Quality Permit, was processed and reported to the State of Nevada, Bureau of Air Quality. The mean concentrations for the PM10 sampling at both of the monitoring locations were 7 micrograms per cubic meter. These values are well below the annual ambient air quality standard of 50 micrograms per cubic meter.

<u>Activity 8.3.1.12.2.1.1 - Site meteorological monitoring program</u>. The revised Study Plan includes plans to install four additional 10-meter towers in the Yucca Mountain vicinity. These towers will provide additional information related to the ESF portal locations, and extends the network toward the north and south directions.

<u>Activity 8.3.1.12.2.1.2 - Data summary for input to dose assessments</u>. No progress during the reporting period; this is an out-year activity.

2.2.8.4 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 activity.

2.2.9 Offsite installations and operations (SCP Section 8.3.1.13)

No progress during the reporting period due to lack of funding.

2.2.10 Surface characteristics (SCP Section 8.3.1.14)

2.2.10.1 Investigation 8.3.1.14.2 - Studies to provide soil and rock properties of potential locations of surface facilities and subsurface access facilities

Study Plan 8.3.1.14.2 received NRC acceptance on January 23, 1992. Revision 2 of the SCPB consolidated all of the anticipated studies under Investigation 8.3.1.14 into one Study Plan. One general concern in NRC's acceptance letter regarding the level of detail in the Study Plan was forwarded to the USGS for response on February 13, 1992.

Field and laboratory testing for this study was scheduled to begin early in the reporting period, but because of design studies relative to final locations of the ramp alignments work was not initiated until late in the reporting period. Multiple ramp alignments and portal locations were considered, including preparation and submittal of geotechnical site selection reports.

All necessary planning documentation for field exploration activities was completed. Soil investigations began in March 1992, and 50% of the planned excavation of test pits and associated in-place testing was completed. Laboratory testing of samples from the test pits commenced in late March. Reconnaissance of areas to be mapped was also underway. The first preliminary design data submittal to RSN was made in March. Engineering data from soil and rock properties investigations are being reviewed and submitted to the design process as they are acquired.

A field workshop was held to examine the effectiveness of planned drillholes along proposed alignments of north and south ramp declines into the ESF. A valuable result of this workshop was a realization by participants that the design process for the TBM relies more on the description of the range of expected ground conditions than the specific extent of conditions. Tentative borehole locations were determined with respect to position of known or inferred structures, to rig access, and to the expected location of ramp alignments. Participants in the workshop included USGS, USBR, YMPO/DOE, and other YMP participants.

2.2.11 Thermal and mechanical rock properties (SCP Section 8.3.1.15)

2.2.11.1 Study 8.3.1.15.1.1 - Laboratory thermal properties

The Study Plan for this study was transmitted to the NRC; the NRC review, based on a verbal agreement between the DOE and NRC, has been postponed until initiation of the drilling program appears to be imminent.

Activity 8.3.1.15.1.1.1 - Density and porosity characterization. The draft of "An Experimental Comparison of Laboratory Techniques in Determining

Bulk Properties of Tuffaceous Rocks" (Boyd et al.) is being prepared for technical review. Weight losses were measured from powdered samples of zeolitized and devitrified tuff in the vicinity of 170°C, which is the temperature at which anomalies in heat capacity data have been observed. The possibility that water is lost in associated silica phase transformations is being investigated.

Activity 8.3.1.15.1.1.2 - Volumetric heat capacity characterization. Preliminary heat capacity determination data on two samples of tuff were compared with results predicted by "Calculation of Heat Capacities for Tuffaceous Units from the Unsaturated Zone at Yucca Mountain, Nevada" (Nimick and Connolly, 1991). The differences in observed values and predicted specific heat values were significant for temperatures above 160°C.

Activity 8.3.1.15.1.1.3 - Thermal conductivity characterization. Relocation of Holometrix's testing facility delayed initiation of the thermal conductivity scoping studies. Operation of testing equipment was verified and calibration of mechanical and electronic measuring equipment and thermal sensors was completed. A change to include an electronic ice reference to the calibration technical procedure (TP-201) was approved and implemented. Calibration of the testing equipment and verification of testing prerequisites are in process. The scoping study on the effects of saturation on thermal conductivity will begin during the third quarter of FY 1992.

2.2.11.2 Study 8.3.1.15.1.2 - Laboratory thermal expansion testing

The Study Plan was sent to the NRC. The NRC review, based on a verbal agreement between the DOE and the NRC, has been postponed until initiation of the drilling program appears imminent.

Activity 8.3.1.15.1.2.1 - Thermal expansion characterization. Optimal operating conditions were established for the dilatometer environmental tube which will be used in the scoping study to examine the effects of sample saturation on thermal expansion. A system for detecting the water level within the environmental tube was incorporated into the design of the tube. Tests using a fused silica reference sample were performed to establish the repeatability and stability of the dilatometer measurements. A calibration correction can be made to the data obtained at temperatures from 25°C to 100°C. However, there is a drift in the dilatometer linear variable differential transformer (LVDT) output during the soak time in which the sample is allowed to dehydrate. The lack of consistency in the drift for different runs precludes making meaningful calibration correction to the data above 100°C. Methods to control the drift in the LVDT output are being investigated. Once the accuracy and reproducibility of the test data is established and the relevant procedures approved, a scoping study of the effects of sample size on thermal expansion will be initiated.

2.2.11.3 Study 8.3.1.15.1.3 - Laboratory determination of mechanical properties of intact rock

Study Plan 8.3.1.15.1.3, entitled "Laboratory Determination of the Mechanical Properties of Intact Rock" was published in May 1991 and was

submitted to the NRC at that time. The NRC review, based on a verbal agreement between the DOE and NRC, has been postponed until initiation of the drilling program appears to be imminent.

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 technical procedures are being drafted in anticipation of sample availability in the next twelve to eighteen months.

Two reports entitled "Mineralogy, Petrology, and Whole-Rock Chemistry Data Compilation for Selected Samples of Yucca Mountain Tuffs" (Connolly, 1992a) and "Mineralogy, Petrology, and Whole-Rock Chemistry of Selected Mechanical Test Samples of Yucca Mountain Tuffs" (Connolly, 1992b) were approved and published in January 1992.

Testing of several rock types is being conducted at no less than eight government and private rock mechanics laboratories in support of the American Society for Testing and Materials/Institute for Standards Research (ASTM/ISR) Steering Committee for the Interlaboratory Testing Program for Rock Properties. An SNL staff member is serving on the committee and is providing test data from contractors for the Phase I testing. The results are being analyzed in order to establish measures of precision for published standard ASTM rock property test methods.

Activity 8.3.1.15.1.3.2 - Effects of variable environmental conditions on mechanical properties. A series of six experiments on saturated samples tested at a nominal axial strain rate of 10^{-9} s^{-1} (per second) has been completed. The data are being reduced, submitted to the Data Records Management System, and reported in a report for submittal to the SEPDB. The data will be analyzed and the results published in an analysis report or will be folded into a later analysis report following additional testing designed to investigate time-dependent properties of the intact rock.

Six samples are being prepared for testing under creep (constant stress) conditions. The samples will be saturated and tested at a pore pressure of 4.5 MPa, a confining pressure of 5 MPa, and a constant differential (or creep) stress of 80 MPa. Each experiment will be performed at room temperature for a week, followed by testing at 250°C for two months. With the appropriate aluminum system calibration checks, the tests will each take approximately three months to complete and will begin in May 1992.

A report entitled "Summary of Procedure Development Study: Low Strain Rate and Creep Experiments" (Martin et al., 1991) was approved and published in October 1991.

A presentation entitled "Modulus Dispersion and Attenuation in Tuff, Sandstone, and Granite" (Haupt et al.) was prepared for the the 33rd U.S. Symposium on Rock Mechanics to be held June 8-10, 1992, in Santa Fe, New Mexico.

An abstract entitled "The Influence of Strain Rate and Sample Inhomogeneity on the Moduli and Strength of Topopah Spring Member Tuff" (Price et al.) has been submitted and accepted for presentation at the 1992 AGU Spring meeting on May 11-16, 1992, in Montreal, Canada.

Two reports entitled "Anisotropy of Topopah Spring Member Welded Tuff" (Martin et al.) and "Experimental Comparison of Laboratory Techniques in Determining Bulk Properties of Tuffaceous Rocks" (Boyd et al.) have been written and are in SNL review.

2.2.11.4 Study 8.3.1.15.1.4 - Laboratory determination of mechanical properties of fractures

The YMPO review of Study Plan 8.3.1.15.1.4 was completed on February 5, 1992.

Several SNL staff members comprise the Fracture Properties Working Group. This group met four times during the last six months to discuss testing plans and progress. One meeting included discussions with staff at the University of Colorado on the role of fractal mathematics in characterizing/modeling fracture surface changes with shear displacement.

Activity 8.3.1.15.1.4.1 - Mechanical properties of fractures at baseline experiment conditions. Detailed characterization and analysis of fracture surfaces will aid in the interpretation of mechanical properties (normal and shear stiffness and frictional shear strength) and transport properties (fluid and solute transport). A project to determine the variability of the roughness and the degree of mismatch of the surfaces of natural fractures is ongoing. The topographies of seventeen natural fractures from various rock types (including tuff from Yucca Mountain) were profiled and analyzed by SNL staff. These data have been compiled and are being included in a report with a simple mathematical model of rough fractures.

Rotary friction has been chosen as the test technique to gather the majority of the data on the mechanical properties of fractures. As a result, the existing laser profilometer system (profiler and software) has been adapted to profile circular samples, as are used in rotary friction experiments.

Activity 8.3.1.15.1.4.2 - Effects of variable environmental conditions on mechanical properties of fractures. The mechanical properties of relatively smooth (or artificial) fractures are most readily described by the simple expression of Amonton's law, an expression with linear coupling of normal stress to shear stress: $t = ms$ (t is the shear stress parallel to the fracture, s is the normal stress across the fracture, and m is called the coefficient of friction). A study is in progress that begins to address whether other variables (e.g., time-of-stationary contact, velocity of sliding, degree of saturation, temperature, and history) are important for inclusion into stability analysis, or whether the simple formulation of Amonton's law is sufficient for most modeling efforts. The preliminary results indicate that these other variables produce second-order effects and may not be needed for stability analyses. Future studies will expand this work to include characterizing and testing relatively rough (or natural) fractures.

2.2.11.5 Study 8.3.1.15.1.5 - Excavation investigations

NRC review of Study Plan 8.3.1.15.1.5 has been deferred pending DOE's evaluation of the new ESF configuration on the planned tests. Activity associated with the revision of Appendix B of the current ESF Design Requirements (ESFDR) and Test Planning Package 91-5 for the experiments covered in this study has been completed.

2.2.11.6 Study 8.3.1.15.1.6 - In situ thermomechanical properties

Activities associated with the revision of Appendix B of the current ESFDR and Test Planning Package 91-5 for the experiments covered in this study have been completed. A study was begun to develop test instrumentation that can survive the hot thermal environment proposed for the in situ thermomechanical experiments.

2.2.11.7 Study 8.3.1.15.1.7 - In situ mechanical properties

Activities associated with the revision of Appendix B of the current ESFDR and Test Planning Package 91-5 for the experiments covered in this study have been completed.

2.2.11.8 Study 8.3.1.15.1.8 - In situ design verification

YMPO review comments on Study Plan 8.3.1.15.1.8 were received on October 10, 1991, and are being resolved. Responses to approximately half of the comments have been developed. Additionally, as a result of the revised ESF design, substantial portions of this Study Plan are being revised.

Activity associated with the revision of Appendix B of the current ESFDR and Test Planning Package 91-5 for the experiments covered in this study has been completed.

2.2.11.9 Study 8.3.1.15.2.1 - Characterization of the site ambient stress conditions

NRC review of Study Plan 8.3.1.15.2.1 was deferred pending DOE's evaluation of the new ESF configuration on the planned tests.

2.2.11.10 Study 8.3.1.15.2.2 - Characterization of the site ambient thermal conditions

No progress during the reporting period due to lack of funding.

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. Storms during October 1991 through January 1992 were not severe at Yucca Mountain or in the surrounding region, and as a result, there was no surface runoff or flooding. A period of increased storm activity began in early February 1992 and continued intermittently through March 1992. Several regional storms caused widespread precipitation over the Yucca Mountain region, and the lower Amargosa River flowed to Death Valley at least four times during this period; however, the rainfall was not intense or prolonged enough to cause flooding at Yucca Mountain. In fact, small amounts of runoff only occurred once in Yucca Wash and in Fortymile Wash at the Narrows. Other Yucca Mountain streams did not flow at all. Las Vegas has had several episodes of minor flooding related to these winter storms. Storm runoff data collected during the summer of 1991 were processed and submitted to the Local Records Center.

The Probable Maximum Flood (PMF) investigation, being conducted by the USBR, continued on schedule. A draft report listing PMF flows of clear water for drainages that include proposed surface facilities has cleared internal review. Flows have since been adjusted to include sediment movement, and maps are being proposed to show potential zones of inundation near planned surface facilities.

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.

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.

2.2.13 Preclosure tectonics (SCP Section 8.3.1.17)

2.2.13.1 Study 8.3.1.17.1.1 - Potential for ashfall at the site

No progress during the reporting period due to lack of funding.

2.2.13.2 Study 8.3.1.17.2.1 - Faulting potential at the repository

Activity 8.3.1.17.2.1.2 - Assess the potential for displacement on faults that intersect underground facilities. An initial scoping analysis of the potential for movement along faults in the repository block as a result of repository heating has been completed and documented. The preliminary results

indicate there is little likelihood of fault slip resulting from the stress changes that occur during repository heating and cooling.

2.2.13.3 Study 8.3.1.17.3.1 - Relevant earthquake sources

Study Plan 8.3.1.17.3.1 was revised in response to YMPO review comments and received DOE approval. The Study Plan was sent to the NRC on January 16, 1992. This study is not funded during FY 1992.

2.2.13.4 Study 8.3.1.17.3.2 - Underground nuclear explosion sources

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

2.2.13.5 Study 8.3.1.17.3.3 - Ground motion from regional earthquakes and underground nuclear explosions

Study Plan 8.3.1.17.3.3 has been reviewed by the YMPO and comments were sent to the Principal Investigator on February 27, 1992. Incorporation and resolution of comments has been initiated.

Activity 8.3.1.17.3.3.2 - Select or develop empirical models for ground motion from underground nuclear explosions. Data collection efforts for this activity were halted because of reductions in funding. However, a small effort has been ongoing to modify the canisters used for emplacing accelerometers downhole for monitoring of underground nuclear explosions (UNEs). The modifications will facilitate accurate placement and orientation of accelerometers, which should improve the accuracy of data obtained, should downhole seismic data become a YMP priority again in the future.

Plans have been developed to analyze data more completely on UNE-generated ground motions. A statistical analysis and an evaluation of travel-path effects and differences between surface and subsurface ground motions have been initiated. The primary prerequisites for both analytical categories are software quality assurance requirements for all computer software to be used. The process has begun, but progress has been slow because funding levels have limited staff to low levels of effort.

A Problem Definition Memo (PDM) that describes the tasks to be performed to accomplish statistical analyses of UNE-generated ground-motion data at Yucca Mountain was developed and approved. The three tasks in the PDM are (1) comparison of data collected under rigorous QA controls to older data; (2) revision of regression equations to incorporate magnitude (rather than yield) as the independent variable; and (3) comparison of ground-motion data as a function of UNE location. If favorable results are achieved with the comparison of old and new data, limiting or eliminating future data gathering may be reasonable options.

2.2.13.6 Study 8.3.1.17.3.4 - Effects of local site geology on surface and subsurface motions

Study Plan 8.3.1.17.3.4 was revised in response to YMPO review comments and received DOE approval. The Study Plan was sent to the NRC on December 4, 1991. This study is not funded during FY 1992.

2.2.13.7 Study 8.3.1.17.3.5 - Ground motion at the site from controlling seismic events

YMP review comments on Study Plan 8.3.1.17.3.5 were received in early March 1992. Responses to these review comments are currently being prepared. This study is not funded during FY 1992.

2.2.13.8 Study 8.3.1.17.3.6 - Probabilistic seismic hazards analysis

No progress during the reporting period due to lack of funding.

2.2.13.9 Study 8.3.1.17.4.1 - Historical and current seismicity

Activity 8.3.1.17.4.1.2 - Monitor current seismicity. Continuous monitoring of the 55-station Southern Great Basin Seismic Network (SGBSN) continued with minimal downtime during the last six months.

A transition plan was agreed on to transfer the SGBSN operation to the University of Nevada-Reno Seismology Laboratory (UNRSL) during FY 1992. Programmatic responsibility will remain with the USGS. A joint earthquake catalog will be produced by the USGS and UNRSL for calendar year 1992.

The upgrade to the SGBSN was suspended so that efforts can be concentrated on the transition plan. A reevaluation of the future of the upgrade will take place later this fiscal year.

2.2.13.10 Study 8.3.1.17.4.2 - Location and recency of faulting near the prospective surface facilities

Responsibility for Study 8.3.1.17.4.2 was transferred to the USGS from SNL at the beginning of FY 1992. The Study Plan was revised to reflect the change in organizational structure.

Activity 8.3.1.17.4.2.1 - Identify appropriate trench locations in Midway Valley. Work proceeded on synthesizing data collected during the summer of 1991 from Trench A/BR-3 to the north of Exile Hill within Midway Valley. Details of excavation and initial findings for this trench were presented in PR #5. This work is being compiled by Geomatrix Consultants, Inc., in a report to be presented to the USGS.

A paper entitled "Recent Characterization Activities of Midway Valley as a Potential Repository Surface Facility Site" (Gibson et al., 1992) was presented at the Waste Management '92 Conference in Tucson, Arizona, in March

1992. The paper summarizes much of the surficial mapping reported in Wesling et al. (in prep). The distribution and description of surficial units, including deposits, soils, and geomorphic surfaces, are outlined in this paper. A second paper entitled "Preclosure Seismic Hazards and Their Impact on Site Suitability of Yucca Mountain, Nevada" (Gibson) will be presented at the IHLRWM Conference in Las Vegas in April 1992. This paper presents recent calculations of expected seismically-induced ground motion and surface ruptures at Yucca Mountain and the impact of these hazards on the suitability of Yucca Mountain as a high-level nuclear waste repository. The first of these papers was also presented as a poster session while the second will be presented orally.

An abstract entitled "Recent Developments Affecting Preclosure Seismic Hazards Assessment for the Potential Nuclear Waste Repository at Yucca Mountain, Nevada" (Gibson, 1991) was presented at at the GSA annual meeting in October 1991.

Details of progress on the Midway Valley work were presented to the NWTRB in Irvine, California, on January 22, 1992. This presentation was one of several to inform the NWTRB of recent progress in seismic hazard evaluation for the Yucca Mountain site.

New field work during the second quarter of FY 1992 has included the excavation of nineteen soil pits, fourteen of which are stratigraphic soil pits to confirm preliminary mapping, while the remaining five are along the trend of the proposed long trench east of Exile Hill.

Activity 8.3.1.17.4.2.2 - Conduct exploratory trenching in Midway Valley. Mapping of an exploratory trench (Trench A/BR-3) across two vegetation lineaments coincident with the mapped trace of the Bow Ridge Fault has been completed. A draft of the basic data report describing the geologic interpretation of Trench A/BR-3 was prepared and submitted for technical review. Results of this trenching were presented at the NWTRB's Panel on SG&G Meeting on January 22, 1992.

Excavation and logging of test pits in Midway Valley was initiated in March 1992. A series of five pits were excavated along the proposed alignment of the continuous trench east of Exile Hill and field examination was begun to provide stratigraphic information at the Reference Conceptual Site for the prospective surface facilities and to provide geologic and geotechnical information for planning the continuous trench. All mapping, soil test pits, and trenching, in the proposed staging area for the ESF immediately east of Exile Hill are scheduled to be complete by November 1992. Soil pits were also initiated to characterize the deposits and soils associated with preliminary principal surficial map units. This work was being done concurrently with the soil pits for the planned continuous trench in the ESF staging area. Work descriptions were prepared for additional soil pits, exploratory trenches, and continuous trenching, which will be initiated during the latter part of FY 1992.

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 submitted to the YMPO for review in March 1992.

Activity 8.3.1.17.4.3.2 - Evaluate Quaternary faults within 100 km of Yucca Mountain. Work began on reviewing, synthesizing, and compiling existing data to fully determine their usefulness, applicability, and quality. A computerized Quaternary fault and reference data base was developed and data entry started. Initial conclusions from the review and synthesis were that although the general distribution of Quaternary faults is well known, there is very little data on the recurrence, slip rate, age of most recent faulting or other information required for either a deterministic or probabilistic seismic hazard evaluation. A field reconnaissance was conducted to familiarize staff with major regional faults. Two possible trench sites were identified on the Bare Mountain fault, approximately 14 km from Yucca Mountain.

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 and is ready for internal USGS review.

Activity 8.3.1.17.4.4.1 - Evaluate the Rock Valley fault system. Aerial photographs and satellite imagery were ordered in anticipation of field work to begin late in the fiscal year.

2.2.13.13 Study 8.3.1.17.4.5 - Detachment faults at or proximal to Yucca Mountain

All comments on Study Plan 8.3.1.17.4.5 were resolved and the revised Study Plan was returned to YMPO for approval on March 25, 1992.

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. A scoping study on conodont alteration in possible lower plate rocks was initiated.

Activity 8.3.1.17.4.5.2 - Evaluate postulated detachment faults in the Beatty-Bare Mountain area. No technical progress as new personnel completed QA indoctrination and training.

2.2.13.14 Study 8.3.1.17.4.6 - Quaternary faulting within the site area

Study Plan 8.3.1.17.4.6 received NRC acceptance October 3, 1991. One general concern with respect to map scales to be used in the study was linked by NRC to SCA Question 1. DOE responded in a letter dated November 4, 1991, and provided an explanation on the Study Plan as well as the SCA Question 1 open-item.

Activity 8.3.1.17.4.6.1 - Evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain. Progress was made on the strip map of Quaternary faults in the Yucca Mountain area and a draft report was completed on the left-lateral motion exhibited by these faults. A reconnaissance study of the Paintbrush Canyon Fault was presented in "Quaternary Movement on the Paintbrush Canyon-Stagecoach Road Fault System" (Whitney and Muhs, 1991).

Activity 8.3.1.17.4.6.2 - Evaluate age and recurrence of movement on suspected and known Quaternary faults. Several trench sites were selected for excavation this fiscal year on the Paintbrush Canyon-Stagecoach Road fault system, and one site was selected on the Solitario Canyon fault. Several older trenches were also selected for detailed relogging.

A technical procedure on the geophotogrammetric mapping of trench walls was written and approved. The technique was used to record geologic information on the exposed walls in Trench 14 that were deepened in 1991.

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 activity.

2.2.13.16 Study 8.3.1.17.4.8 - Stress field within and proximal to the site area

No progress during the reporting period due to lack of funding.

2.2.13.17 Study 8.3.1.17.4.9 - Tectonic geomorphology of the Yucca Mountain region

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

2.2.13.18 Study 8.3.1.17.4.10 - Geodetic leveling

Study Plan 8.3.1.17.4.10 received NRC acceptance October 4, 1991. No progress during the reporting period due to lack of funding.

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 activity.

2.2.13.20 Study 8.3.1.17.4.12 - Tectonic models and synthesis

A draft of Study Plan 8.3.1.17.4.12 was written and received two informal reviews. The Study Plan is scheduled to be revised and submitted for USGS review in the fourth quarter of 1992.

Activity 8.3.1.17.4.12.1 - Evaluate Tectonic processes and Tectonic stability at the site. Steps were initiated to obtain specially enhanced thematic mapper images of the region that clearly discriminate rock types and can be used to guide future detailed field studies.

2.3 REPOSITORY OVERVIEW

2.3.1 Geomechanical analyses (Section 8.3.2.1.4.1)

An important component of the YMP involves the development of constitutive models capable of analyzing the responses of jointed rock masses, which are representative of the potential waste repository site at Yucca Mountain, Nevada. Current compliant joint models represent state-of-the-art analysis capabilities. These models were incorporated into computationally efficient computer codes providing a unique capability for simulation of large-scale field problems. Efforts to improve both the capability and efficiency of the models and codes are ongoing.

A report entitled "JAC3D: A Three Dimensional Finite Element Computer Program for the Nonlinear Quasi-Static Response of Solids with the Conjugate Gradient Method" (Biffle) completed technical and management reviews within SNL and is being prepared for policy review. It is expected that this code will form the backbone of the structural analyses to be performed for the YMP in support of ESF Title II design. The computer program is vectorized to perform efficiently on the CRAY-YMP.

SNL, in conjunction with staff at the University of Minnesota, have begun preliminary work on the development of a linked-boundary-element/finite-element computer model for analyzing thermomechanical problems associated with the design and performance of a potential nuclear waste repository. The linkage with an infinite boundary element domain will allow the finite-element portion of the analysis to focus on the near-field (detailed) aspects of a given problem, while ensuring that more realistic far-field effects are properly accounted for using the boundary-element code. To date, efforts have concentrated on combining a boundary-element computer program, developed previously for calculating thermally-induced displacements and stresses, with an existing boundary-element method for elastostatics to solve general thermoelasticity problems. The combined boundary-element method, when integrated into the finite-element program JAC, will form the foundation of a hybrid program that will satisfy both the thermal and mechanical boundary conditions at the interfaces between the finite-element domain and the boundary-element domain.

Work on a series of numerical analyses of a series of laboratory experiments being performed under WBS 1.2.4.2.1.2 was initiated. The analyses are intended to help evaluate and validate joint models. Pretest analyses of a layered model have been completed and the results are currently being studied and evaluated. The model was loaded to approximately 1000 psi and obtained joint slips in the range of 4.0×10^{-2} mm or 0.04 mm. This work is being summarized into a paper for the ISRM Regional Conference on Fractured and Jointed Rock Masses, to be held in early summer.

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.

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.

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.

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.

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.

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.

2.4.1.4 Design Activity 1.11.1.4 - Preparation of reference properties for the reference information base

Work was initiated on the evaluation of "raw" sources of fracture data in an attempt to identify and define fracture spatial orientations and relative abundances. From this information, rock qualities and rock mass rating can be determined for input to the RIB. For units down to and including the Calico Hills nonwelded unit, spacing and orientation of fractures have been determined and analyzed. Using this and other information, rock quality ratings for each unit were developed. This work is being documented in "Fracture Analysis and RQD Estimation for the Yucca Mountain Site Characterization Project" (Lin et al.). Preliminary results from this effort have been presented to the ESF design team.

Work was initiated on the assessment of rock mass properties. Using data sources, such as the RIB, and output from the fracture analyses described above, properties such as rock-mass strength and modulus have been determined

primarily through the application of empirical methods described in "Drift Design Methodology and Preliminary Application for the Yucca Mountain Project" (Hardy and Bauer, 1991). Properties have been evaluated for thermal/mechanical units down to and including the Calico Hills nonwelded unit. This work is being documented in "Rock Mass Mechanical Property Estimations for the Yucca Mountain Site Characterization Project" (Lin et al.). Output from this study will also be incorporated into the RIB. Preliminary results from this effort have been presented to the ESF design team.

2.4.1.5 Design Activity 1.11.2.1 - Compile waste package information needed for repository design

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

2.4.1.6 Design Activity 1.11.3.1 - Area needed determination

No progress during the reporting period due to lack of funding.

2.4.1.7 Design Activity 1.11.3.2 - Usable area and flexibility evaluation

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

2.4.1.8 Design Activity 1.11.3.3 - Vertical and horizontal emplacement orientation decision

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

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.

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.

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.

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.

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.

2.4.1.14 Design Activity 1.11.5.1 - Excavation methods criteria

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

2.4.1.15 Design Activity 1.11.5.2 - Long-term subsidence control strategy

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

2.4.1.16 Design Activity 1.11.6.1 - Thermal loading for underground facility

A report entitled "Equivalent Energy Density Concept: A Preliminary Reexamination of a Technique for Equating Thermal Loads" (Ryder) completed SNL's internal technical and management reviews and was sent to the YMPO for policy review. The report documents the results of a study that addresses the thermal design problem of bounding induced thermomechanical responses over the expected ranges of waste stream characteristics (fuel age and burnup). Near- and far-field results are presented for baseline thermal loadings of 57 and 80 kw/acre (based on the layout described in the Site Characterization Plan--Conceptual Design Report (SCP-CDR)).

For an oldest-fuel-first receipt scenario, waste stream characteristics (age, burnup, and initial container power output) have been calculated for conceptual drift emplacement container designs being investigated by M&O staff. Based on the No New Orders--Extended Burnup waste projections and a 2010 start date, SNL calculated the waste stream characteristics (age, burnup, and initial container power output) for an oldest-fuel-first receipt scenario to support the CRWMS M&O staff's conceptual drift emplacement container design investigations. The waste stream characteristics were calculated for three sets of waste package configurations: (1) dedicated containers with either 21 pressurized-water reactor (PWR) or 45 boiling-water reactor (BWR) assemblies; (2) hybrid containers holding 15 PWR and 16 BWR assemblies; and (3) hybrid containers holding 19 PWR and 8 BWR assemblies.

A consistent set of three-dimensional calculations of near- and far-field temperature responses to design-basis areal power densities (APDs) of 80, 57, 48, 30, and 22 kW/Acre have been completed. Results were obtained using an analytical model based on a modified version of the potential repository design published in the SCP-CDR. Model assumptions include fully stepped emplacement of spent fuel, segregated emplacement of defense high level waste, and a levelized waste receipt schedule. For APDs of 80, 57, and 48 kW/acre, a 2010 start date was assumed. For loadings of 30 and 22 kW/acre, the emplacement start date was delayed until 2040 and 2070, respectively. These results were presented to the NWTRB in Las Vegas, Nevada, on October 8, 1991. Formal documentation of these results has also been initiated.

2.4.1.17 Design Activity 1.11.6.2 - Borehole spacing strategy

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

2.4.1.18 Design Activity 1.11.6.3 - Sensitivity studies

No progress during the reporting period due to lack of funding.

2.4.1.19 Design Activity 1.11.6.4 - Strategy for containment enhancement

No progress during the reporting period due to lack of funding.

2.4.1.20 Design Activity 1.11.6.5 - Reference calculations

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

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.

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.

2.4.2 Repository design criteria for radiological safety (SCP Section 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.

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

A report entitled "Fault Stress Analysis for the Yucca Mountain Site Characterization Project" (Bauer et al.) completed YMPO review and was submitted to the American Nuclear Society (ANS). The paper will be presented at the IHLRWM Conference in April 1992 in Las Vegas, Nevada.

Work on a series of laboratory experiments continued. Results are intended to be used to help evaluate and validate joint models. The initial experiments are made for a stack of plates of Lexan with a centrally located hole. The plates are loaded perpendicular to the stacking and displacements are tracked and measured using Moire grid techniques. Preliminary experiments

have been completed and analysis of the results is forthcoming. Experimental results to be used as input to analyses being performed in WBS 1.2.4.2.3.1 have been completed. Work continued on analyses of the heated room experiment in support of the ESF design effort. The analysis work has been slowed to complete software QA requirements.

Analyses examining the temperatures, stresses, and strains expected in the vicinity of ESF openings that may become part of the potential repository have been initiated based on an updated layout. The analyses concentrate on quantifying the effects that would be expected for design-basis areal power densities of 57 and 80 kW/acre. Preliminary results for this effort have been presented to the ESF design team.

A report entitled "Drift Design Methodology and Preliminary Application for the Yucca Mountain Project" (Bauer et al.) was drafted and submitted for peer review. In addition, "Rock Mechanics Aspects of Design of a Licensed Nuclear Waste Repository in Hard Rock" (Bauer (SNL) and Hardy (Agapito and Associates)) completed all reviews and was submitted to the meeting organizers of the 33rd U.S. Rock Mechanics Symposium to be held in Santa Fe, New Mexico, in June 1992. Both papers will be presented at a workshop entitled "Geotechnical Design."

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.

2.4.4 <u>Preclosure design and technical feasibility (SCP Section 8.3.2.5)</u>

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.

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.

2.4.4.3 Design Activity 4.4.4.1 - Repository design requirements (RDR) for license application design

Discussions were held with several key staff of the M&O to initiate better integration of thermal and mechanical preclosure performance analyses for the ESF.

In response to the NWTRB comments during the meeting on testing in June 1991, initial contacts were made with the lead investigators in the Canadian Waste Program at the Underground Research Laboratory. An initial technical exchange with the Canadians was carried out in March 1992.

SNL staff and contract support from ITC and Agapito and Associates attended and made presentations at the NWTRB meeting in November 1991. The focus of this meeting was the repository sealing program.

A report entitled "A Summary of the ESF Alternatives Study" (Costin et al.) was submitted for YMPO review. The paper will be presented at the IHLRWM Conference in April 1992. This paper summarizes the conduct of the ESFAS.

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

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

2.5.1.2 Design Activity 1.12.2.2 - A degradation model for cementitious materials emplaced in a tuffaceous environment

The primary efforts completed during this reporting period were hydrothermal experiments on samples of high-silica concrete and grout and numerical analyses, which were performed to simulate the products of the laboratory experiments.

This work was performed to support the YMP repository sealing program. Cementitious materials, together with other materials, are being considered to seal the potential repository at Yucca Mountain. A concern with the cementitious materials is the chemical and mineralogic changes that may occur as these materials age while in contact with local groundwaters. The work reported here was a combined theoretical and experimental approach to determine the ability to theoretically predict mineralogic changes. Samples of the cementitious materials were treated hydrothermally at 200°C with water similar to that obtained from well J-13 on the NTS. Post-test solutions were analyzed for pH as well as dissolved K, sodium (Na), Ca, aluminum (Al), and silicon (Si). Solid phases were also characterized. These findings were compared with the predictions made by the geochemical modeling code EQ3NR/EQ6 (Wolery, 1983). It was concluded that the experimental results combined with the theoretical calculations can provide an effective tool in predicting the long-term stability of cementitious materials. However, the model can only yield useful long-term predictions if the scenario modeled is realistic. The results from this work were presented at the 1991 Materials Research Society annual meeting in Boston, Massachusetts, in December 1991. The title of the paper is "The Hydrothermal Stability of Cement Sealing Materials in the Potential Yucca Mountain High-Level Nuclear Waste Repository" (Krumhansl et al., 1991).

2.5.1.3 Study 1.12.2.3 - In situ testing of seal components

A first draft of the field test definition report was completed. The primary focus of the work was the preparation of a report that defines and describes tests to evaluate the performance of sealing components. The basis

for selecting field tests was the performance and emplacement uncertainties defined in the SCP. The report contains the following: a discussion giving the basis for testing; a description of test area locations; a summary of the applicable hydrologic and geophysical techniques that can be used in the field testing effort and a summary of the seal component test (including a basic description of the test, the basic layout and important parameters, fielding of the test, and miscellaneous requirements test summaries), numerical analyses to support the field tests, and safety and QA requirements.

In addition to this work, two papers were prepared on the field testing program for presentation at the IHLRWM Conference during April 1992 in Las Vegas, Nevada: "Proposed Sealing Field Tests for a Potential High-Level Radioactive Waste Repository" (Fernandez et al.) and "Supporting Hydration Calculations for Small- to Large-Scale Seal Tests in Unsaturated Tuff" (Case et al.).

2.5.1.4 Design Activity 1.12.4.1 - Development of the advanced conceptual design (ACD) for sealing

Design Subactivity 1.12.4.1.1 - Define subsystem design requirements. Two efforts continued at a low level of effort during this period. These efforts were development of a strategy to seal exploratory boreholes, which includes the development of requirements for sealing boreholes, and the development of requirements to emplace sealing components.

In the first area, presentations on a borehole sealing strategy were prepared and presented to the NWTRB on November 12-13, 1991. These presentations were "Overall Approach and Performance Calculations," "Selected Design Calculations," "Technologies to Seal Boreholes," and "Overall Strategy."

The report that will present the strategy to seal boreholes, including all performance and design calculations, will be prepared in the second half of FY 1992.

In the second area, presentations on sealing underground openings were prepared for the NWTRB meeting. These include presentations on backfilling underground openings, placement of specialized sealing components, and shaft and ramp seal. The preparation of an SNL report presenting this information is currently under way and a draft is expected to be completed by the end of FY 1992.

Design Subactivity 1.12.4.1.2 - Perform trade-off studies to support advanced conceptual design development. Work was performed in two major areas. The first area involved a review of suitable computer codes that can be used in the sealing program. The second area involved performing numerical analyses to support current activities.

In the first area, a letter report was completed on Phase I of the "Plan for Sealing Code Development." This involved identification of codes that could be used to assess the performance of sealing components. To complete this assessment, different processes were assumed to affect the performance of the sealing components. These processes directed the types of codes for which

a literature search was warranted. The ultimate objective in the screening process was to select two or three highly capable codes in selected areas, such as mechanical and flow transport. In general, the results of this effort indicated that ample codes exist for modeling the primary processes in the sealing program. However, some modifications to existing codes may have to be performed. For the minor processes of interest, few codes currently exist.

In the second area, a number of numerical analyses were performed. These included evaluations of water flow through a backfilled drift, thermo-mechanical analysis of a grouted fracture, and seismic analysis of sealing components.

Preliminary numerical analyses involving water flow through a backfilled drift were completed. Two discrete analyses were performed. The first analysis involved flow through a drift backfilled with a material simulating a coarse rockfill and will determine the lateral extent of flow in the drift assuming that only coarse material is in the drift. The second analysis involved water flow through a backfilled drift having two different materials. Flow first occurs through a coarse backfill and then through a finer backfill. This analysis provides an estimate of how effective the contrast of materials would be on reducing the lateral extent of water flow.

The results for the first analysis was that the maximum extent of significant migration is predicted to occur over a distance of 220 m. The results of the second analysis indicated that a simple material contrast from a material having a saturated hydraulic conductivity (K_{sat}) of 10^{-1} cm/s to a material having a K_{sat} of about 10^{-4} cm/s could reduce the lateral migration of by one order of magnitude. These preliminary analyses are completed and will be reported in the field test definition document for sealing components.

Numerical analyses were also performed to determine the strength requirements for grouted fractures. Grouting in welded tuff may be used for treatment of the modified permeability zones around shafts, ramps, below seepage control structures, and around exploratory boreholes. The cases that were therefore evaluated included (1) an exploratory borehole, (2) seepage control structure in the mains and in the repository periphery, (3) a bulkhead in a panel, (4) a shaft plug at the repository horizon (vertical fractures oriented parallel to the shaft axis), (5) a shaft plug at the Topopah Spring-Paintbrush Members contact, and (6) a shaft station plug at the repository horizon (vertical fractures oriented perpendicular to the tunnel axis). In comparing the preliminary results of the analyses, clearly the higher thermal environment at the repository horizon of the exploratory borehole or the panel bulkhead results in the worst-case thermal stresses.

Evaluations also began on the seismic evaluation of sealing components to determine seismic considerations in assessing the performance of the sealing components. Four areas of evaluation were initiated: (1) define equivalent static and dynamic loads using a simple harmonic wave for dynamic loads, (2) perform analysis of a rigid sealing component, (3) determine the relationship between static and dynamic results as a function of frequency, and (4) establish the critical angle of incidence and peak loads for vertical and horizontal openings.

2.5.1.5 Design Activity 1.12.4.2 - Development of the license application design for sealing

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

2.6 WASTE PACKAGE DESIGN

The waste package consists of the waste form and the container in which the waste form is placed. The waste package design program includes the development of waste package design bases, design analysis, container materials testing, the development of a reference design, waste form testing, and characterization of the waste package emplacement environment. Status of the waste package program is provided in this section.

2.6.1 Post emplacement near-field environment (SCP Section 8.3.4.2)

2.6.1.1 Design Activity 1.10.1.1 - Consideration of 10 CFR Part 60.135 (a) factors

The transition of the EBS concept development lead to the M&O has begun. This effort is to continue throughout FY 1992. The M&O will use the LLNL Systems Engineering approach to concept development, working with LLNL in a team effort.

LLNL staff made a presentation about EBS design to the MRS-MGDS Design Integration Group. The meeting was held in Aiken, South Carolina, on November 14-15, 1991, and was hosted by Duke Engineering. The information exchange resulted in a better understanding of the organizational interactions and design activities.

Comments were resolved on the LLNL input to the Technical Data Base (TDB) Quarterly Report. The LLNL input describes the Geologic and Engineering Materials Bibliography of Chemical Species (GEMBOCHS) data base. The input includes a comprehensive set of references, a data dictionary, and audit tables for the third quarter and for the upgrade. An electronic data base management program, CNGBOCHS, was written, which produces an audit trail of all data base changes, including the review process. The CNGBOCHS process will be illustrated in the next version of the YMP TDB Handbook.

LLNL participated in two technical data meetings in Las Vegas, Nevada, on February 4, 1992. The first meeting addressed the development status of the RIB and the near term engineering/design needs. The second meeting reviewed progress made on the Parameter Normalization task and requested participant comments on the Task Plan, the Parameter Identification listing, and the Data Dictionary format.

LLNL participated with the YMPO at the International Workshop on Engineered Barrier Systems (EBS) in Strasbourg, France on November 2-3, 1991. Belgium, Canada, Finland, Sweden, and Switzerland participated in the workshop convened jointly by the NWTRB and the Swedish National Board for Nuclear Fuel (SKN). The NWTRB noted that the incoming (to the EBS) groundwater chemistry is largely determined by the thermally modified host rock while the exiting

chemistry is determined by aqueous interaction with the EBS materials. The exiting chemistry will have a significant effect on the transport characteristics of the radionuclides.

Proposed resolutions were completed for all comments on the preclosure and postclosure rock characteristics guidelines and this material was sent to reviewers on December 5, 1991. During the week of December 9, 1991, LLNL staff discussed these resolutions with the reviewers to agree upon responses and finalize ESSE text changes. A final mark-up was delivered to Science Applications International Corporation (SAIC) on December 12, 1991. The Preclosure and Postclosure Rock Characteristics Guidelines in the ESSE Report (Final Draft - January 1991) were given a final review and checked against mark-ups developed during resolution of the Peer Review Panel comments.

The paper entitled "Thermal Performance of a Buried Nuclear Waste Storage Container Storing a Hybrid Mix of PWR and BWR Spent Fuel Rods" (Johnson, 1991) was published in December 1991.

2.6.1.2 Study 1.10.4.1 - Characterize chemical and mineralogical changes in the postemplacement environment

LLNL participated in the Geochemistry Integration (GIT) meetings held in Las Vegas on December 4-5, 1991, and February 24-25, 1992. The focus of the meetings were geochemical issues related to system and subsystem performance assessment calculations and future support of GIT.

Activity 1.10.4.1.1 - Rock-water interactions at elevated temperatures. This work was not funded during this reporting period.

Activity 1.10.4.1.2 - Effect of grout, concrete, and other repository materials on water composition. A change request for the SCPB to incorporate Man-Made Materials activities into the Waste Package Environment Testing area was submitted to the YMP CCB. In February 1992, LLNL requested that a technical review be completed prior to completing the CCB process.

Activity 1.10.4.1.3 - Composition of vadose water from the waste package environment. No progress during the reporting period due to lack of funding.

Activity 1.10.4.1.4 - Dissolution of phases in the waste package environment. The paper entitled "Dissolution and Precipitation of Kaolinite at 80°C and pH 3: The Dependence on Solution Saturation State" (Nagy et al., 1991) was submitted to the American Journal of Science in November 1991.

The paper entitled "Dissolution and Precipitation Kinetics of Gibbsite at 80°C and pH 3: The Dependence on Solution Saturation State" (Nagy and Lasaga, 1991) was submitted to Geochimica et Cosmochimica Act in November 1991.

Activity 1.10.4.1.5 - Effects of radiation on water chemistry. No progress during the reporting period due to lack of funding.

Activity 1.10.4.1.6 - Effects of container and borehole liner corrosion products on water chemistry. No progress during the reporting period due to lack of funding.

Activity 1.10.4.1.7 - Numerical analysis and modeling of rock-water interaction. The report entitled "Modeling Fluid-Rock Interaction at Yucca Mountain, Nevada: A Progress Report" (Viani and Bruton) is in internal review.

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. Most of the LLNL hydrology work in this period was in the two-phase fluid system properties activity.

Activity 1.10.4.2.2 - Two-phase fluid system properties. The chemical testing of the high pressure and high temperature system using deionized water at room temperature continued with the system full of water. Water samples have been collected periodically for chemical analysis.

A feasibility study was started using a resonant cavity to measure the relative humidity in rock samples in the laboratory. To achieve this purpose, a resonant cavity has to be extremely small. A prototype resonant cavity of about 1.0 cm in diameter and 2.54 cm in length is under construction. Theoretical analyses have indicated that a resonant cavity of that size may work. If it works, the resonant cavity will be used in the determination of suction potential vs saturation in rock samples as a function of temperature. The calibration measurement is being done.

Work started on the modification of the constant humidity chamber so that feed-throughs can be installed. The feed-throughs are necessary for the calibration of the chamber itself and measurements within the chamber, such as the calibration of a resonant cavity.

Repository and drift scale hydrothermal model calculations investigated the impact of repository-heat-driven hydrothermal flow on hydrological performance. In the analysis, it was found that the vertical relative humidity gradient, which arises due to the ambient geothermal gradient, causes an upward flow of vapor which condenses and drains back down. For example, a net moisture flux of 0.0 mm/yr results in a vertical upward vapor flux of 0.04 mm/yr at the repository horizon and a corresponding downward liquid flux. (Incidentally, these flux conditions result in a repository saturation of 68.8%). For low APDs that do not generate significant boiling effects, the imposed vertical thermal gradient is much greater than the ambient geothermal gradient. Consequently, the repository-heat-driven two-phase counter-current flow system can include a downward liquid flux which is substantially greater than the naturally occurring flux. Therefore, even for low APDs, repository-heat-driven flow of vapor and liquid in fractures may dominate the ambient hydrological system.

Repository scale hydrothermal model calculations investigated the impact of high APDs on the ambient hydrothermal system. Substantial boiling and dry-out benefits can occur. For an APD of 114 kW/acre and 60-year old fuel, repository horizon boiling conditions were calculated to persist for 10,000 years in the center of the repository and for 5,000 years at the outer edge of the repository. Re-wetting of the repository horizon back to ambient saturation requires more than 100,000 years. For a zero net recharge flux,

re-wetting of the dry-out zone occurs predominantly from below the repository horizon as water is imbibed from the saturated zone. This upward flux of liquid in the matrix will tend to transport any radionuclides in the matrix back towards the repository horizon, as long as repository saturations remain below the initial profile which corresponds to gravity-capillary equilibrium. Preferential re-wetting from the saturated zone results in the residual dry-out zone being centered above the repository horizon at 100,000 years in this zero recharge case. For a very large net recharge flux which may be associated with pluvial climatic conditions, rewetting may be dominated by recharge rather than from the saturated zone. However, the duration of boiling conditions was found to be insensitive to the assumed recharge flux (up to a net downward flux of 0.132 mm/yr) and to initial saturation. Repository performance at high APDs is thus less sensitive to hydrogeologic uncertainty and variability than is the performance at low APDs in which boiling and dry-out benefits are insignificant.

The hydrothermal calculations were carried out with significant post-processing assistance. Color contouring programs have been developed which have been useful in plotting dimensionless saturation contour plots of the repository and drift-scale hydrothermal calculations.

An important conceptual point is that boiling and rock dry-out occur because the thermal loading conditions and heat conductance of the dry-out zone can drive heat flow to the boiling front faster than the far-field heat conductance can dissipate it. Therefore, an increase in heat convection within the dry-out zone will tend to enhance the rock dry-out rate, while an increase in far field heat convection will tend to retard the dry-out rate. It was found that even when a very large heat-convection-dominated heat-pipe zone existed in the two-phase zone above the boiling zone, boiling and dry-out performance were not significantly reduced by the presence of the heat-pipe zone. However, heat-convection-dominated heat flow in the far field (beyond the two-phase zone) has the potential of reducing boiling and dry-out benefits.

The insensitivity of the vertical extent of the lower dry-out zone was attributed to two effects. First, the water table in the model is represented as a boundary with fixed temperature, saturation, and pressure. Because the water table behaves like a temperature sink, it enhances far field cooling as the dry-out front approaches the water table, thereby reducing boiling and dry-out effects. Second, location of the water table is fixed. Because the water table is not de-watered in these calculations, it provides an infinite source of water for capillary-driven flow of water back to the dry-out zone. The Equivalent Continuum Model (ECM) assumes that fracture flow will only occur when the bulk saturation of the equivalent medium, S_b, is greater than the critical bulk saturation, S_b^{crit}. For the 100 μm fractures assumed in the ECM, $S_b^{crit} = 98.4\%$. The saturation profile below the repository horizon approaches 100 percent in the vicinity of the water table. The critical bulk saturation, S_b^{crit}, occurs approximately 166 m below the repository horizon. The contribution of fracture flow to capillary driven flow back toward the dry-out zone has the effect of limiting the net dry-out to the region where $S_b < 98.4\%$.

As a result of the analyses of repository-heat-driven hydrothermal calculations, it has been recognized that three critical hypothesis tests can

be used to help focus model validation work and related site characterization activities. The three hypothesis tests are:

1. Does repository heat-driven-hydrothermal flow dominate the ambient hydrological system?

2. Do boiling conditions and rock dry-out effects dominate hydrological performance?

3. Does the dry-out front correspond to the nominal boiling point isotherm and is far field heat flow dominated by heat conduction?

These three hypothesis tests will require large-scale heater tests at multiple hydrostratigraphic horizons within the unsaturated zone at Yucca Mountain or a suitably analogous site, such as Busted Butte. If the answer to each of the three hypothesis tests is yes, then the validation of hydrologic performance models of the site can be greatly focused, thereby enhancing the probability that adequate validation of hydrologic performance models can be achieved.

LLNL comments on the Individual Software Plan (ISP) for the initial qualification of V-TOUGH code have been incorporated and the ISP has been sent out for comment resolution verification.

A pre-processor has been developed which uses the final conditions of the primary variables of a one-dimensional V-TOUGH calculation to create the initial condition input file for a corresponding two-dimensional V-TOUGH model. Another pre-processor was developed which modifies heat and mass generation tables. This modification takes into account the effects of nuclear waste reprocessing on the heat-of-decay characteristics of hybrid waste packages.

A new release for V-TOUGH has been completed which contains the new data base structures for V-TOUGH. V-TOUGH was ported to the new IBM RISC computers recently acquired by the Open Computing Facility (OCF). Regression testing was performed on the SUNs, the NERSC computers, and OCF's IBMs.

Postprocessing and graphics programs have been converted from Sunview to the X-windows graphical user interface system. This was necessary because Sunview will no longer be supported while X-windows is becoming a standard and is available on many different platforms. The capability to plot fluid flow using vectors was enhanced.

LLNL attended the FRACMAN class in Seattle, Washington, on November 18-21, 1991. This course covered discrete fracture analysis. It has a wide range of applications in site characterization and performance assessment, including analysis of fracture data, geological conceptual modeling, pathways analysis, exploration program planning, and flow and transport modeling.

A Golder Associates representative visited LLNL on January 15, 1992, to demonstrate FRACMAN and to discuss the possibility of using FRACMAN to generate discrete fracture meshes that can be used by V-TOUGH. Discussions also covered the implementation of compressible fluid flow into the MAFIC code.

Presentations were made to the NWTRB Thermal Loading panel meeting held in Las Vegas, October 8-10, 1991.

The paper entitled "The Impact of Episodic Nonequilibrium Fracture-Matrix Flow on Repository Performance at the Potential Yucca Mountain Site" (Buscheck et al., 1991) was approved by YMPO on October 28, 1991, and was presented at the XV International Symposium on the Scientific Basis for Nuclear Waste Management in Strasbourg, France, November 4-7, 1991.

The following papers were accepted for the IHLRWM Conference to be held in Las Vegas, April 12-16, 1992: "Characterizing the Altered Zone at Yucca Mountain: The Beginning of a Testing Strategy" (Chesnut, 1992); "The Impact of Thermal Loading on Repository Performance at Yucca Mountain" (Buscheck and Nitao, 1992); "The Implications of Episodic Nonequilibrium Fracture-Matrix Flow on Site Suitability and Total System Performance" (Nitao et al., 1992).

Activity 1.10.4.2.3 - Numerical analysis of flow and transport in laboratory systems. The development of the Nonisothermal Unsaturated Flow and Transport (NUFT) Code continued. Work on linear equation solvers using the Pre-conditioned Conjugate Gradient (PCG) method for both the V-TOUGH and NUFT codes also progressed. First-degree pre-conditioning, using natural ordering of the variables as well as the combinative pre-conditioning scheme, has been implemented and testing was begun.

Modifications have been made to V-TOUGH which allow for an alternative means of treating the capillary pressure and relative permeability curves near residual liquid saturation. Capillary pressure and relative permeability curve data are lacking in the vicinity of zero liquid saturation. The modifications allow for a smoother transition to zero saturation, thereby reducing the number of trial iterations the code requires to converge. Through benchmarking, it was verified that the dry-out behavior is insensitive to the code modifications.

Development of a precondition conjugate gradient algorithm (D4DKR) for solving the equations for fluid flow and transport has been completed. This method will allow the simulation of larger problems than the current algorithm used in the V-TOUGH and NUFT codes. Testing began to ensure that the solution is correctly implemented.

2.6.1.4 Study 1.10.4.3 - Mechanical attributes of the waste package environment

Activity 1.10.4.3.1 - Waste package environment stress field analysis. A revised draft of Study Plan 8.3.4.2.4.3, "Characterization of Mechanical Attributes of the Waste Package Environment" was submitted to YMPO following incorporation of resolutions made at the comment resolution meeting. The Study Plan was transmitted by YMPO to DOE/HQ on October 15, 1991, for final verification of DOE/HQ comment resolutions.

LLNL attended the ESSE meeting in Salt Lake City on October 4, 1991. LLNL met with the University of Utah to review the Postclosure Rock Characteristics Guideline Evaluation in the ESSE Report.

Peer Review comments on the ESSE Post Closure Rock Characteristics Guideline were received at LLNL. LLNL participated in the ESSE Working Session in Las Vegas on November 20-22, 1991 (including the Core Team Meeting on November 21) to determine how overlapping comments might be resolved and to propose a course of action to the Core Team for closing the comments on each guideline. This approach was presented to the reviewer for the Rock Characteristics Guidelines on November 27, 1991, and a mutually acceptable closure to these comments was verbally agreed upon.

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. The ESF Test Planning Package and ESFDR input were completed and submitted to LANL in October 1991.

The LLNL-YMP Scientific Investigation Plan (SIP) for Initial Engineered Barrier System Field Tests, NF-1, Rev. 1, was transmitted to YMPO for approval on November 4, 1991.

LLNL staff attended a meeting of the NWTRB Engineered Barriers Panel in Augusta, Georgia, on February 11, 1992, and participated in the SRL tour the following day.

Activity 1.10.4.4.2 - Repository horizon rock-water interaction. No progress during the reporting period due to lack of funding.

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 due to lack of funding.

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 Preliminary Waste Form Characterization Report was sent to YMPO for review on March 4, 1992.

LLNL provided comments on the Pacific National Laboratory (PNL) report (Peer Review Draft - Revision 1) "Incentives for Selection of Spent Fuel for Delivery to the Federal Radioactive Waste Management System - A Preliminary Analysis."

A combined meeting was held on February 10-11, 1992, with LLNL, PNL, and Canadian staff at which the U.S./Canada collaboration agreement (SA-2) was discussed. Overview presentations of the spent fuel activities were given at this meeting.

An overview of the LLNL-YMP Spent Fuel Waste Form activities was given at an NRC Technical Exchange in Pasco, Washington, on February 25, 1992.

Preliminary results of the oxidation, dissolution, and cladding activities/ planning were presented.

The following papers were published during the reporting period: "Characterization of Spent Fuel Approved Testing Material - ATM-104" (Guenther et al., 1991); "Characterization of Spent Fuel Approved Testing Material - ATM-105" (Guenther et al., 1991); "The Impact of Burnup and Fission Gas Release Distributions of the U.S. LWR Spent Fuel Inventory on the Selection of Spent Fuel Test Materials for the U.S. Geologic Repository" (Cunningham et al., 1991); and "Estimating the Time for Dissolution of Spent Fuel Exposed to Unlimited Water" (Leider et al., 1991).

Subactivity 1.5.1.1.2 - Integrate glass waste form information. No progress during the reporting period due to lack of funding.

Subactivity 1.5.1.1.3 - Integrate waste package and repository design information. No progress during the reporting period due to lack of funding.

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. A flow-through test measuring both dissolution rate and streaming potential of a uranium dioxide (UO_2) particle specimen at PNL was terminated at 37 days after Si gel precipitation at the column inlet was observed. A second column, which used a solution containing dissolved silicic acid and $NaHCO_3$, prepared using a modified procedure, continued to operate with no apparent precipitation of Si. Zeta potential of the UO_2 particles appeared to become more negative with time in both test columns as the uranium dissolution rate decreased in response to the presence of Si. Since Si is dissolved as a negative species in these solutions, the results suggested that the observed reductions in uranium dissolution rates may be caused by a mechanism in which the negative Si species are adsorbed on or react with the UO_2 surface. The variable flow-rate tests were continued with generally satisfactory results. The results indicated that the concentrations of U in the flow-through columns are well below saturation and that the measured dissolution rates represent the true kinetic rate constants. Some variable flow-rate tests were continued, but testing emphasis has been changed toward completion of the test matrix provided in the test plan.

At PNL, the test plan for this task includes a test matrix for flow through dissolution tests with spent fuel specimens that covers a range of pH, temperature, carbonate/bicarbonate concentrations, and oxygen fugacity. All planned tests at atmospheric oxygen fugacity were essentially completed. The first two of the planned tests at 1% of atmospheric oxygen fugacity were started; the dissolution rates measured in these low-oxygen tests were much greater than expected. Similar tests with unirradiated UO_2 were initiated to determine whether problems with the experimental apparatus may be causing the unexpectedly high results.

A flow through dissolution test was conducted with ATM-105 spent fuel that had been partially oxidized at 175°C to an average oxygen-to-metal ratio of 2.38 and has a U_4O_9 lattice structure. A flow through dissolution test with an unoxidized specimen of the same fuel also was conducted so that the

dissolution rates of oxidized and unoxidized fuel can be directly compared. Both oxidized and unoxidized specimens were supplied by the Oxidation Task of the Geologic Disposal Support Program at PNL. Available data showed no significant difference in the dissolution rates of U, ^{137}Cs (Cesium-137), ^{99}Tc (Technetium), or ^{90}Sr from the oxidized and unoxidized fuel specimens. Related dissolution tests on unirradiated UO_2 and unirradiated UO_2 oxidized to U_3O_7 at 25°C in a dilute bicarbonate solution have approximately the same dissolution rates.

The room temperature UO_2 dissolution part of the LLNL experimental matrix were completed. A fit of the LLNL data to an empirical polynomial yields an excellent description of the experimental results. However, there are a few discrepancies with the PNL results on UO_2, but in general, there is fair agreement. The difference in dissolution data for replication tests performed at PNL and LLNL was analyzed. These tests were on powdered samples which for flow-through testing can form flow channels, and thereby do not wet the total measured surface area of the sample. This type of error, being assessed at PNL and LLNL, would lead to an inferred dissolution rate that is less than the true dissolution rate. Resolution of the differences for powder data may result in a slight modification in the flow-cell design for the flow-through tests.

As a result of some differences in experimental measurements, LLNL and PNL completed flow-through testing to compare each laboratory's systems (flow cells and pumps) under identical experimental conditions of solution chemistry, flow rate, and powdered UO_2 samples. Preliminary data indicated that results at both laboratories were the same. Also, LLNL explored the possible effect of dissolved oxygen diffusion outward through the polymeric tubing used in its experiments. The original results of the dissolution tests in the argon glovebox exhibited a very weak dependence on the oxygen fugacity in the solution. These oxygen diffusion tests measure the degree of possible oxygen diffusion outward from the solution into the argon atmosphere, and whether it would have a significant effect on the initial data. It was planned to correct this by using impermeable metal tubing or by using the same oxygen fugacity outside the system as is present inside.

A paper entitled "Leaching Patterns and Secondary Phase Formation During Unsaturated Leaching of UO_2 at 90°C" (Wronkiewicz et al.) was submitted to LLNL for technical review.

A paper entitled "Inventories and Dissolution Rates of Soluble Radionuclides from the Grain Inventories of Spent LWR Fuel" (Gray et al., 1991) was presented at the XV International Symposium on the Scientific Basis for Nuclear Waste Management in Strasbourg, France, November 4-7, 1991.

A presentation was made on dissolution testing at the DOE/Atomic Energy of Canada Limited (AECL) meeting held in Pleasanton, California, on February 10-11, 1992, and at the NRC technical exchange in Pasco, Washington, on February 25, 1992.

A paper entitled "Dissolution Rates of As-Received and Partially Oxidized Spent Fuel" (Gray et al.) was submitted to the IHLRWM Conference to be held in Las Vegas in April 1992.

Subactivity 1.5.2.1.2 - Oxidation of spent fuel. The dry bath tests at PNL continue as scheduled. An interim exam was conducted on limited samples at 195 and 175°C. Over 20 spent fuel samples have been mounted and subjected to ceramographic examination. Analyses of image analysis data from spent fuel samples examined in FY 1991 is continuing.

Examination of the data from current and past oxidation tests has indicated that a description of the oxidation process of UO_2 to U_4O_9 lattice structure phase may exist, and may be independent of fuel type. If confirmed, the description would have implications for all phases of the storage and disposal process. The transition of U_4O_9 to higher oxidation phases has not yet been observed at the low temperatures (<200°C) in the oven dry baths. A restart of the TGA oxidation activity will be required to address the oxidation kinetics of the U_4O_9 phase transition to higher oxidation states.

A paper entitled "Grain Boundary Oxidation of PWR Spent Fuel in Air" (Thomas and Einziger) was submitted to Materials Characterization in October 1991.

An abstract entitled "Microstructural Analysis of LWR Spent Fuels at High Burnup" (Thomas et al., 1991) was presented at the XV International Symposium on the Scientific Basis for Nuclear Waste Management in Strasbourg, France, November 4-7, 1991.

A paper entitled "Ceramographic Determination of Spent Fuel Oxidation Rate" (Einziger et al.) was submitted to the IHLRWM Conference to be held in Las Vegas in April 1992.

Subactivity 1.5.2.1.3 - Corrosion of Zircaloy. No progress during the reporting period due to lack of funding.

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 due to lack of funding.

Subactivity 1.5.2.1.5 - Evaluation of the inventory and release of C-14 from Zircaloy cladding. No progress during the reporting period due to lack of funding.

Subactivity 1.5.2.1.6 - Other experiments on the spent fuel waste form. No progress during the reporting period due to lack of funding.

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

Unsaturated testing of West Valley Demonstration Project (WVDP) and Defense Waste Processing Facility (DWPF) Glass

The N2 tests (SRL actinide-doped glass) continued with no sampling period occurring this reporting period. These tests have been in progress for 6.0 years. The N3 tests (ATM-10, a West Valley actinide-doped glass) continued and have been in progress for 4.4 years.

Samples of PNL-76-68, SRL-131, and SRL-165 glasses reacted in water vapor (100% relative humidity) for three years at 75°C were removed from the reaction chamber and were investigated using analytical electron microscopy (AEM). These samples are part of a suite of samples that are being tested to evaluate reaction under conditions likely to be present after containment breach. The questions to be answered are how much reaction will take place and what are the reaction products. The results from this suite of tests can be compared with tests performed at higher temperature to evaluate temperature as a parameter to accelerate the reaction. Preparation began on a paper entitled "Low-Temperature Vapor Alteration of Glass Under Potential Storage Conditions" for inclusion in the Yucca Mountain Project Special Issue of the Journal of Nuclear Materials.

Sections of PNL-76-68 and SRL-131 glass reacted in water vapor have been examined. The SRL-131 glass has reacted about ten times faster than the PNL-76-68 glass. This result is similar to previous results at higher temperature in which PNL-76-68 glass reaction appeared to be inhibited due to the formation of Al-bearing secondary phases which quench the ion-exchange process. At lower temperatures, the secondary phases are not present in sufficient quantity for analysis, but the similarity of low and high temperature relative reaction rates for these glasses implies that the mechanism might be the same.

A paper entitled "AEM Analyses of SRL-131 Glass Altered as a Function of SA/V" (Mazer et al., 1991) was presented at the XV International Symposium on the Scientific Basis for Nuclear Waste Management in Strasbourg, France, November 4-7, 1991.

Static leach testing of WVDP and DWPF glass

No progress during the reporting period due to lack of funding.

Parametric studies of WVDP and DWPF glasses based on the unsaturated test

The paper entitled "Parametric Effects on Glass Reaction in the Unsaturated Test Method" (Woodland et al., 1991) was published in November 1991.

Parametric studies of WVDP and DWPF glasses

The paper entitled "The Hydration of Borosilicate Waste Glass in Liquid Water and Steam at 200°C" (Ebert et al.) was submitted to Waste Management in December 1991.

Subactivity 1.5.2.2.2 - Materials interactions affecting glass leaching. No progress during the reporting period due to lack of funding.

Studies of glass surface layers and precipitation

The following papers were submitted to Physics and Chemistry of Glasses and to the American Ceramics Society, respectively: "The Sorption of Water on Obsidian and a Nuclear Waste Glass" (Ebert et al.) and "Repository Relevant Testing Applied to the Yucca Mountain Project" (Bates).

Geochemical interactions

The final flow-through test series was completed. The glasses reached steady-state behavior after 2-3 weeks. The tests were continued at higher flow rates to insure there was no fluid transport control of dissolution rate. Test results indicated that the SRL-165 glass dissolves at the same rate and with the same pH dependence as our simple (5 component) analogue glass of SRL-165. These results showed that the dependency of dissolution rate on glass composition can be simplified by considering the role of each type of individual element in the glass structure, rather than each element contained in the glass.

Subactivity 1.5.2.2.3 - Cooperative testing with waste producers. No progress during the reporting period due to lack of funding.

2.6.2.4 Activity 1.5.3.1 - Integrate scenarios for release from waste package

A representative from the VTT Technical Research Centre of Finland visited with the Metal Barrier staff on October 3, 1991, and described the program that is being carried out in Finland to dispose of spent nuclear fuel. The Finnish program is investigating five sites, all with granite as the host rock. A multiple barrier approach for the waste package is envisioned with, in one design, a 6cm thick copper overpack surrounding a 5cm thick carbon steel inner barrier. The copper barrier would be electron beam welded for closure, while a mechanical closure is planned for the carbon steel barrier. Some consideration is given to using a 0.1% silver alloyed copper for the outer barrier to improve resistance to creep and to stress corrosion. The corrosion and metallurgical testing program that is underway at the VTT laboratories in Espoo was discussed.

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. DBAPP and DOOUT were used to generate revised suites of thermodynamic datafiles that support the EQ3/6 geochemical software package (version 7.0). These datafiles were then piped through EQPT to generate the corresponding DATA1 suites, which were transferred to the Alliant FX/80 where they can be accessed by local users of EQ3/6. The R12 suite was also forwarded to the Center for Nuclear Waste Regulatory Analyses, Southwest Research Institute, San Antonio, Texas.

The internal conversion of all chemical formulas and other references to chemical elements in GEMBOCHS from the historical convention of uniform lower case to the correct convention of mixed upper and lower case (per definition of the individual elements) was completed. The GEMBOCHS administrator has requested that the EQ3/6 software be modified to allow capitalization of chemical element symbols and species names. The EQ3/6 software is essentially data base driven; however, the source code must be modified to allow capitalization as slightly more than a dozen of the elements and species are special and their names must be embedded in the source code.

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Development and implementation of a new output option for DOOUT was completed that facilitates generation of thermodynamic datafiles from GEMBOCHS that are of appropriate format for use with the GT geochemical modeling package. GT calculations are closely analogous to those performed by the EQ3/6 package; hence, implementation of this new DOOUT output option facilitates valuable comparison of the two packages using identical thermodynamic datafiles.

Extensive restructuring and modification of DBAPP continued. This update is intended to expand the capabilities of the software to facilitate interactive review of all data in the data base, tighten access controls on user modification of data, and broaden the range of information that can be included in the data base.

Work continued on the documents "DBAPP: A FORTRAN-Equel Program that Facilitates Review and Modification of the GEMBOCHS Thermodynamic Database" and "CNGBOCHS: An Automated Ingres-Email-Interleaf Filing System for Change Requests Associated with the GEMBOCHS Thermodynamic Database."

LLNL submitted a TDIF for the "Dissolution and Precipitation Kinetics of Gibbsite at 80°C and pH 3: The Dependence on Solution Saturation State" to the SEPDB Administrator at SNL.

The hard-disk on the Sun server crashed on the weekend of February 15-16, 1992. GEMBOCHS and its associated software were located on that disk. Most of the files were restored from weekly backup tapes, but the data base itself could not be restored from normal backup tapes (an unanticipated problem due to the recent INGRES upgrade). A December 1991 INGRES backup was used for data base restoration. By the end of March 1992, GEMBOCHS and its software library had been restored to their pre-crash state.

"The LLNL GEMBOCHS Database and Software Library: YMP-TDB Quarterly Report" 3rd Qtr., 1991 was submitted to YMPO.

A review was completed of the NEA draft document entitled "A Comparison of Radionuclide Sorption Databases Used in Recent Performance Assessments" (McKinley and Scholtis).

The paper entitled "High-Temperature Spectroscopy for Nuclear Waste Applications" (Grant et al., 1991) was approved by YMPO in September 1991 and was published in October 1991.

YMPO review comments on the paper entitled "Hydrolysis and Carbonate Complexation of Dioxoplutonium (V)" (Bennett et al.) were incorporated and the paper was sent to the YMPO on February 26, 1992.

The report entitled "Chemical Thermodynamics of Technetium V" (Rard) and the paper entitled "Photoacoustic Spectroscopy and the Effect of Amplified Spontaneous Emission (ASE)" (Klunder et al.) were sent to YMPO for programmatic approval in March 1992.

<u>Subactivity 1.5.3.2.2 - Develop geochemical modeling code</u>. The documentation for EQ3/6 was completed this reporting period. The following three reports were completed: (1) The EQ3/6 Package Overview and Installation

Guide; (2) The EQPT User Guide; and (3) The EQ6 Theoretical Manual and User Guide. These documents join the EQ3NR Theoretical Manual and User Guide, which had been completed in August 1991. These documents make up the four volume set of basic documentation for EQ3/6. The four documents cover the theory, mechanics and examples of usage, and software architecture of the codes in this software package.

A standard version numbering system was retrofitted to EQ3/6, so that version "3245.1090" is now version "7.0". The two number systems will coexist through these numbers. Only the new system will be employed for future versions.

Effort focused on the verification and qualification of version 7.0 of EQ3/6. Discussions were held with several parties who will be participating in this effort. These discussions have focused on analysis of the source code, code to code verification, adequacy of the test case library, and review of the draft code documents from technical and QA standpoints. The verification/qualification effort was begun as an independent activity, in the sense that the code author is not directing or conducting it, but is available for consultation, as needed.

The EQ3/6 test case library was updated. This was necessary because EQ6 input files depend on the output of EQ3NR runs, and in some cases the output of other EQ6 runs. Software was written to assist in making the necessary updates, which would have otherwise required extensive editing by hand. Updating of the test library can now be performed routinely. In the course of checking the automatic updating, it was found that in several cases the pickup file produced by EQ3NR had to be modified by hand before it was pasted into the input file for an EQ6 test case in order to activate certain options. This condition defeated the automatic updating software. In such cases, one EQ3NR input file was being used to initialize more than one EQ6 test case. Therefore, to simplify the procedure for updating the test case library, such EQ3NR input files were "cloned" so that any option required for a subsequent EQ6 test case was set on the EQ3NR input file itself. Thus, the option is then automatically set on the resulting EQ3NR pickup file.

Analysis was done on reported bugs in the EQ3/6 package. These reports have resulted from efforts to port the software onto three kinds of hardware; a Silicon Graphics IRIS workstation, a 486-chip PC, and a VAX running the ULTRIX (DEC UNIX) operating system. Most of the reported bugs pertained to ports to the IRIS workstation and the 486-chip PC. Most of these bugs are real, the majority of them involving uninitialized variables and local variables whose values are not saved when execution returns to a calling module. These bugs are not detectable on our "home" machines, an Alliant FX/80 and a Sun SPARC station, due to the overly fault tolerant nature of the system software for compiling and linking/loading. The software package runs correctly on these machines despite these bugs.

A bug was eliminated in the software used to update the test case library. This software is used to update EQ6 test case input files, which depend on previous EQ3NR (or EQ6) runs, and hence on the specific set of data files employed. Three of the test case input files were not being updated properly. This problem was noted when the test case library was updated to

conform with the R10 set of data files. The three problematic files were fixed by hand editing from earlier test runs.

Input was provided to the data base task for changes to the thermodynamic data base in order to minimize potential difficulties in usage with EQ3/6. These changes do not concern the thermodynamic data, but rather which species are treated as basis species (general building blocks in writing reactions) and how reactions are written. This affects the definition of mass balances in EQ3/6. In one example, bicarbonate was being "converted" to organics in EQ3NR calculations for Cigar Lake waters with low Eh. This happened because the bicarbonate balance was being treated as a more general carbon balance. To solve this particular problem, it was decided to use acetic acid as a "gatekeeper" species for all organic species (>80 at present). Entering a zero (or finite) concentration for this one species then allows the correct interpretation of the bicarbonate data. Some similar problems regarding elements other than carbon were similarly addressed.

The technical issues involved in resumption of code development were identified and discussion were held to determine resolutions to these issues. There are two immediate technical issues. The first issue is a set of changes that would coordinate with changes to the thermodynamic data base including using upper and lower case letters to identify chemical species. The second issue concerns the incorporation of an ion exchange submodel into a qualified version of EQ3/6. This submodel has already been developed in a prototype branch version. These issues could be dealt with by extending version 7.0 to version 7.1.

2.6.2.6 Activity 1.5.3.3 - Generate models for release from spent fuel

Subactivity 1.5.3.3.1 - Generate release models for spent fuel models. Data reported for Canadian CANDU fuels have indicated that most of the cesium and iodine fission gas release is in the gap inventory. Although a PNL paper concluded that only about one-fourth of the inventory of cesium fission gas release is in the gap inventory of one U.S. LWR fuel, it is premature to conclude that U.S. fuel cesium and iodine rapid-release inventories are only a fraction of the fission gas release. Measurements on additional fuels are needed before such general conclusions can be supported. These results can be represented by the existing model that relates grain and fragment size statistics to the dissolution response.

The LLNL review comments of the paper entitled "The Impact of Burnup and Fission Gas Release Distributions of the U.S. LWR Spent Fuel Inventory on the Selection of Spent Fuel Test Materials for the U.S. Geologic Repository" (Cunningham) were sent to the author for incorporation into the paper.

The paper entitled "Gap and Grain-Boundary Inventories of Cs, Tc, and Sr in Spent LWR Fuel" (Gray et al., 1991) was approved by YMPO on October 28, 1991, and presented at the XV International Symposium on the Scientific Basis for Nuclear Waste Management in Strasbourg, France, November 4-7, 1991. This paper concluded that the Cs gap inventories for different rods from the Calvert Cliffs No. 1 reactor were only about one fourth of the fission gas release (FGR) over the range 7 to 18% FGR. The Cs grain-boundary inventories for these same rods were generally 1% or less of the total Cs inventory.

Technetium and Sr gap and grain-boundary inventories were less than 0.2%. Sibling samples have been retained for measuring iodine inventories when an inductively coupled plasma/mass spectrometer (ICP/MS) adapted for handling radioactive samples becomes available.

The paper entitled "Dissolution Kinetics of UO_2 Flow-Through Tests on $UO_{2.00}$ Pellets and Polycrystalline Schoepite Samples in Oxygenated, Carbonate/Bicarbonate Buffer Solutions at 25°C" (Nguyen et al., 1991) was presented at the XV International Symposium on the Scientific Basis for Nuclear Waste Management in Strasbourg, France, November 4-7, 1991.

The paper entitled "Microstructural Analyses of LWR Spent Fuel at High Burnup" (Thomas et al.) was approved by YMPO in March 1992 and was submitted to the Journal of Nuclear Materials.

2.6.2.7 Activity 1.5.3.4 - Generate models for release from glass waste forms

Subactivity 1.5.3.4.1 - Generate release models for glass waste forms. The rate constant for SRL-165 glass obtained from the flow-through tests was incorporated into the EQ3/6 glass model. The rate constant was programmed into the code as a function of pH and temperature.

Work continued on developing a calculational methodology for evaluating glass performance in a repository. A calculation of the effect of host rock, metal container, and cement on glass performance was performed using EQ3/6. The calculation showed a small negative effect for cement in the repository due to its reaction with water to increase the pH of the system. Glass dissolution rates increase with pH at high pH conditions.

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. A specification for a simplified source term model was provided to SNL for use in their Total System Analyzer model. The simplified model parameterizes the results of the most important processes affecting the source term, and does not attempt to track finer details. Representative data and draft documentation were provided for a performance assessment by SNL.

A UNIX script was developed to provide source code configuration control and change control for PANDORA, a model designed to produce quantitative source terms for the YMP TSPA model. The script combines options of the UNIX utilities SCCS (source code control system) and MAKE (compile and load the latest version of a program). Features of the YMP-tailored script include: (1) provide source code change control and change documentation; (2) provide a date stamp for the date of latest revisions to appear, and (3) recompile only those subroutines that have been changed since the previous compilation.

The PANDORA source code was shortened to only those subroutines and code sections to be used in the first version to be released. This version will concentrate on waste form alteration, transport to the host rock, and release into the host rock. Other modules will be represented by input data sets only

and will be added back into a later release of PANDORA as input data and supporting documentation have been developed for these modules. The shortened version's internal completeness was checked by a trial compilation and execution.

A prototype PANDORA version with advancements in the waste form alteration and release models has been merged into the main version. A functional and design description was written and reviewed for the merge and testing is in progress. The prototype model uses analytical solutions rather than finite difference solutions and calculates whether to apply the concentration or matrix-limited release control for each radionuclide, as it depends on the inputs and on the time-varying inventories.

LLNL's section of the report entitled "Impacts of New Developments in Partitioning and Transmutation on the Disposal of High-Level Nuclear Waste in a Mined Geologic Repository" (Isaacs) was completed. It includes chapters on Performance Analysis and Heat Effects and contributions from UC Berkeley, PNL and SNL staff.

An LLNL representative attended a performance assessment meeting in Las Vegas on October 29, 1991. YMPO, T&MSS, and M&O staff members were briefed on the Yucca Mountain Integrating Model (YMIM). Written in the computer language C, YMIM runs on a MAC-II using EXCELL for input/output. Results from detailed mechanistic models are input as data tables. YMIM provides a framework to couple the processes and complements PANDORA. Because all mechanistic models may not be used in a given run, YMIM is most useful for sensitivity analyses.

LLNL attended the Systems Analysis meeting in Las Vegas, November 18-20, 1991. Presentations entitled "Overview and Discussion of LLNL System Model" (Lamont) and "Simplified Source Term for Total Systems Performance Assessment" (O'Connell) were made.

A report entitled "Diffusion Releases Through One and Two Finite Planar Zones" (Ueng and O'Connell) is in the LLNL technical review process.

Subactivity 1.5.3.5.2 - Development of uncertainty methodology. The following paper was accepted for the IHLRWM Conference to be held in Las Vegas in April 1992: "Demands Placed on Waste Package Performance Testing and Modeling by Some General Results on Reliability Analysis" (Chesnut, 1991a).

Subactivity 1.5.3.5.3 - Water flow into and out of a breached container. The paper entitled "Physical Limits on Steam Generation by Radioactive Decay Heat" (Chesnut, 1991b) was published.

2.6.2.9 Activity 1.5.4.1 - Deterministic calculation of releases from the waste package

Internal QA grading was completed for Activity I-20-27, Prototype Study of Impact of Unanticipated Events.

PA staff reviewed a section of a draft SNL report on the total system performance assessment carried out through November 1991. The section

reviewed describes the source term model and its input data. LLNL provided additional literature citations for the input used. The LLNL report on the source term model provided to SNL has been edited, preparatory to submittal for internal review.

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 waste package performance assessment has been approved for interim use and has been submitted to YMPO.

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 1992.

Subactivity 1.5.5.1.2 - Radionuclide distribution in tuff cores. Sensitivity factors were measured for uranium in silicate as part of the calibration effort. A non-linearity in the response of the Faraday-cup-detector for the ion microscope was discovered and corrected. Work is proceeding on measurement of uranium and thorium sensitivity factors in an ion-implanted sample of Topopah Spring Tuff.

Technical issues related to the measurement of elemental profiles for alkalis, alkaline earths, and uranium in zeolites and small particles have been identified. Samples of zeolite to be used for elemental depth-profiling studies have been collected and have begun to be characterized by optical and x-ray techniques.

The following technical implementing procedures (TIPs) were completed and distributed:

1. TIP-PA-01, Depth Profiling on the Ion Microscope,
2. TIP-PA-02, Data Reduction for Depth Profiles, and
3. TIP-YM-9, Dektak IIA, Surface Profiling

Work continued on the testing of the flow-through system which is designed to study the transport of dissolved and/or colloidal radionuclides through intact tuff core samples at elevated temperatures. A computerized instrument-control and data acquisition system was tested successfully. Room temperature flow tests were completed with a sample of artificially fractured tuff. Tests of the system at 150°C were completed successfully.

Bulk porosity, pore size distribution, and surface area were measured on samples of tuff wafers and fractured core. The data being reduced is necessary to characterize the physical structure of rocks used in diffusion and flow-through experiments prior to modeling the transport rates measured in these experiments.

Scanning Electron Microscopy (SEM) analysis of the core sample to be used in the initial flow-through experiment showed the natural fracture surface to differ from a non-fracture surface in the amount and distribution of iron-bearing phases and in the morphology of the exposed mineral phases.

The concentration, size, composition, and phase-identity were determined for colloids from waters collected from well J-13 and nearby NTS wells.

An attempt was made to size colloids in the leachate from UO_2 dissolution experiments using photon correlation spectroscopy. It has been determined that further analysis is necessary to determine the composition, identity, and source of the colloids detected.

The paper entitled "Colloid Formation During Waste Form Reaction: Implications for Nuclear Waste Disposal" (Bates et al.) was sent to YMPO with responses to major comments on March 5, 1992. This paper discusses the formation of insoluble Pu and Am-bearing colloidal particles during simulated weathering of a high-level nuclear waste glass. Nearly 100% of the total Pu and Am in test groundwater is concentrated in these submicron particles. Models of actinide mobility and repository integrity which assume complete solubility of actinides in groundwater underestimate the potential for radionuclide release into the environment. These findings underline the need to consider colloid transport and colloid trapping in performance assessments.

Experiments to measure the effect of temperature on the acid/base and uranium adsorptive properties of the iron oxide goethite have been initiated at Stanford University. The experimental set-up for elevated temperature measurements has been fabricated, and acid/base titrations of goethite/water suspensions in the presence of varying levels of electrolyte have been completed at ambient and at elevated temperature. Preliminary interpretation suggests that the surface of geothite becomes more basic with increasing temperature.

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.

2.6.4 Waste package production technologies (SCP Section 8.3.4.4)

No progress during the reporting period due to lack of funding.

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)

Work proceeded at Argonne National Laboratory (ANL) on radiation induced effects in the near field environment and the changes in the performance of the container material. The effort is divided into two parts:

1. Yield of nitrogen oxide/ammonia (NO_x/NH_3) in high water vapor to air systems.
2. Modeling/calculation of radiolytic yields in the waste package.

Drift emplacements were studied to support a repository using 114 kW/acre loadings of 60 year old spent fuel. Such a repository would require only 15% of the footprint of the SCP-CD layout and would remain above the boiling point of water for 10,000 years in the central two-thirds of the repository and for at least 5000 years at the outer edge of the repository. In addition, the repository would remain below ambient saturation for at least 100,000 years based on conservative hydrology calculations.

CAD waste package drawings were generated for the M&O and plans to conduct thermal analyses of robust waste package internals were initiated. These analyses were scheduled to begin before the summer of 1992.

The paper entitled "Corrosion Models for Predictions of Performance of High-Level Radioactive-Waste Containers" (Farmer et al., 1991) was published in November 1991.

The paper entitled "Modeling Pitting Corrosion Damage of High-Level Radioactive Waste Containers Using a Stochastic Approach" (Henshall) was approved by YMPO on February 13, 1992, and will be published in the Journal of Nuclear Materials.

2.6.5.2 Activity 1.4.1.2 - Integrate design and materials information (alternate barriers investigation)

No progress during the reporting period due to lack of funding.

2.6.5.3 Activity 1.4.2.1 - Selection of the container materials for the license application design

Subactivity 1.4.2.1.1 - Establishment of selection criteria and their weighting factors. A more detailed report on the recommendations of materials for advanced study during the ACD design phase was planned. This report will supplement the conference paper entitled "Candidate Materials for Yucca Mountain Waste Package Design" (Clarke et al., 1991), presented at the Focus '91 Nuclear Waste Packaging Conference held in Las Vegas in September 1991. The materials recommended are nickel-base Alloy 825, nickel-base Alloy C-4, and titanium grade 12. These materials are recommended for use as single container materials in the SCP-CD thin-walled container design. Alloy 825 is from the list of six candidate materials, and C-4 and Ti-12 have been added based on quantitative ranking of a large group of materials. Other materials and design configurations will also be studied during ACD.

2.6.5.4 Activity 1.4.2.2 - Degradation modes affecting candidate copper-based container materials

Subactivity 1.4.2.2.1 - Assessment of degradation modes in copper-based materials. No progress during the reporting period due to lack of funding.

Subactivities 1.4.2.2.2 through 1.4.2.2.8 - Laboratory test plan for copper-based materials and Activity 1.4.2.3 - Degradation modes affecting candidate austenitic materials. The paper entitled "Survey of Degradation Modes of Four Nickel-Chromium-Molybdenum Alloys" (Gdowski, 1991) was published in November 1991.

2.6.5.5 Activity 1.4.2.3 - Degradation modes affecting candidate austenitic materials

No progress during the reporting period due to lack of funding.

2.6.5.6 Activity 1.4.2.4 - Degradation modes affecting the ceramic-metal, bimetallic/single metal, or coatings and filler system

No progress during the reporting period due to lack of funding.

2.6.5.7 Activities 1.4.3.1 and 1.4.3.2 - Models for copper and copper-alloy degradation and models for austenitic material degradation

No progress during the reporting period due to lack of funding.

2.6.5.8 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 due to lack of funding.

2.6.5.9 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 failure rate as a function of time

Subactivity 1.4.4.1.1 - Deterministic calculation of rates of container degradation in the repository environment. No progress during the reporting period; this is an out-year activity.

Subactivity 1.4.4.1.2 - Probabilistic calculation of rates of container degradation and distribution of time to initiation of release of radionuclides from the waste packages. No progress during the reporting period; this is an out-year activity.

2.6.5.10 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.

2.6.5.11 Activity 1.5.5.2 - Radionuclide transport modeling in the near-field waste package environment

Subactivity 1.5.5.2.1 - Validation of near-field transport model using laboratory and field experimental data. Work proceeded on characterization of goethite surface chemical properties in the temperature range 25°C to 75°C. The literature search was completed on the adsorptive behavior of goethite at elevated temperatures.

Data were analyzed pertaining to the concentration, size and composition of naturally occurring colloids in J-13 and nearby waters from the NTS.

Subactivity 1.5.5.2.2 - Application of near-field transport model to waste package releases. No progress during the reporting period; this is an out-year activity.

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.

2.7.2 Public radiological exposure - normal conditions (SCP Section 8.3.5.3)

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

2.7.3 Worker radiological safety - normal conditions (SCP Section 8.3.5.4)

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

2.7.4 Accidental radiological release (SCP Section 8.3.5.5)

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

2.7.5 Ground-water travel time (SCP Section 8.3.5.12)

2.7.5.1 Activity 1.6.2.1 - Model development

Subactivity 1.6.2.1.1 - Development of a theoretical framework for calculational models. The development of a mathematical framework for the modeling of groundwater 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. Progress on this topic is reported in Section 2.3.1, 8.3.2.1.4.1, Geomechanical analyses.

2.7.5.2 Activity 1.6.2.2 - Verification and validation

Subactivity 1.6.2.2.1 - Verification of codes

Performance assessment:

The following documents have been published and distributed during the review period: "TOSPAC Calculations in Support of the COVE2A Benchmarking Activity" (Gauthier et al., 1991) and "Groundwater Flow Code Verification 'Benchmarking' Activity (COVE2a): Analysis of Participants Work" (Dykhuzien and Barnard, 1991).

"LLUVIA-II: Program for Two-Dimensional, Transient Flow Through Partially Saturated Porous Media" (Eaton and Hopkins) entered internal technical review. Modifications were made to LLUVIA-II to allow treatment of dipping layers. This was done by allowing rotation on the gravitational vector. Other modifications allow initial conditions to be stated as either effective pressure or pressure head and also allow saturated conductivity to be read from an auxiliary file. All of the modifications will enhance our ability to model effective conductivity in nonhomogeneous media. A unit-pressure-gradient boundary condition option has been added to LLUVIA-II. The use of this boundary condition at the extreme down-dip side of a geologic unit will relax the no-flow condition that is generally applied at this location. Infiltration computations will be repeated with this new boundary condition to help determine the impact of numerical boundary conditions on the calculated results.

LLUVIA-II is being used to aid in the determination of infiltration limits that may cause significant lateral diversion of water in Yucca Mountain. Results have been calculated for infiltration rates between 0.01 and 1.0 mm/yr, and for a five-layer model with a down-dip of 6.25 degrees. Material properties given in a memo from Kaplan et al., dated June 25, 1991, are being used. The results showed that the relative amount of lateral diversion decreased with increased infiltration. These results are contrary to those calculated in the PACE exercise and are a result of the changes in the relative magnitudes of the hydraulic conductivities as the in situ moisture content increases with increasing infiltration rate.

An effort is underway to determine if the graphics package PV WAVE can be used on the SPARC workstations as an alternative to DISSPLA. PV WAVE is more versatile and powerful and, in comparison with DISSPLA, is a much more economical package in terms of costs for site licensing. Recently, a test case was run to compare the results of a NORIA calculation plotted with both packages. PV WAVE was successful in producing comparable results.

A quality action team was formed to evaluate the status of code development activities at SNL. Three subteams were formed to discuss options

to propose for inclusion in the computational development plan. The Model Development subteam discussed which processes require modeling, how well the processes can currently be modeled, and where development is necessary. Plans will be proposed both for near-term (2-3 years) and long-term development needs. The Numerical Methods subgroup have discussed a number of topics, including the benefits of finite-element, boundary-element, and finite-difference methods. The pre- and post-processing subgroup has discussed the relative merits of tools such as FASTQ, BLOT, AVS, XDR, CASE tools, and Informix data bases.

Evaluation of the modified version of the JACQ3D code on a two-dimensional infiltration problem was completed. Results of the study were documented in an internal memo. In summary, for a problem involving infiltration into a rectangular domain composed of heterogeneous material with a uniform initial pressure head, JACQ performed well given a moderately dry initial pressure head (-7.34 m). However, for a case with much lower initial pressure head (-100 m), the CPU requirements became prohibitive, and the run was stopped prematurely. Thus, if the code is to be used on very dry problems, a more robust scheme for solving nonlinear equations is needed. One- and two-dimensional benchmarking problems proposed to evaluate the applicability of COYOTEII to flow problems were also completed and will be documented in an internal memo.

A proposal was submitted to investigate vapor flow through fractured material at Yucca Mountain. The study would consider the effects of barometric pumping, the "Bernoulli effect," and diurnal fluctuations on moisture transport.

Rock mechanics:

Work on a series of laboratory experiments whose results are intended to be used to help evaluate and validate joint models continued. The initial experiments are made of a stack of plates of Lexan with a centrally located hole. The plates are being loaded perpendicular to the stacking and displacements are being tracked and measured using Moire grid techniques. Preliminary experiments have been completed and analysis of the results is forthcoming. Experimental results to be used as input to analyses being performed in WBS 1.2.4.2.3.1 (Rock Mass Analysis) have been completed.

Work on a series of numerical analyses of a series of laboratory experiments being performed under WBS 1.2.4.2.1.2 was initiated and remains ongoing. The analyses are intended to help evaluate and validate joint models. Pretest analyses of a layered model have been completed and the results are currently being studied and evaluated. The model was loaded to approximately 1000 psi and obtained joint slips in the range of 4.0 E-2 mm. This work is being summarized into a paper for the International Society for Rock Mechanics Regional Conference "Fractured and Jointed Rock Masses" to be held in early summer.

Subactivity 1.6.2.2.2 - Validation of models

Unsaturated flow through single fractures:

Experimentation into gravity driven fingering in unsaturated fractures continued. A paper entitled "Gravity Driven Fingering in Unsaturated Fractures" (Nicholl and Glass) was completed for presentation at the IHLRWM Conference in April 1992. Gravity driven fingering is known to occur in both porous media and Hele-Shaw cells. A systematic investigative procedure for studying gravity-driven fingering is described in the paper. As a first step toward understanding this system, experiments were performed in an analogue fracture consisting of two roughened glass plates held in close contact. Result from preliminary experiments are presented, including measurements taken from individual fingers within a fully unstable flow field. Preliminary results imply that increasing the volume of fluid contained in the front leads to increases in both finger width and velocity. Finger velocity was also found to increase with gravitational gradient. Implications of the results are discussed with respect to modeling of unsaturated fractured rock units.

Results of a preliminary validation study for the application of the Reynolds equation to saturated flow in a rough-walled fracture were presented at the Fall 1991 AGU Meeting: "Comparison of Measured and Calculated Permeability for a Saturated, Rough-Walled Fracture" (Glass et al., 1991). Two roughened glass plates (15 x 30 cm) held together at 20 psi formed an analogue rough-walled fracture. Average cross-sectional aperture was measured volumetrically as the fracture was flooded with water. Permeability was measured for Reynolds numbers between 0.3 and 6. Aperture fields were characterized by two independent methods: surface profiling before the test (using a laser profilometer) and light absorption through dyed water during the test (using a digital imaging technique). The Reynolds equation was solved numerically for both statistically generated and measured operative fields at several spatial resolutions. Permeabilities calculated from numerical simulations were compared to those obtained in the laboratory, and a paper will be written describing the comparison.

Fracture matrix interaction:

A paper entitled "Wetted Region Structure in Horizontal Fractures" (Glass and Norton) was completed for presentation at the IHLRWM Conference in April 1992. In the paper, small-scale processes that influence wetted structure within the plane of a horizontal fracture as the fracture wets or drains through the matrix are investigated. Our approach integrates both aperture-scale modeling and physical experimentation. Several types of aperture-scale models have been defined and implemented. A series of physical experimental systems have also been designed that allow the measurement of wetted-region structure as a function of system parameters and water pressure head in analogue fractures. In the preliminary proof-of-concept experiment, hysteresis is clearly evident in the measured saturation/pressure relation, as is the process of air entrapment, which causes a reduction in the connected areas between blocks and the wetted region available for flow in the plane of the fracture. A percolation threshold, where the system is quickly spanned allowing fluid conduction in the fracture plane, is observed which is analogous to that found in the aperture-scale models. A fractal wetted and entrapped-region structure is suggested by both experiment and modeling. This

structure implies that flow tortuosity for both flow in the fracture and for inter-block fluid transfer is a scale-dependent function of pressure head.

Field, lab, and numerical experimentation to determine scaling laws for effective media properties in heterogeneous media:

A paper entitled "Field Research Program for Unsaturated Flow and Transport Experimentation" (Tidwell et al.) was written for presentation at the IHLRWM Conference in April 1992. The paper describes the field research program developed to refine and validate models for flow and transport through unsaturated fractured rock. Validation of these models, within the range of their application for performance assessment, requires a more sophisticated understanding of the processes that govern flow and transport within fractured porous media than currently exists. In particular, our research is prioritized according to understanding and modeling processes that, if not accurately incorporated into performance assessment models, would adversely impact the YMP's ability to evaluate repository performance. For this reason, the field program has been oriented toward enhancing the understanding of scaling processes as they relate to effective media property modeling, as well as to the conceptual modeling of complex flow and transport phenomena.

Work has continued on the gas permeameter which is to be used to collect data for testing effective media property models. Data were analyzed and presented at the Fall 1991 AGU Meeting in "Laboratory Study of the Influence of Measurement Scale on Effective Media Property Estimates" (Tidwell et al., 1991). The validity of models for unsaturated flow and transport through porous media is dependent in part on the accurate estimation of effective media properties. For problems where the scale of application is different than the scale of measurement, intermediate conceptual models or scaling laws must be used to define effective properties at the scale of interest. Although significant efforts have been made in the development of scaling laws, relatively little physical experimentation focusing on model validation has accompanied this process. To address this concern, a gas permeameter has been built that allows rapid, precise measurement of rock permeability at scales spanning four orders of magnitude on a per-volume basis. The permeameter consists of a series of valved flow meters and a pressure gauge connected to a source of nitrogen. A specially adapted nozzle, the diameter of which defines the scale of measurement, is used to establish a known boundary condition on the rock surface. Data are collected from slabs of densely to moderately welded volcanic tuff (measuring approximately 0.9 m by 2.5 cm) that are cut in a manner to maximize expression of the anisotropy of the rock. Measurements are taken at four different scales corresponding to inner nozzle-tip-seal radii of 0.63 cm, 1.27 cm, 2.54 cm, and 5.08 cm. These measurements identify variations in the distribution and correlation structure of the gas permeability data as a function of scale. These data also provide the basis for the calculation of effective media properties. Preliminary data suggest that the distribution and correlation structure of the data are sensitive to measurement scale.

Key to making accurate measurements is the establishment of a good seal between the rock surface and the permeameter nozzle. On smooth surfaces, as with core samples or rock slabs, a good seal is easy to make, but on an outcrop sample, sealing is not a trivial matter. In an effort to make a better seal, tests have been run using a seal molded out of caulking putty

rather than the standard sealing materials such as closed-cell foam or silicone rubber stoppers. In recent field tests, the caulking putty has shown to provide a very good seal even in relatively loosely bedded deposits.

Experiments to develop scaling laws for saturated and unsaturated systems containing micro-layering and cross-bedding heterogeneities are being designed. Such heterogeneities are found in all the alluvial sediments at and around Yucca Mountain and in the bedded tuffs units within Yucca Mountain. Incomplete knowledge of the effect of these heterogeneities within a larger scale geologic "layer" undermines calculations for TSPA and in support of the ESF. The first phase in this work is being conducted in the laboratory in conjunction with the LANL intermediate scale caisson experiment. Here, micro-layering and cross bedding heterogeneities are created in thin slabs of sand that will compose the LANL caisson. Using a full field moisture content technique based on light transmission, a sequence of infiltration and drainage experiments will be monitored. The experimental sequence allows the measurement of chamber scale hysteretic moisture characteristic curves, saturated and relative permeabilities, and solute dispersion coefficients. These effective chamber scale properties are measured in a series of experiments where the type and intensity of the heterogeneity is varied systematically. In addition, measured transient moisture content and solute concentration fields are compared with numerical simulations.

To support the microlayering/crossbedding heterogeneity studies, a slab chamber was built that incorporates a grid of tensiometers so that transient pressure fields can be measured. Special rapid-response wall-mounting tensiometers have been developed and fabricated. Design of a flow-through solute (dye) concentration sensor has begun. A data acquisition system for the array of tensiometers/pressure transducers and solute sensors has been acquired.

Development of experimental capabilities:

Efforts have continued in the development of x-ray absorption and transmitted light as techniques for measuring moisture content in porous media. Current activities have focused on the evaluation of measurement precision and accuracy as well as the reporting of results. A paper entitled "X-ray and Visible Light Transmission as Two-Dimensional, Full-Field Moisture-Sensing Techniques" (Tidwell and Glass) was completed for presentation at the IHLRWM Conference in April 1992. Efforts are also being made to publish this material as a journal article in Water Resources Research. These reports describe the two independent high-resolution moisture-sensing techniques, x-ray absorption and light transmission, which have been developed for use in two-dimensional, thin-slab experimental systems. The techniques yield full-field measurement capabilities with exceptional resolution of moisture content in time and space. These techniques represent powerful tools for the experimentalist to investigate processes governing unsaturated flow and transport through fractured and nonfractured porous media. Evaluation of these techniques has been accomplished by direct comparison of data obtained by means of the x-ray and light techniques, as well as comparison with data collected by gravimetric and gamma densitometer techniques. Results show excellent agreement between data collected by the four moisture-content measurement techniques. Furthermore,

measurement accuracy and precision were found to be on the order of + 3% saturation.

Gravity driven fingering in porous media:

A paper entitled "Analysis of Gravity-Driven Fingering Using Modified Invasion Percolation Theory" (Glass, 1991) was presented at the National Symposium on Preferential Flow on December 16-17, 1991. The presentation introduced an invasion percolation model, which was developed and used to simulate the quasi-static infiltration of water downward into two-dimensional networks of air-filled pores in an effort to further understand a gravity-driven instability or "fingering" that can occur in these systems. The model incorporates gravity-induced buoyancy and multiple neck pore-filling facilitation. Pore size distributions are varied to determine their effect on the developing water-filled pore structure. Simulation results are compared to finger widths predicted by linear stability theory in the quasi-static limit. Model simulations are also compared with experiments conducted on 1-cm thick, 25 x 50 cm slabs of unconsolidated sand and 15 x 30 cm analogue rough-walled fractures. The experiments use newly developed optical techniques to rapidly visualize the moisture content distribution integrated over the thickness of the slab and the wetted aperture in glass fractures.

Caisson experiment

An intermediate-scale transport-model validation experiment is being carried out by SNL and LANL at the Experimental Engineered Test Facility at Los Alamos. The experiment involves the detection and prediction of the migration of fluid and tracers through an unsaturated porous medium. The experimental test bed is a 6-m high x 3-m diameter caisson filled with quartz sand with a sorbing layer at an intermediate depth. The experiment was the subject of two presentations made during the first half of FY 1992, entitled "An Integrated Intermediate-Scale Caisson Experiment to Validate Model of Fluid Flow and Contaminant Transport in the Unsaturated Zone" (Siegel and Springer, 1992) and "Design of an Intermediate-Scale Experiment to Validate Unsaturated-Zone Transport Models" (Siegel et al., 1992).

Overview of preliminary design

During the initial stages of design, several different materials were considered for the porous matrix. These included pure quartz sand, zeolites mined from three commercial deposits, quartz sand coated in the laboratory with iron oxyhydroxide, and powdered goethite. The preliminary design assumes that the caisson will be filled with quartz sand, with a 0.5 m thick sorbing layer at an intermediate depth. Quartz was chosen because it is relatively inert geochemically; the sorbing layer will be composed of quartz sand doped with minor amounts of a highly sorbent mineral. It is intended that the reactive tracers will be strongly retarded in this layer, while the non-reactive tracers pass through unretarded.

The properties of the homogeneous sand have been estimated from candidate grain-size distributions and porosities, and used to calculate flow rates consistent with different boundary conditions and saturation states. Several different particle-size distributions for the porous matrix were considered in combination with hydraulic boundary conditions (applied flux and suction).

For preliminary design calculations, the hydraulic properties of the sand were estimated from the grain-size distribution and an expected average bulk density. Both the moisture-characteristic relation and the relative-permeability relation are functions of the pore-size distributions and pore-network structure. For a granular material, the pore-size distribution is related to the grain-size distribution and the packing density (bulk density and porosity). Given steady-state conditions and an estimate of the material properties, the appropriate applied flux at the top boundary and suction at the lower boundary that will result in an acceptable travel time for a conservative tracer can be calculated. Due to the nonlinearities of the system, an initial assumption of unit head gradient was made in order to approximate the flux and suction. The resulting applied flux and suction then were used to define the boundary conditions necessary to solve numerically for the flow field of the caisson and to verify desired travel times of 2-4 days. The LLUVIA-II code, which solves the Richards' equation for the two-dimensional, isothermal flow of liquid water, was used for these calculations.

Preliminary geochemical characterization of candidate materials for the sorbent layer included pH measurements of solutions in contact with the sand and sorbents, measurement of empirical sorption distribution coefficients (Kd's), and mineralogical analysis of the sorbents by x-ray diffraction (XRD), x-ray fluorescence (XRF), and surface area measurements (BET). Initial characterization of the iron-coated quartz sand suggested that high amounts of nitric acid were trapped in pores of the coating during synthesis; thus, this material was eliminated from further consideration. Investigations with the zeolites suggested that they were mechanically and geochemically unsuitable for the experiment.

Preliminary nickel (Ni) sorption data for the quartz sand, limonite, and ceramic solution samplers were collected over the pH range 5 to 12. Batch experiments were conducted in 0.01 M NaCl at liquid:solid ratios of 20-40 mL/g and initial Ni concentrations of 100-200 ppb. The data indicate contrasting sorption affinities of nickel for the three materials. The sand, shown by XRD and XRF to be nearly pure quartz with minor impurities, exhibits a sorption edge near pH 5.5 (50% sorbed) and strongly sorbs Ni at near-neutral pH (K_d = ~35 mL/g at pH = 7.0). The limonite is complex, composed primarily of goethite with minor, admixed, and poorly crystalline lepidocrocite, and contains significant amounts of Si (6.6%), Al (1.9%), and Ni (1-2 ppm). The limonite displays a sharp sorption edge at pH ~6, and very strongly sorbs Ni at near-neutral pH (K_d > 1300 mL/g for pH = 7-8). The contrast in sorption is due primarily to differences in surface area: surface-weighted distribution coefficients (K_a's) using BET-determined areas of 0.2 and 12 m^2/g for sand and limonite yield K_a's of 175 and >110 mL/ms^2, respectively, at neutral pH. The exact composition of the ceramic samplers has not yet been obtained. In the near-neutral pH range (pH = 6.8 to 7.5), the nickel K_d values range from 10 to 80 mL/g for the ceramic sampler; at slightly lower pH (6 to 6.5), Ni sorbs very weakly to the sampler (K_d = 5 to 15 mL/g).

Similar studies of solubility and sorption of other reactive tracers being considered for this experiment (boron and iodide) are currently in progress. Preliminary boron (B) sorption experiments using sand and limonite were carried out to provide an initial estimate of the degree of B sorption by the two minerals and allow evaluation of the precision of the analytical techniques (d. c. plasma spectroscopy) used for B analysis. Batch sorption

studies were conducted at solution/solid ratios of 1 and 10 and the pH was controlled by the solid. K_d values of 0 and 1.7 were obtained for the sand and limonite respectively, indicating that boron shows promise as a nearly-conservative tracer for the caisson experiment. Replicate analyses by the d. c. plasma spectrometer suggest that adequate analytical precision can be obtained for the sorption studies. Scoping iodide (I) sorption experiments yielded anomalous results (negative K_d values) at low total iodide concentrations and have led to a modification of the analytical technique (substitution of a single-junction reference electrode for the double junction electrode) for the next round of experiments.

Sensitivity analysis

The preliminary design currently being used for sensitivity analysis assumes the bulk of the caisson contains Wedron 510 sand with a sorbing layer composed of a mixture of sand and powdered limonite. The preliminary Ni sorption data suggest that only limited Ni transport will occur in the caisson during the course of the experiment. An approximation of the transport distance was required to determine the feasibility of using Ni as a reactive tracer and to guide placement of sampling devices within the caisson. Calculations were carried out with the LEHGC code to estimate the combinations of water flux, tracer feed rate, and location of the sorbing layer that would result in reactive tracer breakthrough within approximately 150-200 days after the start of the experiment. The LEHGC code is a coupled reaction/transport simulator which models transport using chemical equilibrium constants or retardation factors. Retardation of the reactive tracer (Ni) was estimated from K_d data obtained in batch sorption experiments using pure quartz sand or limonite. A linear K_d mixing model was used to estimate the K_d's of mixtures of the two minerals. These calculations suggest that a layer of sand doped with 3 - 5% goethite that is placed 1 meter below the top of the caisson could be detected from the Ni breakthrough curve approximately 150 days after the start of the experiment. Approximately 75 tons of Wedron 510 sand was delivered to LANL during March 1992 to be used to fill the caisson. Approximately 600 pounds of limonite have been ground at the New Mexico Bureau of Mines for the sorbent layer.

Detailed materials characterization

Once the final choices of reactive substrate, solution compositions and tracers have been chosen and the caisson filled and instrumented, efforts will concentrate on detailed pre-test material characterization. The grain-size distribution and porosity (and hence the hydraulic and dispersion properties) in the sorbing layer will be matched to those of the quartz sand layers. This will be accomplished by using a narrow (but not unnatural) grain-size distribution devoid of silt- and clay-size particles. Microlayering and cross-bedding will occur while the caisson is filled and packed. Production of these features will be minimized, but no attempt to destroy them will be made once the sand is emplaced. Scaling laws for effective hydraulic and dispersion properties that integrate these small-scale heterogeneities will be developed as part of the detailed pre-test characterization phase during the next six months.

Batch sorption data are now being obtained systematically over ranges of solution pH and concentrations of solids, tracers, and competing cations and

anions and varying sand/sorbent ratios. Sorption data are being obtained for both pure sand, pure goethite, and for mixtures of the two components in various proportions. Batch systems consisting of 3% limonite/97% sand in 0.01 M NaCl at a solution:solid ratio of 2 were equilibrated over pH's ranging from 3 to 9. The data obtained from these experiments were used to get the linear-K_d-mixing model used in the scoping design calculations described above. The measured K_d at pH 7.2 was 80 mL/g and agreed well with the predicted K_d of 70 mL/g.

In order to better understand the range of pH likely to be encountered in the caisson experiment at LANL, the pH of several batch systems containing sand in 0.01 M NaCl in equilibrium with atmospheric CO_2 were investigated. The results suggest that the Wedron 510 sand contains trace amounts of calcite. Experiments and calculations designed to predict the change in pH of solutions percolating through the sand in the caisson due to calcite dissolution and equilibration with atmospheric CO_2 have been initiated.

Scoping sorption studies

In addition to obtaining data that can be used to calculate K_d's and isotherms, techniques to obtain data that can be analyzed within the conceptual framework of surface-complexation modeling are being developed. A basic assumption of these models is that different adsorption sites compete for adsorbate metals in a manner analogous to the competition among complexing ligands for metals in solution. The validity of this assumption is being assessed by using the complexation constants obtained for individual minerals to model aqueous speciation and sorption properties of mineral mixtures with the HYDRAQL computer code. The predicted sorption properties of various mixtures will be compared to measured K_d's for the same mixtures. Preliminary work in this area is described in "Development and Validation of a Multi-Site Model for Adsorption of Metals by Mixtures of Minerals" (Siegel et al., 1991).

Surface hydrolysis constants will be obtained by potentiometric titrations; specific adsorption constants for the reactive tracers and background eletrolytes will be obtained by batch sorption techniques. Accurate measurement of solution parameters such as pH and tracer concentrations is required to obtain meaningful surface complexation constants. During the first half of FY 1992, progress was made in three areas of technique development: control of pH during sorption experiments, optimization of precision and sensitivity of Ni analysis, and construction of a computer-controlled titrator for surface potentiometric studies.

Control of pH during experiments: pH effects of various plastics and atmospheric CO_2

Efforts to develop titration curves for sand, limonite, and ceramic samplers suggested that the release of protons from the surface of polycarbonate (PC) centrifuge tubes used in the preliminary K_d experiments may affect the pH of the solutions. The effect may result from the 10% HNO3 soaking procedures that are used to remove all trace Ni from the tubes between sorption experiments. The possible effects of seven types of plastic containers (HDPE, LDPE, FEP, PP, PC, PMP, and PA) on pH were evaluated by titrating air-saturated deionized water in the containers to an endpoint of pH 8 and comparing the resulting curves with a theoretical curve for an inert

container assuming continuous equilibrium with air. As a result of these tests, it appears that PA is the best container material for investigations of pH as a function of added base or acid. For studies in which pH titrations are not important (even though final pH may be), PC becomes attractive because of its high mechanical strength and low affinity for a wide range of trace metals. Sorption of Ni by the PA containers is currently under investigation.

In order to reduce the confounding influence of disequilibrium with atmospheric CO_2 on pH measurements, a method to carry out batch experiments under CO_2-free conditions was developed. A low-flow argon (Ar) purge system (Ar flow of ~1 L/min or less) has been assembled which provides the ability to purge the headspace of the batch-experiment containers during pH measurements and maintain CO_2-free conditions. Reagent-container headspace can also be purged. Documentation for the system, including a Pressure-Safety Data Package and a Technical Procedure, was prepared.

Optimization of precision and sensitivity of Ni analysis

The analytical protocol for Ni by Graphite-Furnace AA was optimized and a draft Standard Operating Procedure (SOP) has been written. In this procedure, L'vov platforms are used in conjunction with pyrolytically-coated graphite tubes and measurements made in the 'Peak Area' mode. With careful adjustment of the lamp and wavelength, sensitivity appears to slightly exceed the manufacturer's specifications. Standard operating conditions yield maximum precision for Ni concentrations between 20 and 50 ppb, with a limit of detection of < 0.25 ppb. Precision (1s) is + 3% or + 0.6 ppb, whichever is greater. By altering the volume of sample injected into the furnace, the optimum range may be extended, encompassing 5 to 100 ppb with a limit of detection of <0.10 ppb. Further work will involve development of a method to correct for apparent non-linearity; the degree of non-linearity appears to amount to ~1 ppb for concentrations near 10 ppb.

Construction of a computer-controlled titrator for surface potentiometric studies

Fabrication of a computer-driven autotitrator for acidimetric and alkalimetric determination of mineral surface hydrolysis constants was completed by a subcontractor (G. Redden, Stanford University) during the first half of FY 1992. The autotitrator is an apparatus for dispensing reagents (in this study, acids or bases) from precision syringes, which are driven by stepper motors controlled by a personal computer. Previous attempts to carry out potentiometric titrations of minerals at SNL and other laboratories have been hindered by equilibration problems. Both slow reaction with mineral surfaces and exchange of CO_2 with the atmosphere lead to unstable pH readings and long, labor-intensive studies. The autotitrator can be configured to monitor pH and to carry out the titration according to pre-defined pH stability criteria, thus freeing the researchers from the need to constantly monitor the titration for long periods of time.

General

Tours of the SNL-YMP Flow and Contaminant Transport Model Validation Laboratory were given to DOE Waste Management Environmental Restoration fellowship students and program representatives on October 1, 1991, to M&O

representatives on October 24, 1991, and to the YMP Project Manager on February 5, 1992. During the tour, the approach to model development and validation was discussed and the integrated physical and numerical experimental effort was demonstrated for flow and transport through single fractures, fracture/matrix interaction, and development of scaling laws for heterogeneous media.

The first three weeks of January 1992 were spent reorganizing the Subsurface Flow and Transport Laboratory. The reorganization incorporates an additional light transmission experimental system (to be built over the next three months) for use in sand experiments in support of the LANL caisson project. Additional work areas for undergraduate and graduate students in the laboratory were also created to accommodate two doctoral students and two masters students.

The laboratory program has continued to make use of high school, undergraduate, and graduate students through the many DOE programs designed to promote interest in science and engineering, as well as provide opportunities for underprivileged students. Over the last six months the laboratory has supported eight such students.

2.7.5.3 Activity 1.6.3.1 - Analysis of unsaturated flow system

Subactivity 1.6.3.1.1 - Unsaturated zone flow analysis. Work has been completed on a 2D numerical analysis of the Yucca Mountain region extending from drillholes USW H-5 to UE25a, with offset along the Ghost Dance fault included. NORIA-SP was used to generate a time-dependent flow field. Results show that water infiltrating through the upper boundary tends to saturate regions immediately upstream of the fault and also at the down-dip boundary. However, only a moderate amount of lateral flow was computed as a result of the difference in the geologic unit conductivities and the discontinuity along the fault.

Subactivity 1.6.3.1.2 - Saturated zone flow analysis. The STAFF2D code that was acquired during the previous reporting period was used to calculate flow and transport in the saturated zone for the TSPA, reported in Section 2.3.6.6. An effort was begun to address questions raised by the Saturated Zone Working Group regarding the capability of site-characterization tests to identify features that could be affected by tectonic activity in a way that would cause a dramatic change in saturated-zone flow. An east-west transect that crosses several major structural features and also crosses the high hydraulic gradient has been gridded. Subsequent analyses will attempt to simulate the effects of changes in hydrologic parameters on the flow field. A determination will then be made whether the magnitude of the changes in the parameter values required to alter the flow field can be detected with the available set of tests.

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. Analyses material that might be used in reallocation of performance assessment activities are discussed in Section 2.7.5.4, 1.6.4.1.3.

Subactivity 1.6.4.1.2 - Sensitivity and uncertainty analyses of ground-water travel time. Work performed under this topic is discussed in Section 2.7.5.4, 1.6.4.1.3.

Subactivity 1.6.4.1.3 - Determination of the pre-waste emplacement ground-water travel time. Several activities leading to final calculations of groundwater travel time are so closely related that this summary describes nearly all of the work under a single heading. Much of the effort described here could have been placed in Sections 2.7.5.2, 2.7.5.3, or 2.7.5.5.

The work performed for the task of computing preclosure groundwater travel time includes three major, interactive elements: conceptual model development, tools development, and data analysis. A feedback mechanism among all of these elements allows continuing enhancement of each.

Several studies involving conceptual model development to identify methods of handling uncertainty are in progress or have been completed during this reporting period. "Conceptual, Experimental, and Computational Approaches to Support Performance Assessment of Hydrology and Chemical Transport at Yucca Mountain" (Narasimhan and Wang) has completed SNL management review and is currently undergoing comment resolution. Three members of SNL staff attended the Saturated Zone Workshop hosted by YMP in Tucson, Arizona, on November 13-14, 1991. The purpose of the workshop was to prioritize the needs for information from site characterization. At the meeting, P. Kaplan gave a presentation titled "Lessons Learned from Pre-Emplacement Groundwater Travel." As a result of the success of this meeting, we recommended organizing a similar workshop for issues related to the unsaturated zone. "Statistical Analysis of Yucca Mountain Hydrologic Data" (Rutherford et al., 1991) completed all review processes, was published, and is now available for distribution.

Several activities were completed for the data-analysis portion of this task. The draft of "Pre-Emplacement Groundwater Travel Time Sensitivity and Uncertainty Analyses for Yucca Mountain, Nevada" (Kaplan) was written and has completed SNL internal technical review. For this report, uncertainty and sensitivity analyses were performed to isolate what could be critical factors in the performance of the site with respect to a pre-waste emplacement groundwater travel time criterion. The analyses used geohydrologic data prepared at each of four drillholes used in TSPA-1991 (reported in 1.2.1.4.1). It was found that failure to meet the criterion is sensitive to the estimate of fracture porosity in the upper welded unit of the problem domain. The parameters of importance in estimating fracture porosity include fracture frequency, fracture orientation, and moisture-retention characteristics inferred from the fracture domain. The document includes specific recommendations for data needs from the field investigations currently being planned for site. The data-analysis staff were also involved extensively in rewriting and revising the document describing the TSPA reported in 1.2.1.4.1.

The primary areas in which this element has been contributing to that document are in the use of expert-elicitation techniques and in the development of the geohydrologic parameter set used for the aqueous and gaseous flow problems. Information on the probability distribution function developed for the TSPA was presented at a review meeting in Las Vegas, Nevada, on November 14, 1991.

The tools developed for data analysis during the past 6 months have taken several forms. Work continued on the development of a report on geohydrologic information from the Yucca Mountain and analogue sites used in both the early-site-suitability and TSPA calculations. Plans to follow the hydrologic data document with a natural analogue study were formalized. The second document will focus on fracture properties, because of the high apparent sensitivity of calculational results to fracture parameters reported in Kaplan. Fracture data and transport parameters from currently available site data, as well as from reports on known analogue materials such as the Apache Leap, Bandelier, and NTS tuffs are being complied and interpreted. The report will include a compilation of these parameters, a list of references, and revised distribution functions based on the additional data. The intent of the report is to provide an updated data base for future performance-assessment modeling. A memo was distributed outlining detailed plans to initiate the transfer of RS1 LLUVIA groundwater travel-time simulations to a PC environment. The work was begun, and the projected completion date is early 1992. PV WAVE (a commercial graphics package) was used to contour air-permeability data collected from a slab of Topopah Spring welded tuff. Initial analysis of the contour data revealed a systematic error in transposing the data. The corrected data contained obvious structures that will require a multidimensional analysis of the geologic data.

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.

2.7.5.6 Activity 1.6.5.2 - Definition of the disturbed zone

No progress during the reporting period due to lack of funding.

2.7.6 Total system performance (SCP Section 8.3.5.13)

2.7.6.1 Activity 1.1.2.1 - Preliminary identification of potentially significant release scenario classes

Subactivity 1.1.2.1.1 - Preliminary identification of potentially significant sequences of events and processes at the Yucca Mountain repository site. The tectonism event-tree report is being prepared for review. Staff have attended several expert elicitation meetings, which were hosted by EPRI on seismic issues at Yucca Mountain. Information on general tectonic models developed by the EPRI team of experts on tectonic activity will be incorporated into this report.

An article entitled "Potential for Water-Table Excursions Induced by Seismic Events at Yucca Mountain, Nevada" (Carrigan et al., 1991) was published in Geology. This work was initiated at SNL and was completed by Carrigan at LLNL, under contract to SNL. The paper reports the results of numerical simulations of tectonohydrologic coupling resulting from typical Basin and Range earthquakes. The simulations show that only very small water table excursions, on the order of 2 to 3 meters, are likely to occur in response to pore-pressure fields induced by earthquakes of this magnitude.

Subactivity 1.1.2.1.2 - Preliminary identification of potentially significant release scenario classes. The first rough draft of a report on scenario selection for nominal flow processes has been completed. The rough draft of "Scenarios Developed from Basaltic Volcanism" (Barr et al.), including extensive art work for the report on scenario selection for basaltic igneous activity, is essentially complete. The artist has been very successful in capturing the details of many elements of each scenario. We expect that the addition will make this an invaluable document for visualizing and constructing numerical and analytical models related to basaltic igneous activity.

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.

2.7.6.3 Performance Assessment Activity 1.1.3.1 - Development of mathematical models of the scenario classes

Progress on this topic is reported in 2.7.6.6.

Subactivity 1.1.3.1.1 - Development of models for release along the water pathways. Progress on this topic is reported in Section 2.7.5.3, Subactivity 1.6.3.1.2 and in Section 2.7.6.6.

Subactivity 1.1.3.1.2 - Development of a model for gas-phase releases. "Numerical Studies of Rock-Gas-Flow in Yucca Mountain" (Ross et al.) is being printed. The report includes a description of the gas-flow model, the derivation of applicable equations, and a description of the numerical implementation. Results of the calculations are incorporated into the TSPA described in 2.7.6.6. This work is also reported in "Predicted Gas-Phase Movement of Carbon-14 from a Radioactive Waste Repository" (Ross et al.) which was submitted to Science, and "A Coupled Model of Gas Flow and Heat Transport is Porous Media" (Ross et al.) which was submitted for the AGU Spring Meeting (Montreal, May 12-15, 1992). Presentations were made at the NRC/DOE technical exchange on March 17, 1992, on the gaseous-flow results from the TSPA (in 2.7.6.6) (Wilson), and on models of thermally driven gas flow (Ross).

Subactivity 1.1.3.1.3 - Development of a model of releases through basaltic volcanism. Progress on this topic is reported in Section 2.7.5.3, Subactivity 1.6.3.1.2 and in Section 2.7.6.6.

Subactivity 1.1.3.1.4 - Development of a model of releases through human intrusion. Progress on this topic is reported in Section 2.7.5.3, Subactivity 1.6.3.1.2 and in Section 2.7.6.6.

2.7.6.4 Performance Assessment Activity 1.1.4.1 - The screening of potentially significant scenario classes against the criterion of relative consequences

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

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

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

2.7.6.6 Performance Assessment Activity 1.1.5.1 - Calculation of an empirical complementary cumulative distribution function

A paper entitled "TSPA-1991: An Initial Total-System Performance Assessment for Yucca Mountain" (Barnard et al.) completed internal technical review and was submitted to YMP for policy review. This report contains the results of a set of analyses for the initial total-system performance assessment: groundwater flow, gas flow, human intrusion, and basaltic volcanism. This exercise differed from PACE-90 and analyses associated with the effort on early determination of site suitability (ESSE) in that these simulations were stochastic, the set of phenomena modeled was expanded, the results of the analyses were used (by PNL) to calculate dose, the calculations were run out to the accessible environment, and a large number of radionuclides was included in a more complex source term. The goal of SNL in the TSPA was to demonstrate the capability to abstract data and calculational results for use in higher level calculations. An additional goal was to develop a tool to eventually be used to understand sensitive parameters and processes. Conditional CCDFs were constructed for the elements modeled. These conditional CCDFs were then combined into a single "total-system" CCDF. However, the TSPA was not comprehensive in the components modeled, nor were the models or data considered validated. Therefore, although the analysis reflects our current state of knowledge about the site, this iteration should not be considered a definitive estimate of site suitability.

Results of the analyses reinforced our belief that we should invest more time in modeling water flow and transport in fractures, gas flow in the unsaturated zone, and near-field interactions. Although water flow in the saturated zone appears important, site data are necessary for the tuff and carbonate aquifers before we can adequately model this region. Results for volcanism, and perhaps human intrusion, indicate that little more can be done to cause major changes in the CCDFs unless major changes are made to the current estimates of probability of occurrence.

A number of presentations have been made on the results of this study. Five SNL staff members gave presentations on the TSPA at a performance-assessment review meeting in Las Vegas, Nevada, on November 18-20, 1991. The presentations covered the following topics associated with the TSPA: overview; basic data set; geohydrologic parameter distribution development; SNL source-term implementation; SNL abstracted analyses for flow and transport by groundwater and gas, human intrusion, and basaltic volcanism; construction of a combined CCDF; sensitivity analyses; comparison of SNL and PNL results; comparison of DOE, EPA, and NRC methods for determining compliance; and lessons learned from the abstraction process.

A presentation on results of the TSPA was made at the Geochemistry Working Group meeting on December 4, 1991 (Gauthier). Results of the recently completed initial TSPA were discussed, as well as the geochemistry issues that performance assessment personnel believe to be important. These technical issues include the need for a better understanding of C-14 interactions with the surrounding rock matrix that might cause that nuclide to precipitate out of the system as calcite, how high temperature affects solubility and retardation in the near field, how colloids form and their role in nuclide transport, the retardation characteristics of fracture coatings, and the distribution of groundwater ages. Also discussed was the need for geochemists to provide the full range of unbiased data so that the information can be used appropriately in stochastic simulations.

The TSPA results were also presented at an NRC technical exchange on air and vapor transport and to the NAS in mid-March 1992. Preparations were completed for presentations to the NWTRB, at the IHLRWM Conference, and at an interchange with the SKB, all in early April 1992.

Other ongoing activities include development of the total-system simulator platform, WINGZ, which is being modified to allow parallel processing on four SPARC stations, and the completion of preliminary calculations of the performance of a potential storage system for high level nuclear waste at Yucca Mountain including partitioned/transmuted waste. The status of both of these activities will be reported in papers being presented at the IHLRWM Conference in April 1992.

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.

2.7.7.2 Activity 1.2.2.1 - Calculation of transport of gaseous carbon-14 dioxide through the overburden

See 2.7.6.3, Subactivity 1.1.3.1.2.

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.

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.

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.

2.7.9 Performance confirmation (SCP Section 8.3.5.16)

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

2.7.10 NRC siting criteria (SCP Section 8.3.5.17)

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

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.

3.0 SCHEDULES

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; comments from the NWTRB, 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, 1990b). This Program Cost and Schedule Baseline was revised in March 1991, and again in November 1991. 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 the YMP as of the end of this reporting period (March 31, 1992). More detailed schedules are maintained at the 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 the YMP. Figure 3.1 shows the relationship of the summary milestones to the major activities.

Table 3.1. Summary Milestones[1].

	Baseline Date	Actual Date
Surface-Based Testing		
Obtain Permits	12/91	7/91
Start New Surface-Based Testing	1/92	7/91
Complete Deep Unsaturated Zone Hydrologic Hole Drilling	6/95	
ESF		
Start Final ESF Title II Design	10/91	10/91
Start ESF Site Preparation	6/92	
Start ESF Portal Construction	11/92	
Start ESF In-Situ Test Phase	9/95	
Complete Geologic Drifting	11/97	
Provide Engineering Barrier System Data To Waste Package License Application Design	7/98	
Waste Package/Repository Design		
Complete Repository Program Plan	3/91	9/91
Start Waste Package/Repository Advanced Conceptual Design	10/92	
Start Waste Package/Repository License Application Design	6/96	
Environmental Impact Statement		
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	
License Application		
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	

[1]Table shows approved Program Schedule Baseline and actual completion dates as of March 31, 1992

SCPTABLE.052/7-28-92

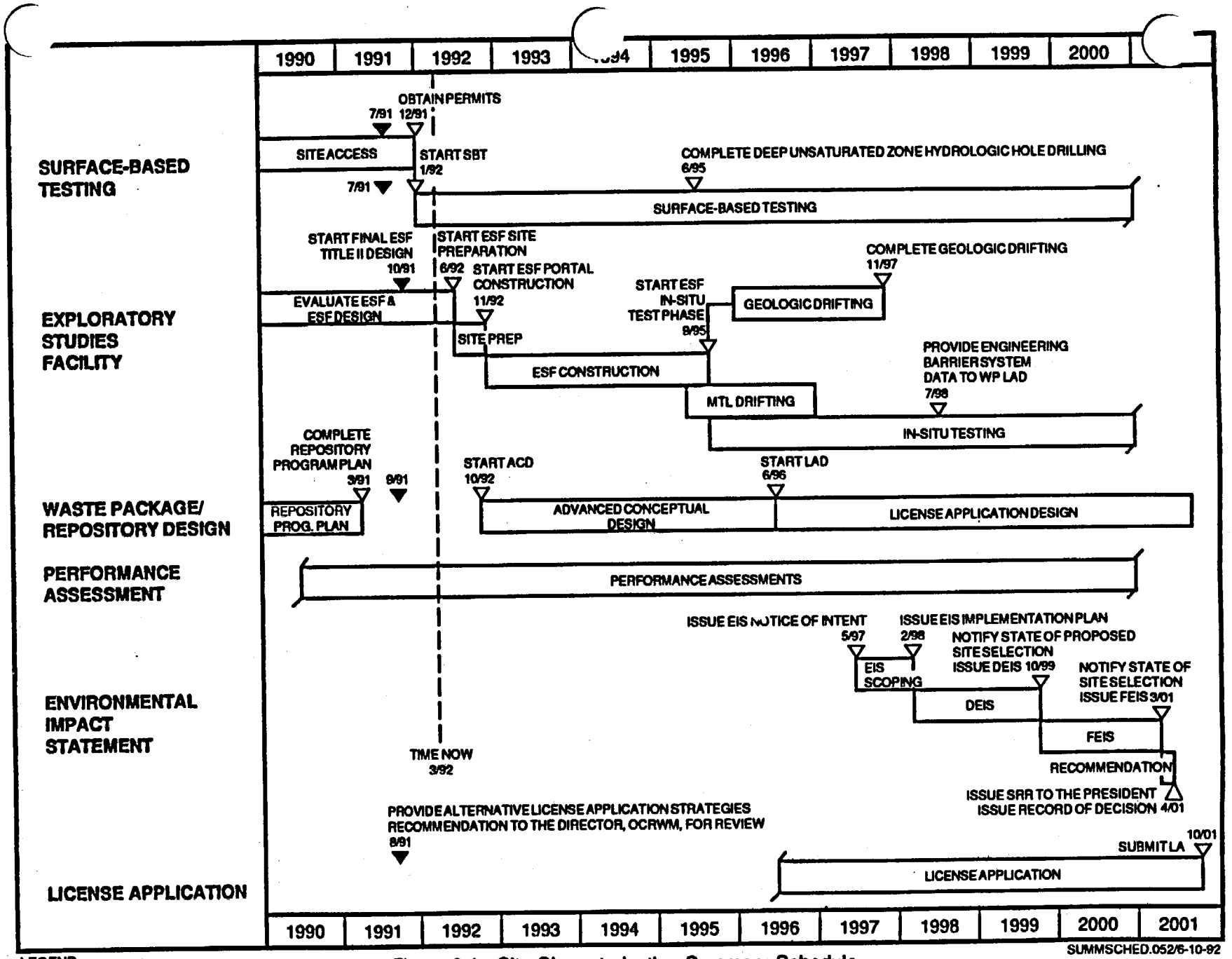

Figure 3.1. Site Characterization Summary Schedule.

LEGEND

▽ PROGRAM COST AND SCHEDULE BASELINE MILESTONE

▼ ACTUAL START/COMPLETION DATE

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All technical reports and research products published by participating organizations on the Yucca Mountain Site Characterization Project (YMP) are 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. All 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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ACRONYMS/ABBREVIATIONS LIST

AAP	annual average precipitation
ACNW	Advisory Committee on Nuclear Waste
AECL	Atomic Energy of Canada Limited
AEM	Analytical Electron Microscopy
AGU	American Geophysical Union
Al	aluminum
ALTS	Apache Leap Test Site
Am	americium
ANL	Argonne National Laboratory
ANS	American Nuclear Society
AO	Annotated Outline
APD	areal power density
Ar	argon
ASTM	American Society for Testing and Materials
BLM	U.S. Bureau of Land Management
Br	bromine
BWR	boiling water reactor
C	carbon
Ca	calcium
CCB	Change Control Board
CCDF	complementary cumulative distribution function
CHRBA	Calico Hills Risk/Benefit Analysis
Cl	chlorine
CWRM	Civilian Radioactive Waste Management
CRWMS	Civilian Radioactive Waste Management System
Cs	cesium
DISA	downhole instrument station apparatus
DOE	U.S. Department of Energy
DOE/HQ	U.S. Department of Energy/Headquarters
DP	detailed technical procedure
DTM	digital terrain model
DWPF	Defense Waste Processing Facility
EA	Environmental Assessment
EBS	engineered barrier system
ECD	Electron Capture Detector
ECM	Equivalent Continuum Model
EEI	Edison Electric Institute
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
ESAAB	Energy Systems Acquisition Advisory Board
ESF	Exploratory Studies Facility (formerly Exploratory Shaft Facility)
ESFAS	Exploratory Studies Facility Alternatives Study
ESFDR	Exploratory Studies Facility Design Requirements
ESSE	Early Site Suitability Evaluation
FID	Flame Ionization Detector
FTIR	Fourier-Transform infrared spectroscopy
FY	fiscal year
GIS	Geographic Information Systems
GIT	Geochemistry Integration
GMS	Geotechnical Modeling System
GOES	Geostationary Orbital Environmental Satellite
GSA	Geological Society of America

ACRONYMS/ABBREVIATIONS LIST

H_3	tritium
HRF	Hydrologic Research Facility
HRU	hydrologic response unit
IDAS	Integrated Data Acquisition System
IHLRWM	International High Level Radioactive Waste Management
IR	infrared
ISP	Individual Software Plan
ISR	Institute for Standards Research
ITE	Integrated Test Evaluation
K	potassium
KSI	kilopounds per square inch
LANL	Los Alamos National Laboratory
LBL	Lawrence Berkeley Laboratory
LLNL	Lawrence Livermore National Laboratory
LVDT	linear variable differential transformer
M&O	Management and Operating
Mg	magnesium
MGDS	Mined Geologic Disposal System
MPA	Mission Plan Amendment
MRS	Monitored Retrievable Storage
MSIS	Management Systems Improvement Strategy
Na	sodium
NaCl	sodium chloride
$NaHCO_3$	sodium hydrogen carbonate
NAS	National Academy of Sciences
Nd	neodymium
NMR	nuclear magnetic resonance
NO_x/NH_3	nitrogen oxide/ammonia
Np	neptunium
NPS	National Park Service
NRC	U.S. Nuclear Regulatory Commission
NTS	Nevada Test Site
NWPA	Nuclear Waste Policy Act of 1982
NWTRB	Nuclear Waste Technical Review Board
OCRWM	Office of Civilian Radioactive Waste Management
OCF	Open Computing Facility
OGD	Office of Geological Disposal
OIEA	Office of Institutional and External Affairs
OQA	Office of Quality Assurance
OSTI	Office of Scientific Technical Information
PACE	Performance Assessment Calculational Exercises
PAS	Photoacoustic spectrometer
Pb	lead
PC	polycarbonate
PDM	Problem Definition Memo
PMF	probable maximum flood
PNL	Pacific Northwest Laboratory
PR	Site Characterization Progress Report
Pu	plutonium
PuO	plutonium dioxide
PWR	pressurized water reactor
QA	quality assurance
REECo	Reynolds Electrical and Engineering Co.
RIB	reference information base

ACRONYMS/ABBREVIATIONS LIST

RSN	Raytheon Services Nevada
SAIC	Science Applications International Corporation
SCA	Site Characterization Analysis
SCP	Site Characterization Plan
SCPB	Site Characterization Program Baseline
SCP/CDR	Site Characterization Plan/Conceptual Design Report
SEM	scanning electron microscope
SF_6	sulfur hexafluoride
SGBSN	Southern Great Basin Seismic Network
SG&G	Structural Geology and Geoengineering
Si	silicon
SIP	Scientific Investigation Plan
SKN	Swedish Nuclear Fuel Supply Company
Sm	samarium
SMF	Sample Management Facility
SNL	Sandia National Laboratories
SOC	Sample Overview Committee
SOF	Statement of Findings
SP	Socioeconomic Plan
SPOC	submersible pressure outflow cell
SQAP	Software Quality Assurance Plan
Sr	strontium
SSSA	Soil Science Society of America
TBM	tunnel boring machine
Tc	technetium
TCD	Thermal Conductivity Detector
TDR	time-domain reflectometry
T&EP	Test and Evaluation Plan
TEM	transmission electron microscopy
Th	thorium
TGA	thermogravimetric analysis
TL	thermoluminescence
T&MSS	Technical and Management Support Services
TPO	Technical Project Officer
TPT	Test Prioritization Task
T&S	Transportation and Systems
TSA	Total Systems Analyzer
TSPA	Total Systems Performance Analysis
TU	tritium units
U	uranium
UO_2	uranium dioxide
UCl_4	uranium tetrachloride
UNE	underground nuclear explosion
UNLV	University of Nevada/Las Vegas
UNRSL	University of Nevada-Reno Seismology Laboratory
USBR	U.S. Bureau of Reclamation
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
USNSN	U.S. National Seismic Network
UZ	unsaturated zone
VSP	vertical seismic profiling
WVDP	West Valley Demonstration Project
XRD	x-ray diffraction
XRF	x-ray fluorescence

ACRONYMS/ABBREVIATIONS LIST

YMP	Yucca Mountain Site Characterization Project
YMPO	Yucca Mountain Site Characterization Project Office
YMQAD	Yucca Mountain Quality Assurance Division

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