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(Section 113)

Site Characterization Progress Report: Yucca Mountain, Nevada

April 1, 1991– September 30, 1991

Number 5

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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 fifth report in a series of reports on the progress of site characterization at the Yucca Mountain candidate site. The document is entitled "Progress Report on Site Characterization: Yucca Mountain, Nevada," and covers the period from April 1, 1991, through September 30, 1991.

The civilian radioactive waste management program is pleased to report that significant progress was made during the reporting period with the advent of new, surface-based field activities at Yucca Mountain in July. These activities were the first new studies undertaken since 1986. This new work was begun after the processing, under court order, and subsequent issuance of two of the requisite environmental permits by the State of Nevada.

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

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

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

EXECUTIVE SUMMARY

In accordance with the requirements of Section 113(b)(3) of the Nuclear Waste Policy Act of 1982 (NWPA), 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 April 1 through September 30, 1991. This report is the fifth 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 analog studies and international programs that are not officially part of site characterization. Information on these activities is provided in order to fully integrate all technical aspects of the Yucca Mountain studies.

The Office of Civilian Radioactive Waste Management (OCRWM) program made highly-visible and significant progress in the reporting period with the start of limited, new field activities at Yucca Mountain on July 8. The three activities initiated were: (1) trenching at Midway Valley to study existing and potential faults, (2) deepening Trench 14 to examine the origin of calcite-silica vein deposits, and (3) excavating pits to study the age and origin of the Lathrop Wells and Crater Flat cinder cones.

The new surface-disturbing work was made possible by the issuance of an air quality permit and an underground injection control permit by the State of Nevada on June 12 and July 17, respectively. These permits were issued after a Federal Judge directed the State of Nevada to take "final action" on the two permits by July 17, 1991. A hearing for the water appropriations permit, which will allow water for site activities to be supplied from on-site wells, was conducted in September and a decision by the Nevada State Engineer was expected by the end of 1991.

Preparations for underground testing have progressed with the completion of the Exploratory Studies Facility Alternatives Study (ESFAS) and the acceptance of the revised ESF Title I Design Summary Report by the Director of OCRWM on September 27. Commencement of the ESF Title II Design was authorized for an initial period of three months with extension pending funding approval by the DOE's Energy Systems Acquisition Advisory Board (ESAAB). Recent cuts in appropriations for fiscal year (FY) 1992 have curtailed ongoing design work, resulting in a projected one-year delay in starting portal construction. As a result of test prioritization and budget restrictions, surface-based testing activities will receive the major emphasis for site characterization in FY 1992.

Efforts continued during the reporting period on the Early Site Suitability Evaluation (ESSE). A core team of DOE contractors conducted the evaluation according to DOE's General Siting Guidelines in 10 CFR Part 960 and produced a preliminary draft report of their analyses, conclusions, and recommendations. The findings and conclusions of the ESSE report will undergo a peer review from scientists outside the program. An internal review by the lead contractor and a Yucca Mountain Site Characterization Project Office (YMPO) management policy review were conducted in July and August, respectively, and the preliminary draft report was revised and transmitted to the ESSE Peer Review Panel on August 23. The peer review comments were expected to be received in mid-November 1991.

The DOE completed a third workshop on strategic principles for the OCRWM program during the reporting period. The results of the strategic principles workshops provided input to the preliminary draft Mission Plan Amendment (MPA), which was issued for public comment on September 9. In addition to describing OCRWM's strategic principles, the draft MPA describes the major technical and institutional changes to the program since the 1987 amendment of the NWPA. The draft MPA also provides a more comprehensive discussion of initiatives resulting from the Secretary of Energy's reassessment of the high-level radioactive waste program (DOE, 1989).

Progress continued during the reporting period on the various components of the system design for the potential repository. The DOE hosted a workshop on engineered barrier systems concepts in Denver, Colorado, on June 18-20. The workshop participants discussed whether an engineered barrier system can be designed and demonstrated to have a reasonable assurance of remaining intact for 10,000 years, a period of time that far exceeds the regulatory requirements. Some potential designs that could assist in achieving such goals were presented by experts in the field.

Implementation of the Management Systems Improvement Strategy (MSIS) continued through the reporting period. Technical reviews of nine requirements documents were conducted. Several baseline documents were submitted to the OCRWM Change Control Board (CCB) for review and approval.

Public outreach has been instrumental in introducing site characterization and nuclear waste disposal concepts to the public. Activities have included public tours of Yucca Mountain which began in March, exhibits at numerous fairs and meetings, and lectures on programmatic and technical issues. Also, there have been substantive interactions with the U.S. Nuclear Regulatory Commission (NRC) and oversight organizations, such as the Nuclear Waste Technical Review Board (NWTRB) and the NRC's Advisory Committee on Nuclear Waste (ACNW).

On September 13, the DOE issued a response package for the State of Nevada's September 1989 comments on the Site Characterization Plan (SCP). This package completes the DOE's response to all comments on the SCP offered during the formal comment period (January 15-June 1, 1989).

Since the issuance of the Section 175 Report (DOE, 1988a), the OCRWM has developed a Socioeconomic Plan (SP) (DOE, 1991a) for Yucca Mountain. The SP describes the OCRWM's socioeconomic program for the site characterization phase and is designed to integrate data collection, data analyses, and reporting efforts. Revision 0 of the SP was issued in May 1991 with the understanding that the document would be revised on an 'as needed' basis.

Five Nevada counties were granted affected unit of local government status, as provided in the NWPA. These counties were Esmeralda (May 20, 1991), White Pine (May 20, 1991), Eureka (May 20, 1991), Mineral (August 2, 1991), and Churchill (September 12, 1991), and also Inyo County in California (May 20, 1991). In addition, the DOE signed an agreement with Nye County to work cooperatively with them in many areas, including the development of a socioeconomic program.

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. Five-year cooperative testing programs were signed on September 23 and 30, with Switzerland and Canada, respectively. In June, the Stripa Project's field work was concluded at the Stripa mine facility in Sweden, and the technical and summary reports on the final phase's activities currently are being prepared. Phase II of the INTRAVAL project, an international cooperative effort focused on performance assessment model validation using data from field, laboratory, and natural analog studies, has been initiated. OCRWM cooperated or explored cooperation with nuclear waste disposal programs in other countries, including Australia, Sweden, Spain, and France.

1.0 INTRODUCTION

1.1 PURPOSE AND SCOPE

In accordance with the requirements of Section 113(b)(3) of the NWPA, the DOE has prepared this report on the progress of site characterization activities at Yucca Mountain, Nevada, for the period April 1 through September 30, 1991. This report is the fifth in a series of reports that are issued at intervals of approximately six months during site characterization.

The DOE's plans for site characterization are described in the SCP for the Yucca Mountain site (DOE, 1988b). The SCP has been reviewed by the NRC, State of Nevada, affected units of local government, other interested parties, and 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 the 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. 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 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 the DOE 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. The DOE will conduct 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 the DOE is required to demonstrate to the NRC that the site and potential repository system meet the regulations governing licensing. If, during the course of scientific investigations, information supports a finding that the Yucca Mountain candidate site is unsuitable, the 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 conditions 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 of a repository; to acquire data necessary to develop more advanced designs for the potential repository and waste package; to conduct the quantitative evaluations or performance assessments needed to evaluate 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, and modeling. 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, non-surface-disturbing characterization studies at Yucca Mountain have been in progress since May 1986, when the site was approved for characterization. These studies have consisted of 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 new surface-based activities were initiated during the reporting period. 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, 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

The OCRWM program made highly-visible and significant progress in the reporting period with the start of limited, new field activities at Yucca Mountain on July 8. The three activities started were: (1) trenching at Midway Valley to study existing faults and determine if alluvial cover shows displacement by unknown faults, (2) deepening Trench 14 to examine the nature and extent of calcite-silica vein deposits, and (3) excavating shallow pits to study the age and origin of the Lathrop Wells and Crater Flat cinder cones. These activities (as part of the planned work described in Study Plans 8.3.1.17.4.2, Location and Recency of Faulting Near Prospective Surface Facilities; 8.3.1.5.2.1, Quaternary Regional Hydrology; and 8.3.1.8.5.1, Characterization of Volcanic Features) are discussed in detail in Chapter 2. Figures 1.1 and 1.2 show the locations where these activities are being performed.

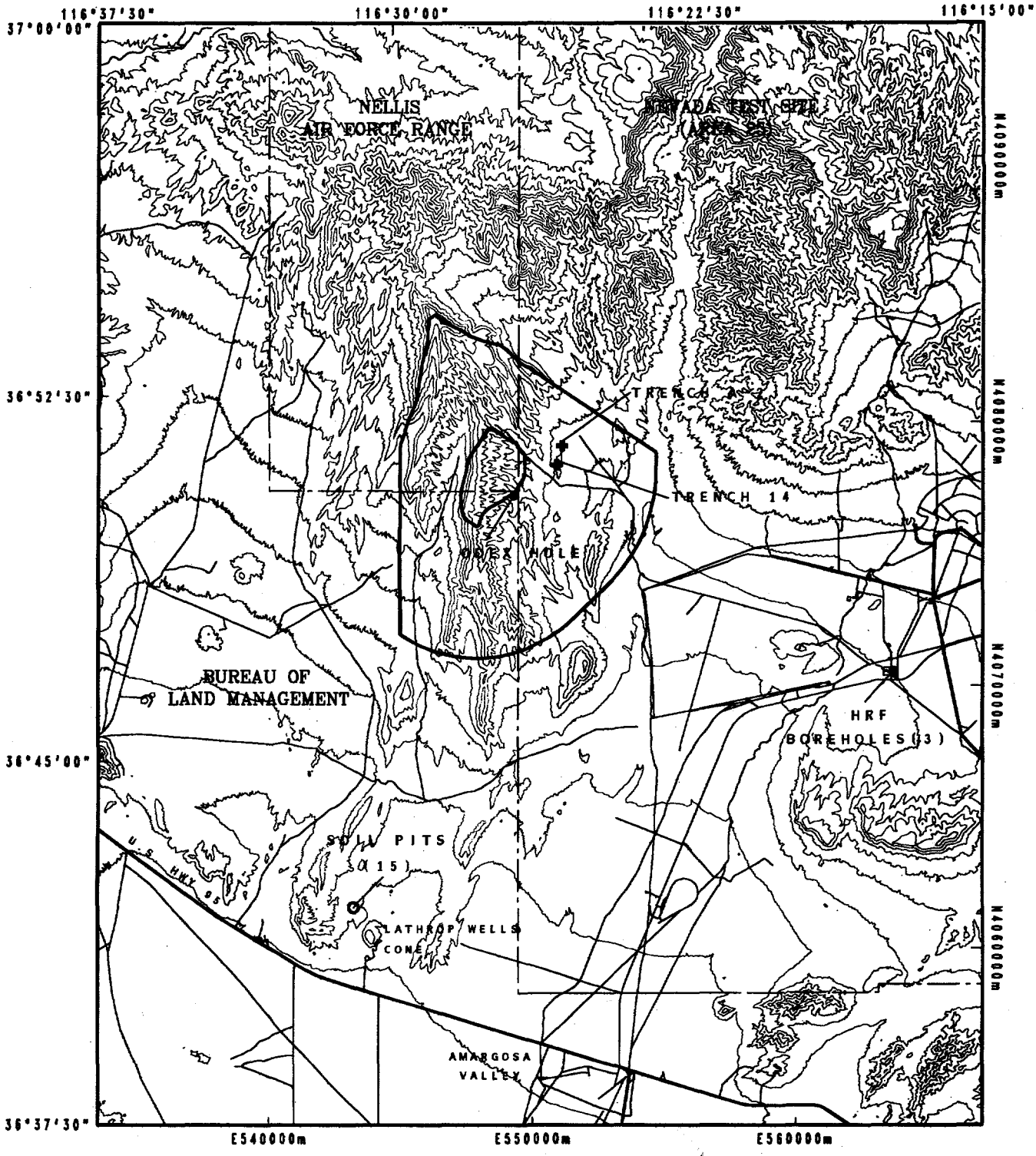
The new surface-disturbing work was made possible by the issuance of an air quality and an underground injection control permit by the State of Nevada on June 12 and July 17, 1991, respectively. These permits were issued only after a May 13 hearing in which a Federal Judge directed the State of Nevada to take "final action" (issue or deny) on the applications by July 17, 1991. Additionally, the Judge indicated to the State of Nevada that he would separately assess the State's processing of the water appropriations applications at a status hearing on July 16, 1991. Public hearings on the appropriations permit, which will allow water for site activities to be supplied from Well J-13, located on the Nevada Test Site (NTS), were conducted in September and a decision by the Nevada State Engineer was expected by the end of 1991. Until the water appropriations permit is issued, water must be hauled to the site from an available source. Water used for the new surface-based activities that began July 8 was transported from Inyo County, California, to Yucca Mountain via tanker truck (approximately 50 miles). On September 13, 1991, the State Engineer granted a temporary permit allowing the DOE to change the place of use of water from Well VH-1 for site characterization activities at Yucca Mountain.

Other new field activities initiated during the reporting period included neutron-access drilling at the northeastern edge of the potential repository block (Figure 1.2). Preparations continued for a number of surface-based activities in anticipation of receiving the water appropriations permit. Shakedown testing in Utah of the LM-300 drill rig was successfully completed on August 23. The rig was anticipated to be available for work on Yucca Mountain in early November.

Preparations for underground testing have progressed with the completion of the ESFAS and the acceptance of the revised ESF Title I Design Summary Report by the Director of OCRWM on September 27. The ESF Title I design contains two ramps that will facilitate testing at the Topopah Spring reference repository level and in a lower level excavated in the Calico Hills unit, as well as an optional shaft. Commencement of the ESF Title II Design was authorized by the Director of OCRWM for an initial period of three months with continuation pending approval by the ESAAB. Recent cuts in appropriations for FY 1992 have curtailed ongoing ESF design work, resulting in a projected one-year delay in starting the portal construction work. As a result of test prioritization and budget restrictions, surface-based testing

Figure 1.1 - Map of the potential repository block and boundary of the accessible environment, showing significant new site characterization activities undertaken during the reporting period.

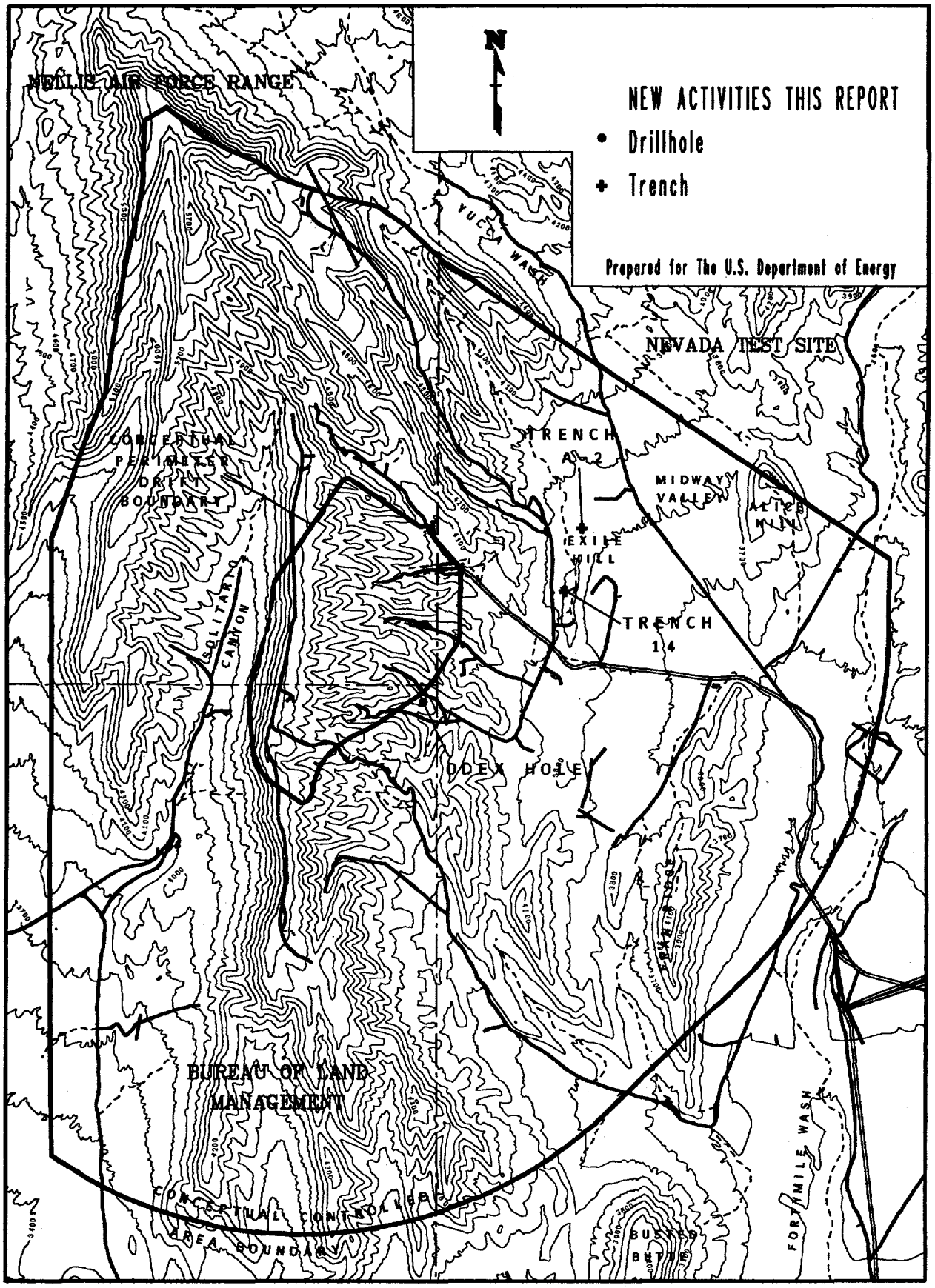
YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT



Prepared for the U.S. Department of Energy EG&G YMP-91-053.1

Figure 1.2 - Map of the Yucca Mountain region showing significant new site characterization activities undertaken during the reporting period.

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT



activities will receive the major emphasis for site characterization in FY 1992.

Performance assessment activities continued in support of site characterization, including preliminary analyses in support of the early site suitability evaluation, and in support of ESF and interface design studies for the potential repository. Performance assessment model development and experimental studies in support of model validation continued. A total-system performance assessment for the Yucca Mountain site continued, involving the analysis of both expected and unexpected conditions.

Public outreach has been instrumental in introducing site characterization and nuclear waste disposal concepts to the public. Activities have included public tours of Yucca Mountain which began in March, exhibits at numerous fairs and meetings, and lectures on programmatic and technical issues. Also, there have been substantive interactions with the NRC and oversight organizations, such as the NWTRB, and ACNW.

On September 13, the DOE released a response package for the State of Nevada's September 1989 comments on the SCP. This package completes the DOE's response to all comments on the SCP. The DOE and NRC are approaching resolution to the NRC's two objections to the SCP. On August 21, the OCRWM requested removal of the NRC Site Characterization Analysis (SCA) Objection #2 on the Quality Assurance (QA) Program. A letter to provide the NRC with the status of the DOE response to the technical concerns related to design as expressed in NRC Objection #1 is being prepared.

1.2.2 Programmatic developments in support of site characterization

With the start of new, limited field work in July, the DOE once again demonstrated its readiness to continue a comprehensive site characterization program. If the water appropriations permit is issued, most of the surface-based field activities can begin, contingent on available funding. However, many permits are still required and it is uncertain how successful the DOE will be at obtaining the required permits from the State in a timely manner. Therefore, the DOE continues to support a legislative solution to the permitting problem.

Efforts continued during the reporting period on the ESSE. A core team of DOE contractors conducted the evaluation according to DOE's General Siting Guidelines in 10 CFR Part 960 and produced a preliminary draft report of their analyses, conclusions, and recommendations. An internal review by the lead contractor and a Yucca Mountain Site Characterization Project (YMP) management policy review were conducted in July and August, respectively, and the preliminary draft report was revised and transmitted to the ESSE Peer Review Panel on August 26. The peer review comments are expected to be received by November 12, 1991.

The DOE completed a third workshop on strategic principles for the OCRWM program during the reporting period. This workshop, open to the public, was held in Denver, Colorado, on April 3-4. The purpose was to provide a forum for discussion of the principles that will guide DOE's decisions and actions in managing the complex repository program, to focus on OCRWM's understanding

of the dialogue at the first and second workshops, and discuss OCRWM's intended responses to the comments and suggestions.

The results of the strategic principles workshops provided input to the preliminary draft MPA, which was issued for public comment on September 9. In addition to describing OCRWM's strategic principles, the draft MPA describes the major technical and institutional changes to the program since the 1987 amendment of the NWPA. The draft MPA also provides a comprehensive discussion of initiatives resulting from the Secretary of Energy's reassessment of the program (DOE, 1989).

Progress continued during the reporting period on the various components of the system design of the potential repository. The DOE hosted a workshop on engineered barrier systems concepts in Denver, Colorado, on June 18-20. The workshop participants discussed whether an engineered barrier system can be designed and demonstrated to have a reasonable assurance of remaining intact for 10,000 years, a period that far exceeds the regulatory requirements. Some potential designs that could assist in achieving such goals were presented by experts in the field.

Implementation of the MSIS continued through the reporting period. Technical reviews of nine requirements documents were conducted. Several baseline documents were submitted to the OCRWM CCB for review and approval.

Since the issuance of the Section 175 Report (DOE, 1988a), the OCRWM has developed an SP (DOE, 1991a) for Yucca Mountain. The SP describes the OCRWM's socioeconomic program for the site characterization phase and is designed to integrate data collection, data analyses, and reporting efforts. The SP was issued in May 1991 with future revisions possible on an 'as needed' basis.

Four Nevada counties were granted affected party status, as provided in the NWPA. These counties were White Pine (May 20, 1991), Eureka (May 20, 1991), Mineral (August 2, 1991), and Churchill (September 12, 1991), and also Inyo County in California (May 20, 1991). In addition, the DOE signed an agreement with Nye County to work cooperatively with them in many areas, including the development of a socioeconomic program.

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.

Two five-year cooperative testing program agreements were signed on September 23 and 30, with Switzerland and Canada, respectively. The cooperative testing agreement with Canada includes diverse activities involving technology and model development related to natural and engineered barrier characterization, performance assessment code verification, sealing material testing and natural analog studies. The agreement with Switzerland involves testing in the underground Grimsel Pass facility in Switzerland as well as laboratory testing of radionuclide sorption behavior.

Field activities for Phase III of the Stripa Project were concluded in June at the Stripa mine facility in Sweden. The international Stripa Project was initiated with the general aim of studying the potential of using fractured, hard, crystalline rock for the isolation of radioactive wastes.

Participants from the OCRWM program developed and tested fracture-flow hydrology codes for the final phase of the Stripa Project. Reports on the Phase III activities are being prepared along with two project summary reports and a final seminar.

The OCRWM program has begun support for the Alligator Rivers Natural Analog study in Australia. DOE is currently reviewing data produced previously in this project and evaluating the benefits of participation in the next phase of the project currently under development.

Phase II of the INTRAVAL project, an international cooperative effort focusing on performance assessment model validation using data from field, laboratory and natural analog studies, began during the reporting period. In Phase II, the OCRWM program is developing a field heater test to be performed in unsaturated volcanic tuffs at the Apache Leap site in Arizona.

The OCRWM program conducted meetings with technical staff from the Swedish waste disposal program for the purpose of discussing technical scopes and terms and conditions for potential cooperative studies in the Swedish Hard Rock Laboratory being constructed at the Aspo location. Meetings have been held with organizations in Spain and France to examine the potential for cooperative activities between the OCRWM program and the waste disposal programs in these two countries.

2.0 STATUS OF SITE CHARACTERIZATION

2.1 PREPARATORY ACTIVITIES

2.1.1 Quality Assurance program

During the reporting period, the OCRWM Office of Quality Assurance (OQA), Yucca Mountain QA Division (YMQAD) conducted five audits. The audits evaluated the following participant QA Programs for compliance to OCRWM requirements and effectiveness of program implementation: Lawrence Livermore National Laboratory (LLNL), United States Geological Survey (USGS), Science Applications International Corporation (SAIC), Raytheon Services Nevada (RSN), and Sandia National Laboratories (SNL). It was determined by the respective audit teams that the participants are implementing effective QA programs.

The NRC staff has determined that the SAIC, LLNL, USGS, SNL, Los Alamos National Laboratory (LANL), and Reynolds Electrical & Engineering Company (REECo) QA programs are acceptable for implementation of site characterization activities and other quality-affecting activities for the YMP, with no exceptions. NRC acceptance of the RSN QA program, based on information previously accepted by the NRC on behalf of the predecessor Fenix and Scisson of Nevada (FSN) and Holmes and Narver (H&N), is conditional based on satisfactory resolution of outstanding NRC comments on the RSN QA Program Description.

The OQA staff resolved recommended actions, resulting from OCRWM audit 90-I-01, necessary for NRC acceptance of the OCRWM QA program. In a letter dated March 11, 1991, the NRC conditionally accepted the OCRWM QA program for initiation of new site characterization activities associated with Midway Valley trenching and Quaternary regional hydrology activities involving calcite-silica studies. As follow-up to the NRC acceptance letter, a DOE letter dated August 21, 1991, requested that the NRC unconditionally accept the OCRWM QA program to start other new site characterization activities and other quality related activities, and also to lift the NRC's QA objection in their SCA.

The YMQAD conducted 13 surveillances of YMP participants: LLNL (1), USGS (2), SNL (2), SAIC (1), YMPO (2), RSN (1), LANL (3), and REECo (1).

Throughout the reporting period, work continued on consolidation of procedures between DOE/Headquarters (DOE/HQ) and the YMPO. The Procedure Consolidation Effort Working Group met in Las Vegas, Nevada, on August 13-14. The group discussed development of a standard format for all OCRWM procedures; identification of a new implementing procedure hierarchy; and identifying those "Q" procedures utilized by YMP management that are unique to YMPO, thereby, not candidate procedures for consolidation.

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, State of Nevada, and affected counties to identify QA issues and participate in the resolution of these issues. These meetings provide information on the status, development, and progress of QA-related actions.

2.1.2 Exploratory Studies Facility design and construction

The OCRWM approval of the Title I Design Summary Report for the ESF Draft Revision 1 took place on September 27. Acceptance by the ESAAB is needed before commencement of Title II Design for the ESF.

2.1.2.1 ESF alternatives study

The final report of the ESFAS was published in September 1991. The design study that was initiated in the previous reporting period was completed in August 1991. This resulted in a Title I (Preliminary Design) design package, and a Title I Design Summary Report for the ESF. The complete package was submitted to OCRWM for review and acceptance in September 1991. Access to the ESF was previously planned to be via two vertical shafts. Although no final decision has been made, the current reference design concept calls for a much larger ESF area with access via two inclined ramps constructed with tunnel boring machines.

Other important activities included a technical exchange between OCRWM and the NRC, discussed in Section 2.1.7.

2.1.3 OCRWM initiatives in surface-based and underground testing

2.1.3.1 Early Site Suitability Evaluation (ESSE)

In December 1990, the Office of Geologic Disposal (OGD) was requested by the OCRWM Director to prepare and implement a plan covering the following actions:

1. Development of a general DOE approach to the evaluation of site suitability, to be considered for presentation in a public forum in mid-1991.

2. An early assessment of the suitability of the Yucca Mountain site according to the general guidelines of 10 CFR Part 960, using methods consistent with the general approach developed under item 1 above. This assessment should include an evaluation of potential disqualifying features and conditions at the site. This assessment was expected to be provided to the OCRWM Director in January 1992.

In January 1991, at the request of the OGD, Technical and Management Support Services (T&MSS) formed a Core Team (a working group consisting of DOE contractor, national laboratory, and USGS scientists) for the ESSE task.

The Core Team compiled the information available from existing site data, design-development, modeling and performance assessment activities, and relevant literature sources. Subsequent to this compilation, the Core Team completed evaluations of this information using the system and technical guidelines of 10 CFR Part 960 as the framework for the evaluation. The Core Team completed a draft report on the results of their evaluations in July 1991. The draft report has undergone internal technical review by non-DOE program participants, and was submitted by T&MSS for an external peer review on August 23, 1991. The peer review panel consists of 14 technical experts

who are independent of the DOE and have expertise in a variety of disciplines. The peer review panel was expected to provide comments to the Core Team on November 12, 1991. Following resolution of peer review comments, the ESSE report was scheduled to be transmitted to the OGD and the OCRWM Director in January 1992.

In its efforts to implement action 1, above, the OGD will present the ESSE report for public comment and discuss this report with interested parties and affected governments in the spring of 1992. The ESSE report, comments provided by interested parties and the public, and other appropriate information will be evaluated by the OCRWM prior to making any formal determination regarding the current status of the DOE's evaluation of the suitability or unsuitability of the site.

2.1.4 Permits

2.1.4.1 Compliance with federal environmental requirements

The YMP has obtained all of the necessary permits and clearances issued by federal agencies to allow new site characterization activities to begin. Endangered species consultations concerning the desert tortoise have already been completed. On April 1, 1991, the National Park Service (NPS) withdrew its protest of the YMP water appropriation permit application based on the DOE commitment to monitor ground-water resources at Yucca Mountain and in Amargosa Valley.

The Floodplain Assessment (FA) and Statement of Findings (SOF) describing potential impacts to floodplains around Yucca Mountain from surface-based investigations was issued on September 26, 1991. This action satisfies the requirements of Executive Order 11988 and 40 CFR Part 1022. The FA identifies potential effects of DOE's proposed action on the floodplain and considers feasible alternatives. The SOF covers surface-based scientific investigation activities involving trenches across fault zones, and other minor surface disturbances within the 100-year floodplain at the Yucca Mountain site. DOE has concluded that there are no practicable alternatives to the proposed action and that all actions will conform to applicable State and local floodplain protection standards. DOE has also determined that the proposed action has been designed to minimize harm to the floodplain.

2.1.4.2 Compliance with state environmental requirements

As a result of decisions made by the U.S. Court of Appeals for the Ninth Circuit and the U.S. District Court for the District of Nevada, the State of Nevada resumed processing DOE's permit applications. On June 12, 1991, an air quality permit was received for surface disturbance. The permit was granted with 10 conditions, including stipulations for dust control and ambient air quality monitoring.

On July 17, 1991, the State of Nevada issued an underground injection control permit for the injection of tracers used in saturated zone hydrological tests. The permit was issued following a public hearing held on July 16, 1991. No public comments were expressed at the hearing.

The State of Nevada has also been processing the water appropriation permit application for the use of water from Well J-13. After processing the permit application to determine its completeness, a nine-day public hearing was held in September and the Nevada State Engineer was expected to make a decision before the end of the year. In the interim, temporary permission to divert was granted in connection with the permit for Well VH-1 to allow the use of water for site characterization at the entire Yucca Mountain site. This temporary permit will expire if a permit for Well J-13 is received.

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.

Nineteen participant requests to initiate site characterization activity were processed during the period. Fifteen of these requests have been completed and access authorization granted. The remaining 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 Bureau of Land Management (BLM) office for surface water monitoring stations; a land use application to the Needles Resource Area BLM office for volcanism studies; two rights-of-way applications to the Barstow Resource Area BLM office for seismic stations; request letters to the Stateline Resource Area BLM office, the Barstow Resource Area BLM office, and the Death Valley National Monument for permission to monitor 19 wells and springs; and a permit request to Clark County, Nevada, for a seismic station.

2.1.6 Public outreach

The Office of Institutional and External Affairs (OIEA) coordinated the YMP Nevada Public Update Meetings in Pahrump, May 20; Las Vegas, May 21; and Reno, May 23, 1991. Approximately 400 people attended these YMP Update Meetings which discussed general issues and, in part, the status of the scientific investigation program.

Beginning in March, YMPO staff coordinated six open house tours of Yucca Mountain and Area 25 of the NTS for 1,500 people, as well as approximately 50 other special purpose tours of the Yucca Mountain site.

OIEA staff hosted approximately 72 tours of the Clark County Yucca Mountain Information Office, located in Las Vegas, and prepared briefing packages, handled logistics, and accompanied YMPO staff to approximately 80 project-related presentations. Staff also began hosting monthly lecture series at the information office and coordinated and supervised construction of the Climax Spent Fuel Test Facility exhibit at the information office. They also coordinated a public open house for the exhibit, handled logistics, and staffed the YMP table-top exhibit at 21 exhibit showings. Staff coordinated media day on July 10 at the site to announce the beginning of new work.

Staff initiated the rural county outreach effort. This is an informal link between the various affected counties and the YMPO. Several staff members serve as YMPO representatives to the affected counties. These representatives are to facilitate communications and help each county and community learn about the YMP. Staff also continued interactions with Nye County.

2.1.7 Interactions with NRC and oversight organizations

The 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 six meetings and one workshop with the NWTRB. These were: (1) a NWTRB full board meeting including a DOE presentation on its Natural Analogs Program on April 16-18, 1991; (2) a NWTRB panel on Transportation and Systems (T&S) including a DOE update on transportation issues on August 15, 1991; (3) a NWTRB Risk and Performance Analysis Panel Meeting on Performance Assessment on May 20-21, 1991; (4) a Hydrogeology and Geochemistry (HG&G) and Structural Geology and Geoengineering (SG&G) Joint Panel on unsaturated and saturated zone testing and rock mechanics on June 25-27, 1991; (5) a NWTRB full board meeting where DOE addressed such concerns as the status of the Management and Operating (M&O) contractor, DOE involvement in international high-level waste management programs, the status of the ESSE effort, and other aspects of the YMP on July 16-18, 1991; (6) a SG&G Panel on ESF Design Status meeting on September 18-19, 1991; and (7) a NWTRB Engineered Barrier System (EBS) Workshop on June 18-20, 1991.

A successful technical exchange on ESF Design Control took place in Washington, D.C. on September 16, 1991. The exchange resulted in a verbal agreement with NRC that it would remove the design control portion of SCA Objection 1 upon its receipt of additional documentation confirming matters presented and discussed in the technical exchange.

The YMPO also participated in several interactions with the NRC. Technical exchanges conducted over the reporting period included (1) a NRC bimonthly QA meeting on April 25, 1991; (2) NRC interactions scheduling meeting on May 30, 1991; (3) a technical exchange on Data Management on July 30, 1991; (4) a NRC meeting regarding glass as a waste form on August 7-8, 1991; (5) a technical exchange on QA on August 28, 1991; and (6) a NRC Management meeting on procedural agreements on September 12, 1991.

In addition, the YMPO has participated in the ACNW working groups on Geophysics, Thermal Loads, DOE SCP Comment Response Process, Computer Modeling, and Performance Assessment Capabilities. The YMPO also participated in the International High Level Radioactive Waste Management (IHLRWM) Conference held on April 28 to May 3, 1991 in Las Vegas, Nevada, and the workshop on 40 CFR 191 sponsored by the Electric Power Research Institute (EPRI) held on September 24-27, 1991, in Washington, D.C.

2.1.8 Hydrology peer review task

The "Unsaturated Zone Hydrology Peer Review Record Memorandum," dated June 24, 1991, was approved by the YMPO in August 1991, and was printed and distributed to the participants and the NRC in September 1991 (DOE, 1991b).

2.1.9 Comments on the technical program

The NWPA, Section 113(a), requires the DOE to receive and fully consider comments on the SCP. The DOE has received a total of 4,615 comments on the statutory SCP (released on December 28, 1988) and its earlier Consultation Draft (released for comment in January 1988). DOE has responded to all of these comments as of the end of this reporting period. Recommendations by the NWTRB contained in their semiannual reports to Congress are treated as comments on the SCP and site characterization program and are responded to on a continuing basis. The YMPO has responded to 91 letters from citizens commenting on the SCP since it was released.

The DOE completed responses to 1,917 comments on the SCP received from the State of Nevada on September 1, 1989. This response document was returned on September 13, 1991, to the State's Nuclear Waste Project Office (DOE, 1991c). These comments were received by DOE after the formal SCP comment period had expired (January 15 - June 1, 1989) and were deferred until responses to comments received during the comment period had been completed. Bjerstedt et al. (1991) explains the process used by the YMPO to receive, respond to, and track comments on the SCP and on the site characterization program in general.

In a letter dated July 26, 1991, the NRC informed the DOE that objections, comments, questions, and any resultant open items that were created and tracked prior to the SCA (NRC, 1989) were intended to be subsumed or superseded by the objections, comments, and questions in the SCA itself. Table 2.1 in Progress Report 3 identified these pre-SCA open items (DOE, 1991d) which are now considered closed. With the exception of open items resulting from the Waste Acceptance Process for the vitrification of high-level waste, all pre-SCA open items on the SCP and a list of ESF open items maintained by the DOE since the late 1980s are considered closed by both DOE and the NRC.

The NRC assessed DOE's responses (DOE, 1990a) to their SCA and, in a letter to DOE dated July 31, 1991, identified open items that were not considered closed on the basis of DOE's responses. Table 2.1 identifies each open item and contains a brief description of the item and possible means to move toward closure. The possible or proposed method of closure indicated is not a committed course of action, rather it is a means to continue a dialog with the NRC with respect to their concerns. The DOE intends to work with the NRC to further address their concerns at appropriate points in the site characterization process.

TABLE 2.1 STATUS AND POSSIBLE MEANS TO ADDRESS NRC OPEN ITEMS ORIGINATING FROM NRC REVIEW OF DOE RESPONSES TO THE SCA (PR = SITE CHARACTERIZATION PROGRESS REPORTS)

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*KEY TO POSSIBLE/PROPOSED METHOD OF RESOLUTION:

1. Acquisition of new site data is needed for resolution.
2. Concern addressed through ESF Alternatives Study or new ESF design configuration.
3. Concern addressed through Calico Hills Risk/Benefit Analysis (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 Project plan, Study Plan/activity or other design studies in current technical baseline.
6. 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 intent to send documentation with respect to resolving the U.S. Nuclear Regulatory Commission's Objection 1.
12. DOE intent to send documentation with respect to resolving the U.S. Nuclear Regulatory Commission's Objection 2.

TABLE 2.1 STATUS AND POSSIBLE MEANS TO ADDRESS NRC OPEN ITEMS ORIGINATING FROM NRC REVIEW OF DOE RESPONSES TO THE SCA (PR = SITE CHARACTERIZATION PROGRESS REPORTS)

SCA OPEN ITEM		SUMMARY OF OPEN ITEM	RESOLUTION STATUS* (see codes, page 2-7)
OBJECTION	1	Adequacy of Title I Design Control Process	2, 3, 6, 8, 11
	2	Acceptability of DOE QA Program	7, 11, 12
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	1, 4, 5
	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	1, 3, 4, 5
	15	Solitario Canyon fault	5
	16	Characteristics of Calico Hills hydrologic properties	1, 3, 4, 5
	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 ground-water 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 (PR = SITE CHARACTERIZATION PROGRESS REPORTS)

SCA OPEN ITEM		SUMMARY OF OPEN ITEM	RESOLUTION STATUS* (see codes, page 2-7)
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 3-D models	5
	34	Integration of drilling program	3, 5, 11
	35	Adequacy of lithological, structural, and drifting activities to characterize the site	2, 3, 4, 11
	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, "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	2, 8

TABLE 2.1 STATUS AND POSSIBLE MEANS TO ADDRESS NRC OPEN ITEMS ORIGINATING FROM NRC REVIEW OF DOE RESPONSES TO THE SCA (PR = SITE CHARACTERIZATION PROGRESS REPORTS)

SCA OPEN ITEM		SUMMARY OF OPEN ITEM	RESOLUTION STATUS* (see codes, page 2-7)
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	5, 9
	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	2
	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 (PR = SITE CHARACTERIZATION PROGRESS REPORTS)

SCA OPEN ITEM		SUMMARY OF OPEN ITEM	RESOLUTION STATUS* (see codes, page 2-7)
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 carbon-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 EPPM	10

TABLE 2.1 STATUS AND POSSIBLE MEANS TO ADDRESS NRC OPEN ITEMS ORIGINATING FROM NRC REVIEW OF DOE RESPONSES TO THE SCA (PR = SITE CHARACTERIZATION PROGRESS REPORTS)

SCA OPEN ITEM		SUMMARY OF OPEN ITEM	RESOLUTION STATUS* (see codes, page 2-7)
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 carbon-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	2, 3, 5, 8, 11
	128	Design Acceptability Analysis	2, 11
	130	Design Acceptability Analysis	2, 11
	132	Design Acceptability Analysis	2, 11
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 analog	5

TABLE 2.1 STATUS AND POSSIBLE MEANS TO ADDRESS NRC OPEN ITEMS ORIGINATING FROM NRC REVIEW OF DOE RESPONSES TO THE SCA (PR = SITE CHARACTERIZATION PROGRESS REPORTS)

SCA OPEN ITEM		SUMMARY OF OPEN ITEM	RESOLUTION STATUS* (see codes, page 2-7)
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	3, 11
	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 (PR = SITE CHARACTERIZATION PROGRESS REPORTS)

SCA OPEN ITEM		SUMMARY OF OPEN ITEM	RESOLUTION STATUS* (see codes, page 2-7)
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	2, 5
	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	8, 11
	62	Basis for 500 ft of separation of ESF from waste emplacement and 30m of separation from ESF and waste emplacement panel	11

2.1.9.1 Comments on SCP Study Plans

The DOE and the NRC follow protocol established in an agreement resulting from a December 15, 1988, meeting on Study Plans. Details of the protocol were explained in this section in Progress Report 4 (DOE, 1991e). The NRC notifies the DOE within three months of receipt of a Study Plan if there are objections to starting work on any study. The NRC also provides detailed technical comments on specific Study Plans, at their discretion. To date, forty comments have been received on five Study Plans. The DOE has responded to four of these packages. 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 thirty-seven comments on six Study Plans and the DOE has responded to five of these comment packages.

Table 2-1 in Progress Report 4 (DOE, 1991e) showed the status of comments on Study Plans at that time. In this and future editions of the Progress Report, the status of Study Plan comment response is reported in Chapter 2.2, under the sections referring to specific Study Plans.

2.1.10 Site Characterization Program Baseline (SCPB)

Revision 0 of the SCPB was prepared and issued as a controlled document by the OGD on February 7, 1991. The SCPB contains aspects of the SCP technical program that OGD elected to place under a formal change control procedure. Changes to the SCPB are approved by the YMPO CCB. The SCPB consists of SCP Chapter 8 excluding Section 8.5 (milestones, decision points, and schedule), Section 8.6 (quality assurance), and other sections that contain information pertaining to schedules, milestones, technical procedures, and the application of results. The SCPB identifies the DOE's baselined site characterization program and provides a means by which the DOE can demonstrate traceability for changes in the site characterization program, including the rationale for those changes.

Controlled revisions to the SCPB and Study Plans are the means by which the DOE will keep the NRC informed of changes to the technical program. SCP Study Plans are consistent with the SCPB. Study Plans are revised in response to SCPB changes through the YMPO review, approval, and revision procedure for Study Plans. PRs report CCB actions pertaining to the SCPB for each reporting period. Changes to the Study Plans governing each site characterization study are reported under the status section for each study. Changes to individual Study Plans can occur without a corresponding change to the SCPB as long as the change is consistent with the scope of work contained in the SCPB.

Revision 1 of the SCPB was issued on April 5, 1991. This revision updated information related to the ESF in preparation for the start of Title II design studies. This revision of the SCPB incorporates changes to program planning based upon the reference ESF design concept resulting from the ESFAS. Revision 2 of the SCPB was planned for October 1991.

2.1.11 Performance assessment

The nominal case analyses of the performance assessment calculational exercises (PACE-90) activities were published in the "Technical Summary of the Performance Assessment Calculational Exercises for 1990 (PACE-90), Volume 1: Nominal Configuration Hydrogeologic Parameters and Calculational Results" (Barnard and Dockery, 1991).

A determination of ground-water travel time was furthered by the continued development of a probabilistic model that explicitly handles uncertainty in the calculations needed for guiding site characterization. With this model, it proved possible to use newly available site data to obtain fresh insights from such calculations. The following reports or papers were published in support of this effort: "Conceptual, Experimental and Computational Approaches to Support Performance Assessment of Hydrology and Chemical Transport at Yucca Mountain" (Narasimhan and Wang, 1991), "Dual Porosity Models for Solute Transport at Yucca Mountain" (Dykhuizen, 1991), and "A Summary of Subsurface Hydrological and Hydrochemical Models" (Mangold and Tsang, 1991).

Total-system assessment 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 complementary cumulative distribution functions 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 following reports were published in support of the ESSE and the total-system analyses: "One-Dimensional Human Intrusion Analysis of Paleozoic Aquifer, as Part of Site Suitability Effort at Yucca Mountain, Nevada" (McGraw et al., 1991), "Waste-Package Release Rates for Site Suitability Studies" (Lee et al., 1991), "Preliminary Calculations of Release Rates of TC-99, I-129, CS-135, and NP-237 from Spent Fuel in a Tuff Repository" (Apted et al., 1991), and "Prediction of Release Rates for a Waste Repository at Yucca Mountain" (Sadeghi et al., 1991).

Support to evaluations of the ESF design included evaluations of alternative portal and shaft locations, and a report entitled "An Assessment of the Hydrological Impact of Extending Exploratory Shafts into the Calico Hills Nonwelded Tuff Unit at Yucca Mountain" (Freshley, 1991).

Support to design work for the potential repository has produced, among other accomplishments, a series of sensitivity studies that calculate temperature distributions around a potential repository and suggest new recommendations for the emplacement of waste.

Experimental laboratory studies of critical phenomena associated with flow in unsaturated fractured media were conducted to support the validation of models for performance assessments. They have also produced a variety of new techniques for use in the highly difficult experimental study of such flow.

The results of a 1990 workshop were documented, which was held to evaluate the state-of-the-art of radionuclide sorption and related processes and to formulate recommendations for future work, both experimental and mathematical; see "Summary and Evaluation of September 1990 Sorption Workshop" (DOE, 1991f).

2.1.12 Management and Operating Contractor

The Management and Operating (M&O) contractor initiated the development of a transition plan in February 1991, in accordance with the M&O's approved Start-Up Plan. The transition plan was created in order to establish the M&O contractor as the implementor of OCRWM policy and to provide overall management and technical direction for the YMP.

The M&O team's first six months of activity (February to August) involved the performance of studies and analyses as well as the conducting of Technical Information Exchange Meetings with each YMP participant. The results of these YMP familiarization efforts provided the DOE with specific transition implementation recommendations, with the intent of minimizing project cost and schedule impacts and to reduce duplication of effort by program participants.

In order to perform the tasking in accordance with the recommendations contained in the transition plan, the M&O team first had to become qualified to conduct the prescribed activities. It was determined that a dual approach was necessary considering the time and complexities associated with establishing an M&O set of Implementing Line Procedures (ILPs) in accordance with NQA-1. The M&O team embarked on the creation of these ILPs with particular attention to those procedures necessary to perform the immediate tasks agreed upon with DOE/YMPO management. In addition, M&O personnel also started training to become qualified to do work under the YMPO procedures. This approach ensured that the M&O's team could start assuming task responsibilities by October 1, 1991. Both the establishment of M&O ILPs and training under YMP procedures were accomplished by the September 30, 1991, goal and some task responsibility has been assumed. The M&O is awaiting a formal readiness review in December 1991, in order to assume complete responsibility of activities, as agreed upon with DOE management.

Technical activities during the period from February to September 1991 were limited as a result of readiness preparations and YMPO training requirements prior to undertaking quality-affecting work. However, after YMPO procedure training was completed by the majority of M&O personnel, support to the DOE/YMPO was provided in several areas. An M&O team of surface and subsurface design and development personnel supported the management and technical ESF Title I design review. This review has been completed and recently the YMPO initiated limited work on the detailed ESF Title II design. In addition, the M&O has been delegated by the YMPO as the ESF Construction Manager. As such, a Construction Management Plan and Construction Implementation Plan have been developed and submitted to the YMPO for formal QMP 06-04 review and acceptance.

Other activities such as the assumption of system integration responsibility, planning and management of site characterization efforts, support of the MSIS and the development of Repository and Waste Package Plans

have recently been undertaken by the M&O team and will continue to occupy the majority of the M&O's team in the immediate future.

2.2 SITE PROGRAMS

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

- Geohydrology - investigates surface and subsurface hydrology on both site and regional scales, with ground-water flow system characterization and modeling for both the unsaturated and saturated zones (SCP Section 8.3.1.2).

  Summary of progress during reporting period

  Monitoring of the Yucca Mountain precipitation network continued. Correlation between the lightning and precipitation patterns during a notable storm that occurred August 31 is being attempted. Collection of regional meteorological data continued and a statistical analysis of the probability of precipitation occurring on any given day of the year was concluded. Natural infiltration evaluation activities continued and drilling of new neutron access boreholes began September 23. Development of a conceptual model of natural infiltration with detailed information from Pagany Wash was completed. Deterministic analysis was initiated on the spatial variability of moisture profiles.

  Evaluation of the methodology for handling, transporting, and preserving core samples from Yucca Mountain drilling was completed and prototype testing continued on several laboratory techniques. A 550-sample set of small diameter diamond drill core representing every lithologic unit in the volcanic stratigraphy from the Calico Hills unit to the Tiva Canyon tuff was collected from outcrops and analyses began in the laboratory for physical and hydrologic properties and calibration.

  Analysis of mining company borehole data, geophysical, and lithologic logs from exploration holes drilled in the Amargosa Desert continued. Results of pneumatic, pumping, recovery, and tracer testing in 8-inch diameter vertical holes at the Apache Leap site were analyzed for permeability and porosity. Shakedown drilling for the LM-300 was completed in Utah during July and August resulting in a list of several needed modifications. Prototype intact fracture, percolation, radial borehole, and diffusion tests continued relative to the ESF. Aqueous-phase chemical investigations continued on core samples and development of conceptual and numerical models for fluid flow in unsaturated fractured rock continued. Monitoring of water levels in the saturated zone also continued.

- Geochemistry - investigates and models rock chemistry and mineralogy, ground-water chemistry, and geochemical behavior of materials along potential radionuclide transport pathways (SCP Section 8.3.1.3).

  Summary of progress during reporting period

  Sorption studies continued with emphasis on laboratory measurements of the sorption behavior of neptunium on pure mineral phases, experiments on the effects of rock crushing on the measured sorption coefficients for cesium, strontium, and neptunium, and the development of the capability for atomic force microscopy. Development of sorption models focused on a strategy for incorporating sorption reactions into transport calculations, and detailed sorption models for the adsorption of neptunium into major Yucca Mountain mineral phases. Solubility and speciation measurements, and solubility modeling continued. Analysis of the transport behavior of selected elements in solutions prepared with water from well J-13 as a function of mineralogy was completed.

- 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).

  Summary of progress during reporting period

  A data compilation report was initiated containing fracture data from the Tiva Canyon and Topopah Spring members of the Paintbrush Tuff including quantitative, semi-quantitative, and qualitative measurements at each locality. Scoping studies of spatial continuity and determination of material properties continued on 658 samples that comprise a composite vertical profile through all units constituting the unsaturated zone. Alternative interpretations of the lithologic contacts between thermal/mechanical units in existing core holes were reevaluated by the Sample Overview Committee. A proposal to raise the lithologic contact elevations in the northeastern part of the potential repository block as much as 100 meters was presented to the YMP CCB and three-dimensional models were recalculated. Limitations of existing geometric modeling capabilities have become more apparent so that evaluation began of replacement software and hardware that would allow integration with developing geostatistical methodologies.

- Climate - analyzes paleoclimate, paleohydrology, and paleoenvironment, and characterizes modern climate, future climate, and future hydrology (SCP Section 8.3.1.5).

  Summary of progress during reporting period

  The regional climate model, MM4, was used to generate three years of regional climate simulations using data from the European Center for Medium-Range Weather Forecasts. Analysis involved comparing model

results to data from the National Climate Data Center and data from the Southern Great Basin. Analog recharge studies involved evapotranspiration field work and precipitation monitoring at Stewart and Kawich Creeks, the Safford site, and Organ Pipe Cactus National Monument. Uranium and strontium isotopic analysis continued on vein carbonates from drillholes and Trench 14. During July, Trench 14 was deepened to 20 feet and samples of the newly exposed veins and tuff were collected. The veins were observed to narrow to a width of 4-5 cms at the bottom of the trench. Several abstracts and papers were presented summarizing results of the isotopic analyses and proposing models for the formation of pedogenic carbonate.

- Erosion - characterizes modern and past erosion and evaluates the potential effects of future climate and tectonics on erosion (SCP Section 8.3.1.6).

  Summary of progress during reporting period

  This activity is not currently funded.

- Postclosure Tectonics - characterizes tectonic features such as igneous activity and fault and fold deformation in the Yucca Mountain vicinity, with emphasis on volcanic activity, and analyzes the potential effects of tectonic processes on a potential repository and the site ground-water system (SCP Section 8.3.1.8).

  Summary of progress during reporting period

  A range of models of structural controls on volcanic activity was considered and used in calculations of the probability of magmatic disruption of the potential repository. An independent review of the geochronology studies was completed by D. DePaolo, Chair of the Department of Geological Sciences at the University of California, Berkeley. Staff discussed the use of 40Ar/39Ar studies with experts on this technique. P. Zeitler, Lehigh University, agreed to participate in future geochronology studies.

  New surface-disturbing work was successfully completed on July 9-10 and continued on August 29-30 at the Lathrop Wells volcanic center. This work consisted of constructing soil pits for observation of stratigraphic relations and sampling of appropriate units. Sampling was also completed of the 3.7 million years old (Ma) centers for petrology and geochronology studies.

  Strontium, Nd, and Pb isotopic analyses of the Lathrop Wells volcanic center were initiated through a contract with the University of Colorado isotopic laboratory and data was received for the Sr and Nd isotopic systems. Examination of these data and instrumental neutron activation analysis (INAA) data continued in order to test eruption models.

- 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).

  Summary of progress during reporting period

  Several geologic maps were completed illustrating data on mines, types of deposits, prospects, and mineral resources in the southwest Nevada volcanic field. Draft reports on hydrocarbons in the vicinity of Yucca Mountain and a geophysical assessment of mineral resource potential were completed. A major compilation of existing information, "Mines, Prospects, and Mineral Occurrences in Esmeralda and Nye Counties, Nevada, Near Yucca Mountain" (Bergquist and McKee, 1991) was published.

- Meteorology - characterizes the site and regional meteorological conditions of the Yucca Mountain vicinity (SCP Section 8.3.1.12).

  Summary of progress during reporting period

  Synthesis of meteorological monitoring data and characterizing the potential extreme weather phenomena and their recurrence intervals have been incorporated into revision 1 of the Meteorological Monitoring Plan.

- 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).

  Summary of progress during reporting period

  This area is inactive.

- Surface Characteristics - characterizes the properties of surficial soil and rock materials and topographic characteristics in the site area (SCP Section 8.3.1.14).

  Summary of progress during reporting period

  All three studies are being combined into a single study. A final version of this Study Plan was prepared after comment resolution for DOE approval.

- 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).

Summary of progress during reporting period

Several technical procedures required to perform thermal conductivity and expansion characteristics tests have been approved. Prototype experiments and technical procedures have been completed for laboratory tests of mechanical properties of intact rock. The topographies of fractures in igneous and sedimentary rocks were profiled and software has been developed to analyze these data.

- 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).

  Summary of progress during reporting period

  Ongoing monitoring of weather conditions and situations conducive to flooding continued with the main focus on the probable maximum flood investigations. A draft report was prepared listing probable maximum flood magnitudes for drainages that include proposed surface facilities.

- 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).

  Summary of progress during reporting period

  One trench was excavated in the Midway Valley area and no evidence for faulting was observed. Mapping of surficial units in Midway Valley continued with preparation of maps, description of units, and field verification of mapped units. Required environmental permits were obtained for the thirteen soil pits that are planned as the next phase of surface-disturbing work. Preparation continued of strip maps of faults in the Yucca Mountain area and of a draft tectonic map of the Death Valley-Yucca Mountain region.

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 was sent to the NRC on June 21, 1991.

Activity 8.3.1.2.1.1.1 - Precipitation and meteorological monitoring. Monitoring of the Yucca Mountain precipitation network continued. The network consisted of 93 plastic collection gages and 13 tipping bucket automated gages. Four plastic gages were added at two planned drill sites (USW UZ-N55

and USW UZ-N36) late in September. During the reporting period there were 18 days on which precipitation events occurred. The most notable at Yucca Mountain was the storm of August 31 when 37 millimeters fell in about 35 minutes at the weather station on the crest.

Weather station and tipping bucket data were collected, archived, and evaluated for consistency and quality. Technical procedures for laboratory calibration of the heated Qualimetrics rain/snow gage and the Sierra-Misco rain gages were completed and approved. Calibration of new tipping bucket gages continued; however, no new buckets were deployed in the field.

The receipt of Geostationary Orbital Environmental Satellite (GOES) data continued. Data are collected and archived a maximum of every 3 hours. The images cover all of North America and are received as quadrants.

Lightning data (cloud-to-ground) collection and archival continued. An effort will be made to correlate the lightning pattern, during the August 31 storm, with the precipitation pattern in an effort to derive a relationship between the number of lightning strikes and the amount of precipitation recorded.

The collection of regional meteorological data, primarily precipitation data, continued. The data are used in regional geostatistical analyses of precipitation patterns and in studying storm trajectory. Preliminary scoping work was concluded using historical precipitation data from Desert Rock Airport, Nevada (1979-1990); Beatty, Nevada (1979-1990); and the NTS climatological gage, 4JA, in Jackass Flats (1958-1990). The work included a statistical analysis of the probability of precipitation occurring on any given day of the year. As might be expected, the probabilities were very low. Further study is planned to include spatial and seasonal comparisons of precipitation probabilities at these three locations.

2.2.1.2 Study 8.3.1.2.1.2 - Characterization of runoff and streamflow

Study Plan 8.3.1.2.1.2 received NRC acceptance May 5, 1991. DOE responses to 7 comments by the State of Nevada on this Study Plan were returned to the State on August 20, 1991.

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. The installation of 4 additional stream-flow monitoring sites, three on the upper Fortymile Wash and one on the Amargosa River, were completed. Three alert transmitters were also installed and await the placement of a repeater on or near the area of Sawtooth Mountain before activation. Several runoff events occurred, and estimates of peak discharges were computed for areas on the Amargosa River tributary #1 near Johnnie, Fortymile Canyon below Pah Canyon, Cane Springs Wash tributary near Cane Springs, and Fortymile Wash near Rattlesnake Ridge. Runoff was also documented at N.F. Coyote Wash, Ghost Dance Wash, Abandoned Wash and Dune Wash on Yucca Mountain. Compilation of the 1986-91 surface-water records continued. Levels were run at network stream gage sites in line with USGS standards.

Activity 8.3.1.2.1.2.2 - Transport of debris by severe runoff. The summer runoff of 1991 was too light for significant debris transport. Data were collected and are being processed for one small debris flow resulting from a thunderstorm in the Walker River drainage of western Nevada.

A substantial amount of data were collected on the August 1990 debris flow at Copper Canyon, Walker Lake, Nevada. This debris flow was a classic mudflow that consisted of several flow surges. Data from this flow are currently being processed and interpreted.

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 was sent to the NRC on February 15, 1991.

Activity 8.3.1.2.1.3.1 - Assessment of 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 is 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. The analysis of mining-company borehole data, geophysical, and lithologic logs from exploration holes drilled in the basin-fill sediments of the Amargosa Desert, was resumed. The geophysical and lithologic data base was inventoried and catalogued. The archived drill cuttings were reexamined, and existing borehole lithologic logs were supplemented. New lithologic logs were compiled from the microscopic examination of archived drill cuttings from three boreholes drilled by the mining company in 1990, and also from 12 older Amargosa Desert boreholes not previously logged by YMP staff. A complete photographic record was made of all the logged cuttings. The conversion of the lithologic and geophysical data to standard log formats was begun, using commercially available software. Two formats include a suite of four different borehole geophysical logs plus lithology, and one format is a detailed lithologic log. The result of this process will be a data package that can be used for stratigraphic correlation in the Amargosa Desert, in support of regional hydrogeologic framework studies.

Planning and preparations for data collection from three wildcat wells in the Amargosa Desert were made in joint effort with USGS, Geologic Division, Petroleum Branch personnel. The first well was spudded on September 17, 1991. On-site cuttings collection and logging have been performed and may be continued by YMP personnel throughout the duration of drilling of the three wells. Discussions were held with representatives of the petroleum industry concerning design strategies for instrumenting these wells. The possibility of performing a vertical seismic profile survey in one of the wells was discussed with representatives from Lawrence Berkeley Laboratories (LBL).

Water level measurements were made in about 40 wells in the northern and southern parts of the Amargosa Desert. The position of well NT-1 was established through field reconnaissance during which latitude and longitude of this location was obtained. A status report was prepared on water-level measurements in the Amargosa Desert. Information for all wells in the area

contained on the Death Valley Junction and Beatty 1:100,000 maps has been retrieved from the USGS National Water Information System data base. Information included: (1) location in latitude and longitude; (2) site ID; (3) well depth; (4) casing diameter; (5) altitude of measuring point; (6) height of measuring point above land surface; (7) depth to water in meters; (8) water-level altitude in meters; and (9) date of last measurement. Draft contour maps of the regional potentiometric surface were prepared using water-level data from wells contained on the Beatty 1:100,000 series base map. Detailed lithologic descriptions of cuttings from several boreholes in the Amargosa Desert were prepared prior to the field reconnaissance of exposures of basin-filling sedimentary rocks in the central and southern Amargosa Desert. Old log books and other water-level records were reviewed for data on the water-level network sites not stored in ground-water site inventory (GWSI) data base.

A poster entitled "Hydrogeologic Inferences from Drillers' Logs and from Gravity and Resistivity Surveys in the Amargosa Desert, Southern Nevada" (Oatfield and Czarnecki, 1990) was published by the USGS and the Journal of Hydrology.

Activity 8.3.1.2.1.3.3 - Fortymile Wash recharge study. Technical discussions were held with representatives of the unsaturated zone section of the Hydrologic Investigations Program (HIP) on the status of plans for obtaining and analyzing water samples from drillholes in Fortymile Wash. Existing data on Fortymile Wash recharge have been compiled and analyzed on a continuous basis.

Technical procedure development for artificial recharge has been continued. This task has involved the review of literature on artificial infiltration as well as discussions on the natural infiltration events with participants involved in unsaturated zone studies. Preferred pathway moisture movement through the unsaturated zone will need to be addressed in the artificial infiltration experiments as uniform wetting fronts may not exist in material such as alluvial deposits.

Neutron meter moisture measurements were performed in boreholes UE-29 UZN #91 and UE-29 UZN #92 in Fortymile Wash to monitor moisture movement after a combined runoff and rainfall event at UZN #91. Preliminary analysis of neutron logs indicates that moisture moved approximately 0.3 meter down into the alluvial sediments.

Channel geometry characteristics were measured on Fortymile Wash, Amargosa River, and Topopah Wash. The drainage areas computations and drawing boundaries of these areas on 1:24,000 USGS topographic maps were initiated.

Activity 8.3.1.2.1.3.4 - Evapotranspiration studies. Text was revised for a report describing the deployment of a multilevel sampler at Franklin Lake Playa, Inyo County, California. A multilevel sampler was used to obtain vertical hydrochemical profiles in a well at Franklin Lake Playa for purposes of examining the process of evaporative enrichment of salts in the shallow ground-water flow system.

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 in the comment resolution process after review by the YMPO.

Activity 8.3.1.2.1.4.1 - Conceptualization of regional hydrologic flow models. Contour plots of simulated hydraulic head were generated for simulation involving increased recharge coupled with an abrupt increase in hydraulic conductivity in the vicinity of the large hydraulic gradient northwest of the potential repository block.

An abstract for a paper entitled "Preliminary Simulations Showing Potential Effects of a Wetter Future Climate Coupled with a Localized Increase in Hydraulic Conductivity on the Ground-water Flow System of Yucca Mountain and Vicinity, Nevada-California" (Czarnecki, 1991) was published. A paper entitled "Conceptual Models of the Regional Ground-water Flow System, and Planned Site-Characterization Studies, Yucca Mountain and Vicinity, Nevada-California" (Czarnecki and Wilson) was revised and sent to the Journal of Hydrological Science and Technology: Short Papers of the American Institute of Hydrology, for consideration.

Technical discussions were held with staff at Kent State University on the status of developing a computer code module for the USGS Precipitation Runoff Modeling System surface-water flow model to describe recharge within arid stream reaches. Also, the geometry and flow units involved in various models of ground-water flow in the vicinity of the NTS were discussed with personnel from Intera, Inc., a part of the new M&O contractor.

Activity 8.3.1.2.1.4.2 - Subregional two-dimensional areal hydrologic modeling. Simulations were performed to predict the effects of ground-water withdrawals from Well J-13 on the ground-water flow system of Yucca Mountain and vicinity. These simulations provide an estimate of the maximum flux that could be sustained without producing a serious impact on water levels in the vicinity of Amargosa Valley (formerly Lathrop Wells). The simulations were made primarily in preparations for the water-permit hearing with the State Engineer's Office in September 1991. A report entitled "Simulated Water-Level Declines Caused by Withdrawals from Wells J-13 and J-12 Near Yucca Mountain, Nevada" (Czarnecki) received USGS approval and YMPO concurrence.

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 modeling. A three-dimensional model grid was developed for the region surrounding Yucca Mountain area. The grid is necessary for evaluating the data reduction process and model evaluation. A number of geologic maps were scanned and edited for use as input data for the three-dimensional model. These machine-readable maps provide the foundation for developing the third dimension, depth, for the geohydrologic model. Several other model parameters, such as soil type, have been reduced to machine-readable form.

2.2.1.5 Study 8.3.1.2.2.1 - Characterization of unsaturated-zone infiltration

Study Plan 8.3.1.2.2.1 received NRC acceptance on May 31, 1991.

Activity 8.3.1.2.2.1.1 - Characterization of hydrologic properties of surficial materials. Approximately 550 small-diameter (one inch) core samples were collected from outcrops at Yucca Mountain and vicinity using a portable, gas-powered core drill. Core samples were collected from several transects on 5- to 10-foot spacings for vertical transects and on 500-foot spacings on a horizontal transect. A vertical transect from near the bottom of Solitario Canyon to Yucca crest sampled the upper one-half of the Topopah Spring Member of the Paintbrush Tuff, the bedded tuffs, and the Tiva Canyon Member of the Paintbrush Tuff. A vertical transect at Busted Butte provided samples from the entire Topopah Spring Member of the Paintbrush Tuff from the basal vitrophyre to the quartz latitic caprock. The tuffaceous beds of Calico Hills were sampled in a vertical transect near Prow Pass. A horizontal transect along the top of Yucca Crest from borehole USW G-3 to near the Little Prow provided samples from the upper part of the Tiva Canyon Member of the Paintbrush Tuff.

The core samples were collected to provide data on the range in values of the hydrologic and physical properties of the samples, the vertical and horizontal variability in the hydrologic and physical properties of the tuffs, and to provide information for the development of technical procedures. The core samples are being tested to determine bulk density, grain density, porosity, saturated hydraulic conductivity, and sorptivity.

A field trip was conducted at Yucca Mountain for three LBL scientists who are currently working on unsaturated-zone infiltration and saturated-zone flow models.

Activity 8.3.1.2.2.1.2 - Evaluation of natural infiltration. Monitoring continued at a Class A evaporation pan at Jackass Flats where an improved automated refill and data collection system was developed to allow winter season operation, improve measurement accuracy, and to improve the efficiency of operation. The 90-gallon water transport tank and pump system was also modified for improved operation. Calibration and testing of the new automated refill reservoir was initiated.

An analysis of the feasibility of continuously monitoring the moisture in a shallow uncased borehole in unconsolidated alluvium in Topopah Wash was completed. The instrument string was recovered from the borehole and was reassembled to perform instrument verification. Analysis of the field data and post retrieval testing of the instruments continued.

Prototype testing of equipment and methods for measuring evapotranspiration using the Bowen Ratio Energy Balance technique continued at the instrument station located at the mouth of Pagany Wash. Preliminary results of this investigation indicated the soil heat flux to be the most difficult parameter to measure. A thermal conductivity probe was ordered and the development of a soil heat flux model using measurements from a soil heat flux plate was initiated. This study will be a very important component of the overall deterministic modeling effort and the characterization of natural infiltration.

The program for monitoring natural infiltration in the shallow unsaturated zone by the periodic logging of 74 shallow boreholes using a neutron moisture meter continued as scheduled on monthly to bimonthly intervals. The tabulation and analysis of neutron count data is continuing for all boreholes. Locations for 10 new neutron access boreholes were identified and approved. Locations for 2 additional boreholes have also been identified but are awaiting resolution due to possible interference with environmental survey plot boundaries.

Drilling of the first neutron access borehole in WT-2 Wash was initiated near the northeastern part of the potential repository block on September 23, 1991 (Figure 1.1), providing new data on the thickness of the alluvial cover. Neutron holes are drilled dry with a small ODEX rig, and core samples are being collected for future analysis. The borehole was logged with a neutron moisture meter after each day of drilling and casing. Analysis of the moisture profiles indicated significant drying of the borehole during drilling, but a recovery to predrilling equilibrium within a time period of several days was also observed. This information is very important concerning the calibration of borehole instruments in new neutron access boreholes using measurements obtained through continuous coring and sampling.

Development of a conceptual model of natural infiltration with detailed information from Pagany Wash for a 9-month period following a 1984 summer thunderstorm runoff event indicated both lateral and vertical unsaturated flow within the alluvium profile. Preliminary results from the Pagany Wash 2-dimensional finite difference infiltration model for 5 boreholes located in a transect across the wash indicated the existence of lenses or layers with varying material properties within the alluvium. Alluvium/colluvium stratigraphy was studied at trench sites and natural exposures in Pagany Wash and at nearby field sites in an effort to investigate the average horizontal continuity of the various identifiable layers and lenses. Field observation indicated the existence of caliche layers and possibly an A-B soil horizon transition which may correspond to low permeability zones indicated by the moisture profiles and preliminary results of inverse modeling using the 2-dimensional model. The 2-dimensional model is being developed as part of the deterministic Pagany Wash water balance model that will incorporate daily precipitation and evapotranspiration data.

An analysis of gamma-gamma density logs was initiated to obtain measurements of formation porosities for neutron access boreholes. This information is critical for calculating saturations needed for the deterministic infiltration models, to help analyze infiltration mechanisms, and to characterize material properties. The density profiles were also compared with the volumetric water content profiles in an effort to help identify various zones and layers within the alluvium in Pagany Wash.

Field sampling of surficial materials at locations in Jackass Flats and Pagany Wash, and the development of moisture characteristic curves for these materials, were completed. These results are needed for the development of deterministic models to characterize natural infiltration, evapotranspiration, and for the interpretation of field measurements of moisture content and moisture profiles.

Evaluation of the spatial variability of moisture profiles using geostatistics, and also deterministic analysis, was initiated. Preliminary results of this activity were presented in June to the NWTRB. A geostatistical analysis of volumetric water content obtained from neutron logs of shallow boreholes in Pagany Wash was initiated for the development of the 2-dimensional infiltration model. A deterministic analysis of moisture profiles of all boreholes within Pagany Wash is also underway to investigate the variability of upstream versus downstream profiles, sideslope versus channel profiles, and bedrock versus alluvium profiles.

A paper entitled "Collimated Neutron Probe for Soil Water Content Measurements" (Klenke and Flint, 1991) was published by the Soil Science Society of America (SSSA).

Activity 8.3.1.2.2.1.3 - Evaluation of artificial infiltration. Support equipment for the precipitation network, such as storage gages, and tipping bucket rain and snow gages have undergone much evaluation. Field testing continues to seek refinement of the precipitation measurement, and these techniques will be applied to the artificial infiltration plots.

Field testing of the time-domain reflectometry (TDR) system proceeded following a spring storm. Field samples were collected for moisture content and water potential determination. Work proceeded on field calibration procedures, along with controlled laboratory experiments to aid understanding of the TDR trace output.

2.2.1.6 Study 8.3.1.2.2.2 - Water movement tracer tests

The Study Plan is undergoing revision and is in LANL review. Major changes include (1) plans to sample surface-based drillholes and to collect soil profiles, (2) more detail on the technical procedures that will be followed, and (3) an error analysis of the expected level of uncertainty in the ^{36}Cl-based estimates of the residence time of water in the unsaturated zone.

Activity 8.3.1.2.2.2.1 - Chloride and chlorine-36 measurements. The principal investigator (PI) made a presentation to the NWTRB joint meeting of the Hydrogeology and Geochemistry Panel and the Structural Geology and Geoengineering Panel in Denver, Colorado, during its June 25-27, 1991, meeting. The talk, entitled "Isotopic Constraints on Transport Models Based on ^{36}Cl Analyses," emphasized changes to be incorporated into the Study Plan revision.

Five detailed technical procedures (DPs) have been satisfactorily revised in response to technical and QA review comments. Five additional draft DPs remain to be submitted for review.

Sample collection for this activity was coordinated with the field activities of the USGS for Characterization of Unsaturated-Zone Infiltration; the interface was through the Sample Management Facility (SMF). Drilling the first of twelve neutron-access boreholes for the USGS study began on September 23, 1991, and the drilling procedure was modified to provide samples for ^{36}Cl analysis. After consultation with SMF staff, sample requests by the LANL PI

were approved by the YMPO SOC according to the process specified by YMPO procedure.

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 was sent to the NRC on May 10, 1991.

Activity 8.3.1.2.2.3.1 - Matrix hydrologic properties testing. Evaluation of the methodology for handling, transporting and preserving core samples from Yucca Mountain drilling was completed. Hermetically-sealed, steel "soup" cans will be utilized to preserve small samples for gravimetric water content (GWC) measurements. Tests of these cans revealed that water lost through evaporation was less than one milligram per day for a 100-gram water sample. The remainder of the cores will be preserved in polycarbonate tubes with polyethylene endcaps. Although tests have shown that the plastic tubes do allow enough moisture loss from the cores to effect state-variable measurements, the plastic will adequately prevent the rocks from drying out enough to cause changes in the physical properties of the samples. The humidity-oven drying procedure, the technique of cutting and trimming core plugs, and the method of saturating cores with water under a vacuum after flushing the pores with carbon dioxide gas have been evaluated, and development of these procedures is in the final stages.

Prototype testing continued and is near completion on several laboratory techniques. Water retention measurements using the submersible pressurized outflow cell (SPOC) have been much more successful since new barrier materials were tested. A microporous, permeable filter membrane backed up by a ceramic plate has been tested up to 12 bars without being breached. Problems still exist with sealing the barrier against the body of the cell, and with temperature and air current instability affecting the load cell used to weigh the apparatus. These problems are being addressed and should be resolved soon. YMP staff visited with personnel at Washington State University in Richland, Washington, to evaluate and discuss a new steady-state centrifuge method that allows for the determination of water retention curves and unsaturated hydraulic conductivities on fairly tight rock samples. The device appeared to work very effectively, and plans have been made to procure a similar centrifuge for analyses.

A low-pressure permeameter was fully operational in the Hydrologic Research Facility (HRF), but has only one coreholder. An additional coreholder was in the process of being added, and two more are planned. The major restriction on plumbing multiple coreholders onto the permeameter is the lack of pressure and flow sensors to feed data into a computer. These will be added to the unit as they are procured and tested. A single coreholder, low-pressure permeameter is also planned to allow analysis of whole HQ-size core samples without having to undercore one-inch plugs. The machined endcaps, plastic PVC pipe for the confining vessel, pressure sleeves and other components necessary to construct the device have been received, and the equipment will be assembled soon. Efforts have been initiated to obtain two stainless steel coreholders and various other components for measured, densely-welded tuffs, which are too tight to measure under the relatively low pressure limits of the current PVC plastic pipe coreholders.

A redesign of the apparatus used to measure water imbibition into dry cores has been completed and is undergoing tests. Problems with evaporation, temperature fluctuation and air currents were resolved by placing the apparatus in an environmental chamber. When fully developed, this system will be able to run simultaneous imbibitions on multiple samples. Depending on the number of load cells used and the size of the water pan, it should be possible to measure imbibition on at least a dozen cores at one time.

A helium pycnometer which measures grain density and volume using a Boyle's Law gas expansion method was evaluated and found to supply useful physical property measurements fairly quickly on individual samples. A chilled-mirror psychrometer for measuring water activity using a dewpoint temperature sensor was obtained and is currently undergoing calibration. Water potential has been a very difficult measurement to make accurately on the dry rocks and soils at Yucca Mountain, and this new instrument should provide repeatable, calibrated data. Components have also been obtained for the Nikon petrographic microscope to perform epifluorescence observations on thin sections with pores impregnated with fluorescent rhodamine-b dye.

Approximately 550 samples were collected from outcrops on Yucca Mountain, along transects designed to ensure that every lithologic unit was represented from the Calico Hills unit to the Tiva Canyon tuff caprock. All of the samples were analyzed in the laboratory for physical properties (bulk density, grain density, and porosity) using the planned procedure for core analysis. This has provided a large data base on the spatial variability of rock physical properties, while also supplying information for a thorough evaluation of the procedure. Hydrologic measurements, including saturated hydraulic conductivity, intrinsic permeability to gas, water retention and imbibition, were made on a limited number of representative samples.

A report entitled "Preliminary Permeability and Water Retention Data from Nonwelded and Bedded Tuff Samples, Yucca Mountain Area, Nye County, Nevada," (Flint and Flint, 1991) was published. An abstract entitled "Laboratory Analysis of Porosity and Permeability in Unsaturated Tuffs at Yucca Mountain, Nevada" (Soeder et al.) was accepted by the Geological Society of America (GSA) for a poster presentation at the Annual Meeting in San Diego 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.) has been accepted by the SSSA for oral presentation at the American Society of Agronomy/SSSA Annual Meeting in Denver on October 29, 1991. Current plans call for this abstract to be expanded into a full-length paper, and submitted to a refereed journal for publication.

Activity 8.3.1.2.2.3.2 - Site vertical borehole studies. Three 40-foot deep boreholes, located adjacent to the HRF were drilled in September 1991. Two of these three boreholes were scheduled for instrumentation during the week of October 7; the third is scheduled for instrumentation in February 1992. The HRF boreholes were designed and constructed to provide a test-bed facility for the deep unsaturated (UZ) borehole instrumentation program. The primary purpose of these boreholes is to evaluate long-term sensor drift characteristics. Unlike the deep UZ borehole instrumentation program planned for Yucca Mountain, the HRF boreholes are designed in a manner that will allow the downhole sensors to be removed and recalibrated in a laboratory under conditions which exactly replicate the initial calibrations. Thus sensor

drift and the adequacy of in situ recalibration procedures to correct for drift can be determined. The HRF boreholes will also be used to test and evaluate procedures for conducting gas tracer diffusion and water injection tests at Yucca Mountain and as a training aid for new staff assigned to the YMP. An important aspect of the HRF borehole program was the design and construction of a downhole instrument station apparatus (DISA) to house the sensors and control devices needed for routine monitoring, in situ recalibration, gas sampling, gas tracer diffusion and water injection testing. Ten DISAs were built to instrument HRF boreholes #1 and #2. Minor modifications to the original DISA design will be incorporated into the design of the DISAs that will be used to instrument the third HRF borehole. These modifications will include down-sizing of one of the two tubes for gas sampling and evaluation of impolene tubing as a cheaper alternative to Teflon tubing.

Various grout mix designs, using calcium sulfate as the primary ingredient, were tested in conjunction with work at the HRF borehole site. Grout plugs will be used to isolate downhole instrument stations and to provide structural support to the stemming packages (electrical cable, tubing, central support pipe, and polyethylene beads that surround the DISA) placed in the instrumented boreholes at Yucca Mountain. Samples of the grout mix were made available to the UZ hydrochemistry section to evaluate the chemical compatibility of the grout with their planned sampling program at Yucca Mountain. The grout mix selected for use in the HRF boreholes appears to have excellent engineering characteristics for use in the deep UZ borehole instrumentation program, i.e. low heat of hydration, low viscosity, fast setting times (less than about 30 minutes), and relatively high compressive strength (1000 psi). Additional testing (primarily matrix properties) will be conducted once it has been established that the grout mix selected will be compatible with the requirements of the UZ hydrochemistry program.

All instruments, equipment, and parts for assembling the first of three multi-station gas sampling apparatuses were delivered during the reporting period. The gas sampling apparatus consists of a complex array of mass flow meters, mass flow controllers, chilled mirror hygrometers, electronic data acquisition equipment, switching relays, in-line filters, piping, manifolds and solenoid valves. The system is designed to support vacuum withdrawal of nearly vapor saturated gases from up to twenty downhole instrument stations simultaneously without condensing water vapor in the sampling tubes. Measurements taken at the ground surface are used to compute the vapor pressure of the source gas and thus provide an independent means of verifying the accuracy of the downhole thermocouple psychrometers that are used to measure water potential. All gas streams are kept isolated in a manner that preserves their integrity for UZ hydrochemistry sampling and analysis. The concept of gas withdrawal using a dry carrier gas to lower the dew point temperature of the source gas was successfully tested in a single station configuration during the summer and fall of 1990. Software to run a multi-station system, where key instrument measurements are shared by multiple sample lines, is currently being written. Assembly of the system was begun in August with completion scheduled for late November 1991. Initial testing will be conducted at the HRF boreholes in January 1992. Additional testing is scheduled for spring 1992, following acquisition of equipment (described below) needed to calibrate key components of the system.

A primary standards two-pressure humidity generator was ordered in June 1991 and is scheduled for delivery to the HRF calibration laboratory in early March 1992. This equipment will be used to maintain calibration of the chilled mirror hygrometers that are used in the gas sampling apparatus (described above). Market research for a primary standards mass flow calibrator was completed during the reporting period. This equipment will be used to maintain calibration of the mass flow meters and mass flow calibrators that are used in the gas sampling and air permeability testing programs. This equipment will be ordered in October 1991. The delivery date for this equipment is not known.

Preliminary work was begun on developing a set of technical specifications and procedures for diagnostic evaluation and performance verification of all electronic equipment being used in the UZ calibration laboratory and that will be used in the UZ borehole monitoring program. The primary purpose of implementing this procedure is to reduce the frequency of removing electronic equipment from service to satisfy arbitrary and often unnecessary recalibration schedules. With the exception of a direct current calibrator, all equipment needed to implement this procedure has been acquired. The direct current calibrator will be ordered in October 1991.

Results of pneumatic, pumping, recovery, and tracer testing in 8-inch diameter vertical holes at the Apache Leap tuff site (ALTS) were analyzed for permeability and porosity. Analysis included models for well-bore storage, skin effects, and double porosity. The tracer tests were used to calculate velocities, which were combined with the pump rates to estimate effective porosity. Permeabilities calculated from the single-hole tests showed very good agreement between drawdown and recovery tests. Differences were generally less than 15 percent. Permeabilities from single-hole tests agreed well with permeabilities from cross-hole tests. Porosity calculated from the cross-hole pneumatic tests are believed to represent matrix porosity. Models, based on the ALTS data, suggest that in order to measure fracture porosity in these cross-hole tests, the early-time sampling-frequency must be increased. Porosity calculated from the tracer tests also supports this conclusion.

The 8-inch diameter packer assembly was completed. Ports for the 12-inch packer assembly are in the procurement stage. The support trailer modifications to expand to a 12-inch system have taken longer than expected, but are now complete. The trailer will be completed by January 1992 and field testing is scheduled for the spring of 1992.

A report entitled "Geohydrologic Data from Test-Hole USW UZ-13, Yucca Mountain Area, Nye County, Nevada" (Kume and Hammermeister, 1991) was published.

Software development for the Integrated Data Acquisition System (IDAS) during the past 12 months has proceeded much slower than expected. The USGS software development coordinator plans to have a fully functioning system ready for the field by early April 1992, and a fully tested, debugged, documented, and QA-approved software system in place by January 1993. Redesign to incorporate a MicroVAX ARC-2 is nearly complete; progress is being made in developing code for the Interactive System, which permits direct control of a field site for purposes of performing sensor checkout, instrument diagnostics, and in-situ recalibration. Redesign of the instrument shelter

and systems (power, communications, security, and environmental control) to permit mass production of modular, interchangeable units have been completed. Proposals from seven vendors have been evaluated, and it is expected that a contract will be negotiated with one of these vendors before the end of October, with receipt of the first shelter 12-14 weeks later.

Data have been generated for three physical models to complete development of the vertical seismic profiling (VSP) and cross borehole seismic imaging processes. The three models are as follows: 1) a simple fault model, 2) the Yucca Mountain model which contains a large number of reflecting horizons and ten or more high angle imbricate faults and 3) a three dimensional tunnel model. Imaging of the fault model and tunnel model is essentially complete. The principal thrust of this activity for the next six months is to complete the imaging of the very complex Yucca Mountain model. This modeling effort involves acquisition of more than 20,000 separate source-receiver combinations.

The VSP mode separation program has been completely rewritten and is now a stable and effective data processing tool. It is essential that sheer and compressional wave modes be separated prior to imaging a VSP data set. A procedure was developed that predicts and corrects for polarity reversals of P to S converted wave reflections. Imaging of P to S converted wave reflections requires polarity reversal corrections to avoid destructive interference effects and the consequent loss of information.

Shakedown drilling in Utah for the LM-300 drilling rig began during the first week of July 1991 and finished the last week of August 1991. The hole was drilled in the middle of the historic Barrick-Mercur gold mine. This activity consisted of hammer drilling, coring, and reaming the core hole to a depth of 2,041 feet. All of the rig components were tested under operating conditions similar to those that will be found at Yucca Mountain. During this period of activity, a few immediate rig modifications had to be made to the drilling equipment, including a redesign and installation of a heavier pipe handling system hydraulic cylinder. A list of several modifications was made for Lang to do before the rig is delivered to Yucca Mountain. These changes are currently being done at the Lang yard in Salt Lake City, Utah.

Extensive filming of rig activity was performed. These films will be edited into training videotapes for YMP participating companies and for use by the DOE institutional affairs department. All phases of the drilling operation were filmed to provide a very comprehensive documentary of what will take place during surface-based testing.

Continued testing of coring and reaming bits is being performed at the Colorado School of Mines. This testing had shown that the Yucca Mountain rocks are quite hard and formidable to drill using an air-only circulating and cooling system. These tests have shown that the reaming bit design concept will need to be changed to allow for uncut rock in the center of the bit. Some of the current designs are leaving a "volcano cone" type of uncut rock during the reaming cycle. Diamond bits will need to be designed for light weight and high/low rpm conditions. This is due to some of the limited equipment capability for some Yucca Mountain studies. The initial round of testing at the NTS should be finished in November 1991. Further testing of prototype bits from manufacturers will continue in order to develop the best

possible drilling tools for the rock types to be encountered at Yucca Mountain and the equipment to be used during various phases of the study.

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

2.2.1.8 Study 8.3.1.2.2.4 - Characterization of 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 preparing a large block for prototype testing related to the percolation tests in the ESF, Activity 8.3.1.2.2.4.2. support included air permeability testing of instrumentation boreholes, transducer calibrations, test chamber enclosure completion, installation and wiring of TDR and electrical resistivity sensors and numerous other tasks.

Papers entitled "Assessment of Fracture-Sampling Techniques for Laboratory Tests on Core" (Severson and Boernge, 1991) and "Fracture Characteristics of Fracture Roughness and Aperture Data" (Kumar et al., 1991) were presented at the IHLRWM conference held in Las Vegas, Nevada, in April 1991. The second paper discussed the fractal dimensions of the fractures in the rock cores collected using the methods presented in the first paper.

Development of the Moire projection method for fracture profile characterization progressed. Two draft papers were submitted for review, "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.). Significant progress was made using fast-Fourier transform analysis and stereo viewing.

Activity 8.3.1.2.2.4.2 - Percolation tests in the Exploratory Studies Facility. Work progressed on two sets of prototype experiments: (a) water imbibition experiments on small welded and nonwelded cores, and (b) large-block ponding-tests experimental setup.

Water imbibition experiments were conducted on cores of welded and nonwelded tuff samples. This set of experiments was designed to study the effects of air entrapment on the water imbibition process and maximum achievable water saturation. Experiments on nonwelded samples were repeated with unsealed and sealed samples. Results showed that the effect is negligible. An experiment was conducted on a welded tuff rock sample using an unsealed core.

The large-block ponding-test experimental setup was near completion. The block (54 cm long x 47 cm wide x 80 cm high) was placed on a frame with sand layers below and above it. The block was instrumented with TDR probes to estimate water content qualitatively. A set of electrical resistance

electrodes also was installed on the block to estimate changes in water content. Air permeability measurements were conducted to estimate fracture permeabilities and connections between existing fractures in the block. Several cores from the same boulder from which the block was cut were taken to estimate matrix permeability values in different directions.

A report entitled "Alternative Method to Mariotte Reservoir for Maintaining Constant Hydraulic Pressure" (Thamir, 1991) was presented at the IHLRWM Conference which was held in Las Vegas in April 1991.

Activity 8.3.1.2.2.4.3 - Bulk permeability test in the Exploratory Studies Facility. No progress during the reporting period due to lack of funding.

Activity 8.3.1.2.2.4.4 - Radial borehole tests in the Exploratory Studies Facility. Prototype gas injection cross-hole testing was conducted at the ALTS near Superior, Arizona, during May 1991. Cross-hole test data analysis showed very good correlations of permeability and porosity between the test gases and different injection rates. Preliminary analysis showed that the calculated permeabilities and porosities were not dependent on the injection rate for the rates tested. The air and nitrogen injection cross-hole testing were at injection rates from 13 slpm (standard liters per minute) up to 75 slpm.

Preliminary cross-hole test data analysis along with single-hole test results were presented at the June 1991 NWTRB meeting. Cross-hole and single-hole tests were analyzed with a variety of solutions. The analyses consisted of the simple radial and spherical flow models, well-bore storage models, skin effect models, and double-porosity models. Sensitivity analysis of the single-hole and cross-hole tests showed the single-hole data reduction was very sensitive to start time. All the prototype equipment functioned well. The thermistors and thermocouple psychrometers gave good results of down-hole temperatures and relative humidities. The thermistors showed that the single-hole and cross-hole tests were basically isothermal with the maximum temperature change occurring in the injection zone and being less than 0.5°C.

Activities 8.3.1.2.2.4.5-10 of this study have no progress. Due to their out-year status, they are not currently funded.

2.2.1.9 Study 8.3.1.2.2.5 - Diffusion tests in the Exploratory Studies Facility

The revised draft of Study Plan 8.3.1.2.2.5 was prepared and submitted to the YMPO on June 12, 1991. YMPO comment verification is in progress.

Activity 8.3.1.2.2.5.1 - Diffusion tests in the Exploratory Studies Facility. A test planning package (91-4, R0) describing the requirements for the prototype testing and the diffusion tests in the ESF was approved by the YMPO. The requirements of the diffusion tests in the ESF to be utilized as input for the ESF Functional Analysis were also prepared.

Input describing the "Diffusion Tests in the Exploratory Studies Facility," intended for Test Planning Package 91-5 and the ESF Design Requirements was prepared, reviewed, and submitted.

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 was sent to the NRC on June 24, 1991.

Activity 8.3.1.2.2.6.1 - Gaseous-phase circulation study. Gas sample collection from boreholes USW UZ-6, USW UZ-6s, USW UZ-N93, USW UZ-N94, and USW UZ-N95 was completed. Eight zones were sampled in USW UZ-6, nine zones were sampled in USW UZ-6s, and one zone was sampled in each of the three neutron-access boreholes. Trace gas samples were collected for geochemical analysis in a gas chromatograph. Additional gas samples were collected using a potassium hydroxide (KOH) solution for analysis for $^{14}CO_2$. Soil gas samples for $^{14}CO_2$ analysis were collected from the surface of Yucca Mountain using a KOH solution. Tabulation and analyses of data obtained from the laboratory analysis of these samples was initiated. These results will be used to complete the progress report on air flow and geochemistry for unsaturated-zone gaseous-phase movement.

2.2.1.11 Study 8.3.1.2.2.7 - Hydrochemical characterization of the unsaturated zone

Study Plan 8.3.1.2.2.7 was sent to the NRC on May 8, 1991.

Activity 8.3.1.2.2.7.1 - Gaseous-phase chemical investigations. Fifteen carbon dioxide gas samples from the February 1991 USW UZ-1 borehole sampling trip and ten carbon dioxide gas samples from the March 1991 Apache Leap sampling trip were degassed, measured and sent to a vendor for Carbon 14 and 13/12 analyses. Results were received in May and June and were similar to prior results. Samples of the gases extracted from 44 Apache Leap-cores by one-dimensional compression were analyzed by gas chromatography for carbon dioxide, methane, and sulfur hexaflouride. Results indicated no drilling contamination of core gases.

Raw data from USW UZ-1 and from Apache Leap were processed and tabulated. Reduced data from Apache Leap was tabulated and analyzed using graphical and statistical techniques. Tabulation of the USW UZ-1 gas data was in progress. An outline and first draft was prepared for a report entitled "Unsaturated-Zone Methods Development Studies at Prototype Borehole USW UZP-5 Near Superior, Arizona, 1990-1991" (Peters et al.).

Representative Yucca Mountain tuffs and stemming materials were crushed and sieved to three sizes. Surface mineralogy and chemical analysis of each of the sieved sizes were performed. A gas sorption experiment of these materials was designed and the equipment for the experiment was obtained.

A portable gas chromatograph was obtained and instrumentation and methods development begun. Several new columns were procured and installed in a bench-top gas chromatograph to speed up the analysis of carbon dioxide,

oxygen, nitrogen, sulfur hexafluoride, and freons. A dynacalibrator was obtained and operating methods were studied and used in mixing trace concentrations of gases. A rotary-vane pump was calibrated for its pumping capacity for various sampling tube lengths.

Activity 8.3.1.2.2.7.2 - Aqueous-phase chemical investigations. Fifty-five pieces of core were prepared (ends squared, moisture contents measured and resealed) for pore-water extraction by compression. Thirty-seven cores (15 densely welded and 22 nonwelded) were compressed by one-dimensional compression. Twenty-eight cores were compressed using a "second-generation" cell and 9 using a "first-generation" cell. The "second-generation" cell was much more efficient in expressing water from densely-welded cores.

A paper entitled "Pore-Water Extraction From Unsaturated Tuffs Using One-Dimensional Compression" (Mower et al., 1991) was presented at the IHLRWM meeting in April 1991. A draft report entitled "Pore-Water Extraction from Unsaturated Tuff by Compression Methods, Nevada Test Site" (Yang et al.) was completed.

Results of chemical analyses for 217 pore-water samples were received from the contract laboratory and checked for acceptability of the data. An additional 180 pore-water and standard-reference water samples were sent to the laboratory for analyses. An ion chromatograph (IC) was calibrated for chloride, bromide and sulfate analyses and will be used in future data acceptability determinations.

Water samples from 48 cores were distilled and collected for oxygen 18/16, deuterium/hydrogen and tritium analyses. A draft paper entitled "Flow and Transport Through Unsaturated Rock-Data from Two Drill Holes, Yucca Mountain, Nevada" (Yang) was completed and will be submitted to the IHLRWM Conference, Las Vegas, Nevada, April 12-16, 1992.

Water samples were collected from neutron hole UE-25 N#2 and from nearby rain gages and submitted for chemical and isotopic analyses. YMP personnel attended a demonstration of the "Seamist" drill-hole instrumentation and fluid sampling system. This system can be used to collect downhole water samples on adsorbent pads, and gas samples through gas-sampling tubes. Present plans include the use of this system to possibly collect fracture and fault water samples from open, shallow, surface-boreholes and ESF boreholes.

Elevated tritium levels were found in cold storage rooms and in laboratory and distillation racks located in Building 56 at the Denver Federal Center (DFC). Elevated levels were associated with the proximity of G-tunnel rock samples. These locations were cleaned out and rinsed with "dead water." The "dead water" rinse was analyzed for tritium. Results indicated that tritium levels were reduced to background level by the cleaning. Samples of water and water vapor were also collected from the HRF and the SMF at the NTS. Elevated concentrations at the SMF appeared also to be connected to G-tunnel rock samples. The SMF was cleaned and rinsed. Elevated tritium levels at the HRF appeared to be associated with something other than G-tunnel rocks. Tritium analysis of "dead water" used to rinse out glassware stored in the HRF indicated that the glassware, which is used at USW UZ-1 for tritium collection, was not contaminated by residing in the lab. Additionally, "dead water" left in the HRF for 2 days had tritium concentration of about 700 Tu.

It was subsequently found that 16 exit signs in the HRF had, according to the manufacturer's specification, 25 curies each of ^{3}H in the self-powered lighting system. These exit signs will be removed from the building.

One-hundred six cores were sealed by 10 different sealing methods and weighed monthly to determine moisture loss. Preliminary results indicate a large moisture loss from 3 of the sealing methods and that the use of polycarbonate liners, in combination with Protecore appears to be the most favorable sealing method. An outline for a report on core sealing methods has been prepared.

The use of blocking materials (Hydrastone and Sulfaset) to core rubble samples was tested to determine the effect of the heat produced during curing on the moisture content of the rock sample. Results of the testing indicate that there is no significant heating in the area and therefore, probably no moisture loss as a result of blocking.

Data and information obtained as a result of the work performed in G-tunnel to support the Dry Coring and Optimal Rubble Prototype Tests has been compiled. A report entitled "The Collection of Core and Rubble Samples from G-Tunnel" (Peters et al.) is in preparation. Data obtained from rubble coring was graphically and statistically reduced. Initial data indicate little impact on core water content as a result of dry coring. An outline for a report entitled "The Effect of Dry-Coring Rubble Samples on Moisture Content and Water Chemistry" (Peters et al.) was 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 underwent resolution of comments from the YMP.

Activity 8.3.1.2.2.8.1 - Development of conceptual and numerical models of fluid flow in unsaturated, fractured rock. A paper entitled "Lubrication Theory Analysis of the Permeability of Rough-Walled Fractures" (Zimmerman et al., 1991) was presented at the IHLRWM Conference in Las Vegas in April. This work provided theoretical justification for simulating flow within fracture apertures that vary continuously in space with computational cells of constant, but spatially varying aperture, and provided criteria for cell size in terms of aperture variance. This work forms the theoretical foundations for simulating flow through variable aperture fractures with models such as VSFRAC.

An additional paper entitled "Fractal Characteristics of Fracture Roughness and Aperture Data" (Kumar et al., 1991) was presented at the IHLRWM Conference in Las Vegas in April. This work illustrated the relation between aperture distribution within a single fracture and surface-wall roughness and surface correlation for fracture surfaces that are fractal in their roughness characteristics. It compared the calculated fractal dimensions measured for fracture apertures with those of the bounding surfaces.

Simulations intended to explore the influence of areally averaged flux and average matric potential on the channeling behavior, matric potential variability and bulk properties of a simple fracture network containing fractures of various hydraulic apertures were attempted. These simulations

were not completed due to convergence problems, originally attributed to the use of tabular data rather than closed-form expressions for the fracture properties. Standard functional relations of the van Genuchten type were fit to the hypothetical fracture data and incorporated into the TOUGH model in this form. It was found that the van Genuchten model, originally developed for unconsolidated porous media, fit the curves generated by VSFRAC reasonably well. However, simulations with TOUGH continued to suffer from convergence problems and efforts are continuing in an attempt to resolve these difficulties.

Numerical simulations were run using a modified version of the VS2DT code that simulates gas flow. The simulations depicted the injection of air into a borehole penetrating a fractured tuff formation with properties believed to be similar to those tested at Apache Leap, Arizona, as part of work associated with SCP Study 8.3.1.2.2.6. The pressure squared difference versus time relations at various radial distances from the borehole were then treated as real data and were analyzed using the TMATCH program, being developed by SCP Study 8.3.1.2.2.6, in an attempt to determine the accuracy with which input parameters that described the formation properties could be reproduced, thereby providing a verification of both codes. Type curves developed for water-saturated, double-porosity formations, which included the effects of well-bore storage, were used in conjunction with dimensionless parameters adapted for use with highly compressible fluids, that is, gases. The synthetic data generated by VS2DT were fit by the type curves quite well. A preliminary analysis using "data" for both the injection hole and various observation distances has produced permeability estimates that are generally within 30 percent of the known input permeability. Estimated drained porosity is close to the fracture (rather than total) porosity. Differences between the input permeability and the derived permeability are attributed to truncation error associated with finite numerical methods and errors associated with visually matching the type-curves to the hypothetical data. No conclusive insights have yet been drawn concerning the actual test data collected from Apache Leap.

A paper entitled "A Simple Approximate Solution for Horizontal Infiltration in a Brooks-Corey Medium" (Zimmerman and Bodvarsson, 1991) was published during the reporting period. The solution developed therein will allow rapid estimation of hydrological parameters from laboratory imbibition data.

Activity 8.3.1.2.2.8.2 - Validation of conceptual and numerical models of fluid flow through UZ fractured rock. No progress during 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

Study Plan 8.3.1.2.2.9 was completed and submitted to YMPO on January 25, 1991 for review.

Activity 8.3.1.2.2.9.1 - Conceptualization of the unsaturated-zone hydrogeologic system. Review of recent literature, reports and existing data bases of Yucca Mountain for site-scale modeling continued in conjunction with development of a coarse, three-dimensional model. To this end, quarterly

meetings were held to facilitate the modeling and collected data needs of both the site characterization and performance assessment programs. Representatives of the USGS, LBL, PNL, SNL, and SAIC/Las Vegas attended these modeling meetings. Topics such as the topographical information needed to facilitate 3-D model gridding on the ground surface, the paucity of borehole data needed to adequately describe the water-table surface, limits of hydrogeological units, and effects of faults on the stratigraphy were discussed. These participant modeling meetings will be used to assist in the guidance of ongoing modeling work being done under Activity 8.3.1.2.2.9.2 (Sections Development, and Testing of Hydrologic-Modeling Computer Codes) at LBL, for the initiation of work for FY 1992 under Activity 8.3.1.2.2.9.3 (Simulation of the Natural Hydrogeologic 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. A major effort during this period was the collection of all relevant information to be used in the development of a site-scale model for Yucca Mountain. The data base maker, ENDNOTE was used to store all references received to date and the INGRES management system was installed in order to help store and retrieve the data.

Meetings were held with USGS and SNL representatives to exchange information and discuss the integration of the present and future data into the site-scale model. The main emphasis was on the design of the vertical grid for the site-scale model. The main difficulties encountered deal with the geometry of elements including faults and the highly faulted areas, as well as with the definition of the boundaries between hydrologic units. Preliminary isohypse and isopach maps for the hydrological units Tiva Canyon, Paintbrush non-welded, Topopah Spring, Calico Hills non-welded facies and the ground-water table were developed using well data and geologic maps. The displacements along the Ghost Dance, Abandoned Wash, and Dune Wash faults were built into these maps. In order to choose the vertical definition of the grid, a sensitivity study was conducted to calculate liquid saturations for a column of single elements with variable thicknesses around the unit boundaries. The saturation profiles were very similar for the various simulations. A methodology was developed for efficient design of the vertical mesh and the main hydrogeological units were divided into subunits using percentages of the whole unit. Computer programs were adapted to automatically generate the nodal points of the subunits.

Activity 8.3.1.2.2.9.3 - Simulation of the natural hydrogeologic system (UZ). No progress during the reporting period; this is an out-year activity.

Activity 8.3.1.2.2.9.4 - Stochastic modeling and uncertainty analysis (UZ). 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

NRC review of Study Plan 8.3.1.2.3.1 (Activities 1-6) and 8.3.1.2.3.1 (Activity 7) is ongoing.

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 17 wells and quarterly measurements were made in three. Hourly water-level data were collected from 19 zones in 12 wells; in two of these wells, continuous data also were collected. Approximately 55 transducer calibrations were performed on the continuous network and approximately 10 transducers were replaced. The rate of instrument failure was reduced from the previous 6-month period. One additional satellite data-collection platform was installed to supplement the five already in service. One additional strip-chart recorder was installed to continuously monitor water levels in two zones. This recorder supplemented other strip charts already monitoring two zones. The new recorder monitors water levels in the upper zone of well USW H-4 and pressures in the lower zone. This recorder should enable observation of seismically induced water-level changes.

A new type of transducer was tested that appears to be less prone to excursions. This transducer, which costs nearly twice as much as previously used models, has been tested on a limited basis for over 18 months. Of the nine transducers that failed during this 6-month period, only one was of the new type.

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. Three such excursions occurred during this 6-month period. The excursions occurred during periods of unsettled weather with low barometric pressure, rain, and lightning. Satellite data-collection platforms that routinely send data directly to a Prime computer in Denver every 4 hours, but transmit immediately during an excursion, were used to attempt to monitor the apparent excursions. However, none of the excursions during this period occurred in sites with these platforms.

The report, "Water Levels in Periodically Measured Wells in the Yucca Mountain Area, Nevada, 1989" (O'Brien, 1991), was published during the reporting period. The report, "Water Levels in Continuously Monitored Wells in the Yucca Mountain Area, Nevada, 1985-88" (Luckey et al.), was submitted for USGS approval and YMPO concurrence in July. A draft report on the 1989 continuous data received internal USGS review and is being revised. The report, "Precision and Accuracy of Water-Level Measurements Taken in the Yucca Mountain Area, Nevada, 1988-90" (Boucher), received internal USGS review and is being revised.

Additional access tubing was added to well UE-25 WT#18 in December 1990 to reach within a few meters of the bottom of the well. Water was present at the bottom of the well for several months, but it is unknown if this water represented the water table. Later measurements during this reporting period indicated that the well was dry.

Activity 8.3.1.2.3.1.3 - Analysis of single- and multiple-well hydraulic-stress tests. The manuscript for the C-hole complex hydrogeology was submitted for review. Work on the manuscript for the C-hole intra-borehole flow and hydraulic stress test report continued during the reporting period.

Measurements of the difference between atmospheric pressure and air pressure (the latter in the annular space between inner and outer casings) was initiated at UE-25c#3. These data (along with similar data from some neutron and UZ holes) will be used to compute pneumatic diffusivity. These pneumatic diffusivity values can, in turn, be used to confirm values obtained independently from atmospheric loading analysis of data from cased holes, or to extend atmospheric loading analysis to boreholes where the casing does not continue all the way to the water table.

Test well USW H-4 was instrumented with a 2.5-inch-diameter packer inside the piezometer tube for monitoring the lower (below-packer) zone, in order to provide the "packed-off" pressure values needed for analysis of hydraulic effects of seismic stress. The effect of an April 23, 1991, earthquake in Costa Rica, and that of an August 16, 1991, earthquake in California, were successfully monitored in test wells UE-25b#1 and USW H-4, respectively. The effect of a underground nuclear explosion (UNE) on June 15, 1991, was successfully monitored in USW H-4. Water level fluctuations were monitored in USW H-4 and UE-25b#1 for hydraulic effects of earth tides and atmospheric loading. A technical presentation on the monitoring and analysis of strain-related water level and pressure changes was made at the June 1991 meeting of the NWTRB in Denver.

A report entitled "Geohydrology of Rocks Penetrated by Test Well USW H-5, Yucca Mountain, Nye County, Nevada" (Robison and Craig, 1991) was published.

Activity 8.3.1.2.3.1.4 - Multiple-well interference testing. A change request for the SCPB to add an additional hole at the C-hole complex location was prepared and submitted to the YMP CCB. The additional hole will be drilled at an angle to obtain information on sub-vertical fractures.

A request was submitted to rerun the television camera logs of UE-25c#2, and c#3, to obtain better quality and more depth-complete logs. The logs will be used as input into the process of selecting test zones in the future hydraulic and tracer tests.

Staff supported presentations to the NWTRB in June 1991 on the planned hydraulic and tracer tests.

Activity 8.3.1.2.3.1.5 - Testing of the C-hole site with conservative tracers. Design of the tracer injection system continued. As part of this process, and the process of designing the future tracer tests at the C-holes, meetings were held to coordinate with LANL and University of Nevada/Las Vegas

(UNLV), who are cooperating with the USGS on the tracer tests. Also, work was done on the selection of thermistors (for downhole temperature measurements) and solenoid valves (for the electronic control of tracer injection into a particular test zone). Samples of tubing being considered for the tracer injection, associated fittings, and chemical-compatibility charts, were supplied to UNLV to conduct tests on the sorption of various proposed tracers onto the tubing wall. A permit from the State of Nevada was granted on July 16 to inject a limited number of tracers during the upcoming tracer tests.

Staff made a technical presentation on the proposed tracer tests at the June 1991 meeting of the NWTRB.

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. Preparations for carrying out the batch sorption experiments with lithium on C-Wells tuff material were completed. This task included the following items: (1) acquiring intact core at appropriate depth intervals from the SMF, (2) collecting J-13 water samples for use in the experiments, 3) writing the necessary detailed technical procedures for the analytical balances and the operation of an ion chromatograph, and 4) crushing and sieving the tuff particles to be used in the experiments.

Significant progress has been made on software development and documentation for two applications. First, the application SORBEQ, a one-dimensional simulator of transport with equilibrium sorption, successfully completed the requirements and design phases. Also, the requirements phase has been completed for the FRACNET application, a two-dimensional, dual-porosity fracture network/matrix flow simulator.

A conceptual model is being developed for radionuclide migration in the saturated zone to show that diffusion of radionuclides from the fractures into the fluid in the rock matrix could have a profound effect on radionuclide migration in the saturated zone. Preliminary model results will show that a series of inter-well tracer tests, using conservative and reactive tracers, should validate or refute the conceptual model.

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

2.2.1.15 Study 8.3.1.2.3.2 - Characterization of the saturated-zone hydrochemistry

A comment resolution meeting for Study Plan 8.3.1.2.3.2 was held in May. A revision based on resolved comments is in preparation.

Activity 8.3.1.2.3.2.1 - Assessment of saturated-zone hydrochemical data availability and needs. Extant field reconnaissance information and hydrochemical data, dating from the early 1950s to the 1970s, were assembled and sent to USGS staff in Las Vegas for inspection, compilation, and entry

into a Las Vegas data base, with plans for subsequent transfer to the USGS/YMP data base. The data comprise sites from the NTS and the surrounding region.

Information was solicited from, and meetings were held with, United States manufacturers of mobile laboratories and downhole hydrologic and hydrochemical equipment to discuss respective potential relevance to YMP activities. Based on these discussions, some equipment options have been deleted, and equipment specifications have been modified to include the incorporation of tools from several entities in the overall downhole equipment package planned for purchase from the Svensk Karnbranslehantering AB (SKB). Contact has also been established and maintained with RSN staff supporting the Weapons Program's Ground-Water Characterization Program (GCP) activities to coordinate searches and exchange information regarding similar downhole equipment needs and program objectives. This has resulted in additional avenues of investigation and identified sources of some requisite equipment components.

Activity 8.3.1.2.3.2.2 - Hydrochemical characterization of water in the upper part of the saturated zone. USGS YMP staff collected ground-water samples from a shallow borehole at Yucca Mountain following a late spring storm. The water very likely represents temporary accumulation of precipitation and runoff waters that percolate into the subsurface via local fracture system(s). The analytical data from the samples confirm the local nature and recent occurrence of the "recharge."

The DOE/Atomic Energy of Canada Limited (AECL) agreement for joint investigations was signed in late September. In anticipation of the signing, a meeting was held with SKB staff and the manufacturer (IPA Konsult AB) of the SKB in situ hydrochemical tool to identify and discuss specifications requisite to both laboratory and field testing of the tool at the AECL Whiteshell Nuclear Research Establishment Borehole Instrumentation Test Facility and at the Lac du Bonnet site area. A pump similar to that planned for use in YMP field efforts was delivered to IPA for preliminary consideration of its incorporation into the downhole equipment system. Recent modifications and additions to the system also were examined and discussed at this meeting. It was agreed, also, that descriptive information and available specifications of additional equipment to be incorporated will be provided to IPA at the earliest opportunity for their consideration and preliminary planning.

A meeting was also held with the SKB investigators responsible for hydrochemical characterization and testing at the Aspo Hard Rock Laboratory (HRL) to discuss planned characterization efforts at both the Yucca Mountain and Aspo sites, and proposed joint DOE/SKB investigations at the HRL. In the course of these meetings, aliquots of archived water samples from the HRL were obtained and brought to the United States for scoping analyses. This information will be of use to both SKB and USGS investigators in planning future work.

Activity 8.3.1.2.3.2.3 - Regional hydrochemical characterization. The DOE GCP began construction of the first borehole of the program in the general vicinity of Rainier Mesa. This and additional planned boreholes will provide geohydrologic information and hydrochemical data and/or samples to YMP investigators that will enable refinement of regional and site conceptual

models. They will particularly augment the information base in the region north of Yucca Mountain. The designation of sample- and data-collection equipment and methodologies was uncertain in September; this could perhaps influence the utility of data and samples that derive from the effort.

A meeting was held with NPS staff to discuss proposed sample- and data-collection at springs within the boundaries of Death Valley National Monument. This effort will provide insight to boundary considerations for the regional and sub-regional conceptual models of the geohydrologic system.

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 was returned to the USGS after the YMPO review was completed on August 27 and is being revised.

Activity 8.3.1.2.3.3.1 - Conceptualization of saturated-zone flow models within the boundaries of the controlled area. Work on the revised potentiometric map using the 1988 average water levels continued. The effects of fluid density and gravitational variations on these water levels are being investigated by techniques discussed in Oberlander (1989). A paper entitled "Evaluation of Geographic Information Systems for Three-Dimensional Ground-Water Modeling, Yucca Mountain, Nevada" (Turner et al., 1991) was presented at the IHLRWM conference in April. Planning continued for the hydrogeologic field trip of Yucca Mountain and vicinity for the GSA Fall 1991 meeting. The report accompanying the field trip, entitled "Hydrogeologic Overview and Field Trip of the Regional Ground-Water Flow System in Relation to Yucca Mountain, Nevada" (Galloway et al.), was approved for publication.

Activity 8.3.1.2.3.3.2 - Development of fracture-network model. A new method for borehole bias correction was developed by LBL staff. The method reconstructs the fracture-space geometry (orientation and dip distribution) taking borehole bias into account. The resulting geometry is the best-guess fracture frequency distribution in polar grids. An algorithm that generates self-similar fracture patterns was designed by LBL to be used with outcrop maps from Crater Flat Tuff as input. Various improvements have been made to a 3-dimensional LBL fracture network flow and solute transport code TRINET. Newly incorporated schemes are a conjugate gradient solver with incomplete Cholesky preconditioning, a restart option and a more space-efficient array storage scheme. Simulation of tracer tests in hydrologically conditioned synthetic fracture networks to be used in the EDM (Equivalent Discontinuum Model) was conducted using TRINET. A sensitivity analysis of the resolution of the inverted fracture network on the number of well tests and observation wells was performed.

Initial outcrop fracture mapping was completed in the Bullfrog Member of the Crater Flat Tuff east of Little Skull Mountain by YMP staff. Nine preliminary 2 by 2 meter grids were mapped in addition to seven reconnaissance joint surveys. An abstract entitled "Fractures in the Bullfrog Member of the Crater Flat Tuff East of Little Skull Mountain, Nye County, Nevada" (Ervin and

Chornack) was submitted for the Fall meeting of the American Geophysical Union (AGU).

At the request of YMP staff, EG&G/EM flew aerial photos of the outcrop east of Little Skull Mountain at a scale of 1:6,000. A study of the lineaments and large scale fractures and their relation to other fracture mapping methods will be made from these photos. Fracture mapping began at the second mapping location at Raven Canyon, the type locality of the Crater Flat Tuff, by YMP staff. Coordination between USGS and LBL continued regarding fracture data collection and modeling needs.

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 was revised to resolve review comments, reviewed by LANL, and sent to YMPO for review on March 15, 1991.

Activity 8.3.1.3.1.1.1 - Ground-water chemistry conceptual model. Sensitivity analysis of USGS water chemistry data from carbonate aquifers in the southwestern United States was completed. The analysis was used to refine methods to develop a ground-water chemistry model. Contribution from this activity was also used to model sepiolite formation for aqueous solutions by step-wise evaporation for the mineralogy/petrology task.

The Geochemistry Integration Technical Exchange was held at the NTS on July 29-31, 1991. Staff from LANL, LLNL, and USGS made technical presentations and a tour was offered, including Yucca Mountain, Trench 14, the SMF, and the HRF at Area 25. A talk on pH and Eh of Yucca Mountain ground water was presented.

Activity 8.3.1.3.1.1.2 - Ground-water chemistry mathematical model. No progress during reporting period; this is an out-year activity.

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

Comments on the Study Plan were received from the NRC. LANL sent proposed responses to the YMPO on August 19, 1991.

Activity 8.3.1.3.2.1.1 - Petrologic stratigraphy of the Topopah Spring Member. Petrographic studies continued at a low level, with analysis of data already collected. Samples of the Topopah Spring Member from drill core USW G-4 were obtained for a test of strontium-isotopic stratigraphy of the rhyolitic Topopah Spring Member by USGS.

By September, software certified under LANL-YMP-SQAP, R0, was available for most relevant analytical procedures. However, software for quantitative

regression of x-ray diffraction (XRD) data has not yet been approved, and completion of the Solitario Canyon study hinges on its approval.

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 is now available for most relevant analytical procedures except quantitative XRD. Quantitative XRD data will be required to complete the study of surface samples at Yucca Mountain (adit siting work). Other aspects of this study (petrographic and chemical analyses) have been completed, and the data are being analyzed.

The trace-mineral studies, looking at the maghemite component in spinels and hematite, were completed.

Activity 8.3.1.3.2.1.3 - Fracture mineralogy. A report entitled "Fracture-Lining Minerals in the Lower Topopah Spring Tuff at Yucca Mountain" (Carlos et al., 1991a) was published in the proceedings of the second annual IHLRWM conference held in Las Vegas, Nevada, in April 1991. This report subdivides the fracture minerals into three paragenetic groups: (1) those related to lithophysal cavities, (2) mordenite and manganese (Mn)-oxides on planar fractures, and (3) late-formed coatings of zeolites, smectite, and calcite. A related report, "Distribution of Fracture-Lining Minerals at Yucca Mountain" (Carlos et al., 1991b), briefly summarizes the fracture-mineral distributions throughout the Paintbrush Tuff, Calico Hills tuff unit, and Crater Flat Tuff at Yucca Mountain.

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

The Study Plan was revised in response to YMPO review comments and was submitted to the YMPO on June 13, 1991, for verification of comment resolution.

Operating software for the electron microprobe and scanning electron microscopes has received QA approval.

Activity 8.3.1.3.2.2.1 - History of mineralogic and geochemical alteration at Yucca Mountain. A paper entitled "Mineralogic Alteration History and Paleohydrology at Yucca Mountain, Nevada" (Levy, 1991) was presented at the second annual IHLRWM Conference in Las Vegas, Nevada, in April 1991. Based on the distribution of vitric and zeolitized tuffs and the structural history of the site, the highest static water levels were reached and receded downward about 11.6 to 12.8 myr ago. Since that time, the water level at central Yucca Mountain has probably not risen more than about 60 m above its present position.

Specimens from Trench 14 were prepared for x-ray diffraction and instrumental neutron activation analysis. Sample splits were prepared for isotopic study by the USGS. The trench was deepened in July, and samples were collected from the new exposures.

Activity 8.3.1.3.2.2.2 - Smectite, zeolite, manganese minerals, glass dehydration and transformation. Thermocouples from ovens to be used for

hydrothermal experiments were calibrated to National Institute of Standards and Technology (NIST)-traceable standards. The standard operating procedure for use of pressure vessels at temperatures up to 250° was completed.

Long-term zeolite-heating experiments continued. Glass dehydration/rehydration experiments are now in the rehydration stage.

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 study is not funded.

2.2.2.5 Study 8.3.1.3.3.2 - Kinetics and thermodynamics of mineral evolution

No progress during the reporting period; this study is not funded.

2.2.2.6 Study 8.3.1.3.3.3 - Conceptual model of mineral evolution

No progress during the reporting period; this study is not funded.

2.2.2.7 Study 8.3.1.3.4.1 - Batch sorption studies

The Study Plan is being revised to incorporate DOE/HQ review comments and the sorption strategy that resulted from the Sorption Workshop held in Los Alamos in October 1990.

Activity 8.3.1.3.4.1.1 - Batch sorption measurements as a function of solid phase composition. Sorption studies are continuing, concentrating on laboratory measurements of the sorption behavior of neptunium (Np) on pure mineral phases; experiments on the effects of rock crushing on the measured sorption coefficients for cesium (Cs), strontium (Sr), and neptunium (Np); and the development of the capability for atomic force microscopy. The main concern in the Np sorption experiments was to determine the influence of pH on the sorption coefficient. The experiments on the effects of rock crushing were designed to evaluate the extent that crushing the rock samples used in batch sorption experiments influences the value of the sorption coefficients.

Activities 8.3.1.3.4.1.2-5 showed no progress during the reporting period due to priority being assigned to Activity 1 or no funds being allocated.

2.2.2.8 Study 8.3.1.3.4.2 - Biological sorption and transport

The revised Study Plan, incorporating YMPO review comments, was submitted to DOE for comment resolution verification on August 28, 1991.

Experiments were completed to determine the effect of extracellular material on the agglomeration of clay colloids.

As reported in the previous progress report, 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. A nuclear magnetic resonance (NMR) and Fourier-Transform infrared spectroscopy (FTIR) spectrum have been performed.

2.2.2.9 Study 8.3.1.3.4.3 - Development of sorption models

This study focused on (1) elaborating a strategy for the incorporating sorption reactions into transport calculations and (2) the development of detailed sorption models for the adsorption of neptunium (Np) onto major mineral phases in Yucca Mountain.

The elaboration of the "sorption strategy," developed as a result of the Sorption Workshop held in October 1990, has focused on poorly sorbing radionuclides, such as neptunium (Np) and uranium (U). The sorption coefficients for these elements are a function of the pH of the ground water that is in contact with the tuff. Because it is unlikely that the spatial and temporal variations in pH of ground waters in the unsaturated and saturated zones of Yucca Mountain will ever be known in detail, a probabilistic approach to the derivation of sorption coefficients for these elements is being developed in conjunction with performance assessment modelers at SNL. Input to the total system model was provided to SNL during this reporting period.

Ongoing work continued to develop detailed triple-layer sorption models for the adsorption of Np onto quartz and feldspar, major minerals in the devitrified units of Yucca Mountain. The triple-layer model parameters were obtained in experiments with pure quartz and feldspar separates. These experiments identify all the major chemical controls on Np sorption behavior and will provide a basis for identifying the important parameters that need to be investigated in future whole-rock batch experiments on tuffs, from which most of the sorption coefficient data will be derived.

2.2.2.10 Study 8.3.1.3.5.1 - Dissolved species concentration limits

Study Plans 8.3.1.3.5.1 and .2 were submitted to the DOE on August 17, 1990, and are undergoing YMPO review.

D. Morris replaced D. Hobart as the PI for this study.

Development of a detailed strategy for solubility, speciation, and modeling studies was undertaken. The goal of this effort was to summarize the studies as proposed in the Study Plans, with particular emphasis on identifying constraints in the studies and delineating the "integration points" with other YMP tasks.

The Geochemistry Integration Technical Exchange held at the NTS on July 29-31 was attended by various staff members. A talk entitled "The Role of Ground-Water Chemistry in the Solubility/Speciation Task" (Morris) was given that described the strategy behind the Study Plan and presented some recent results from work at LANL and LBL.

Activity 8.3.1.3.5.1.1 - Solubility measurements. The controlled-atmosphere glovebox employed in this study was renovated to eliminate the potential for contamination from the degraded aluminum interior. More custom polyether-etherketone cells have been fabricated for the solubility experiments in UE25p#1 water at 60°C. A leak-test was also conducted on 15 Beckman Micro Combination pH electrodes to ensure that the solubility solutions do not become contaminated by the electrode's filling solution (saturated Na/AgCl) during the experiment. All electrodes failed the test and could not be used for these experiments. A manufacturer was found for suitable replacement electrodes, and a leak test on one electrode was satisfactory.

Work continued in the preparation of new plutonium (Pu), neptunium (Np), and americium (Am)/neodymium stock solutions for the UE25p#1 solubility experiment at 60°C. Difficulties were encountered in preparing individual plutonium oxidation state solutions. The Pu(III) solution, which was prepared by electrolytic reduction, did not remain stable when the potential was switched off. There is no clear explanation for this behavior, but the presence of a foreign unidentified oxidizing substance is implicated; therefore, this solution cannot be used for the experiments. Preparation of a new solution from plutonium dioxide was begun.

LBL staff continued preparing three draft detailed technical procedures (DPs). Two new drafts are "Balance Operation and Calibration" and "Determination of Actinide Concentrations in Solubility Samples," and one revised draft is "Operation and Calibration of Low Energy Gamma Counter." The balance procedure cannot be completed until the revised LANL "Procedure for Calibration of Measuring and Test Equipment" is completed. The calibration weight set that was calibrated against a NIST-certified weight set is currently being calibrated.

Activity 8.3.1.3.5.1.2 - Speciation measurements. The glovebox installation for plutonium model complex chemistry under inert atmospheres was completed. Thermodynamic studies of Pu(VI) (as PuO_2^{2+}) speciation in complexing carbonate media using high-field Fourier-Transform NMR continued. These experiments focused on determining line-broadening parameters for characterization of the ligand-exchange process between bound and free carbonate. Model complex studies are also continuing with a recent focus on preparing to study a novel model equilibrium between monomeric and dimeric forms of an U(IV) complex.

The instrumentation problems with the photoacoustic spectroscopy (PAS) system were remedied, and the linearity check of the PAS response was completed in early June. For these studies, Pr^{3+} was chosen as the analyte because it has a weak f-f transition in the same spectral region as the transition that will be used to determine speciation in Pu^{4+} (~490 nm). Preliminary work was also initiated to determine speciation in the Pu^{4+}/carbonate system. The initial experiments have been designed to re-examine previous results reported by Eiswirth et al. (1985). These preliminary experiments are approximately 80 percent complete. Work also continued on the literature search of plutonium (Pu) and neptunium (Np) speciation in carbonate and hydroxide media; most of the references have been obtained and are under study. Calibration of two UV-VIS-nIR spectrometers was completed.

The development of coding standards for QuickBASIC continued. The PAS instrumentation control code will be classified as manifest product, in keeping with the concept of real-time verification of proper functioning of the code. A slightly more detailed life-cycle specification was prescribed to acknowledge the unique aspects of this code.

Activity 8.3.1.3.5.1.3 - Solubility modeling. An integration meeting was held on July 22, 1991, in Las Vegas to facilitate integration between this study at LANL and the counterpart task at LLNL. Many action items were identified, including the urgent need for modeling support activities for both organizations.

Several meetings were held during the reporting period with LANL staff from this activity and from the Ground-Water Modeling study. Discussions included planning joint experiments--in particular, modeling activities to address data needs and future directions for this activity--and addressing topical areas not previously considered in great detail--especially the role of redox buffering and inherent mineral redox capacity, with respect to the speciation of the very redox-sensitive actinide elements.

2.2.2.11 Study 8.3.1.3.5.2 - Colloid behavior

The Study Plan has been in YMPO and DOE/HQ review since September 1990. LANL intends to combine this study with Study 8.3.1.3.5.1 prior to the approval of this Study Plan.

Activities 8.3.1.3.5.2.1-2 of this study have been inactive due to a 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 YMPO and DOE/HQ comments.

A strategy for the validation of sorption data, utilizing dynamic transport and diffusion studies, has been created. The software qualification process for 13 codes utilized in the Dynamic Transport and Diffusion studies was initiated. Core from the SMF was received and inventoried.

Staff members served as hosts for LANL's exhibit at four YMP Open House tours. A presentation on the importance of radionuclide migration work was prepared for DOE/HQ, based on the YMP Open House exhibit.

Activity 8.3.1.3.6.1.1 - Crushed tuff column experiments. Staff completed the analysis of data describing the transport behavior of strontium (Sr), cesium (Cs), barium (Ba), neptunium (Np), and plutonium (Pu) (in solutions prepared with water from the Well J-13) as a function of mineralogy. The minerals studied are zeolite (clinoptilolite), clay (montmorillonite), silicate (quartz), carbonate (calcite), iron oxide (hematite), iron oxyhydroxide (goethite), manganese oxide (hollandite), and manganese oxyhydroxide (romanechite). Batch sorption and column techniques were utilized for these studies. The analysis and interpretation of the data was the subject of the paper entitled "Radionuclide Migration as a Function of

Mineralogy" (Triay et al., 1991), which was presented at the IHLRWM Conference in Las Vegas, Nevada. Several conclusions have been drawn from the completion of these studies and presented in this publication. Oxides and oxy-hydroxide minerals bind actinides strongly. Strong ion exchangers (such as montmorillonite and clinoptilolite) do not sorb Np strongly. This is probably due to the large size of the neptunyl cation (and the unfavorable energetics involved in its dehydration to fit into the exchangers' sites) as well as the presence of a Np-carbonate complex, which is negatively charged and has very little affinity for cation exchangers. Rapid Np kinetics of sorption is implied by the batch experiments performed. Qualitatively, the same general trends for Pu sorption exist regardless of whether the J-13 solution was prepared from Pu(IV) or Pu(VI); this indicates that Pu speciation in J-13 water achieves the same pseudoequilibrium regardless of its initial oxidation state.

In Triay et al. (1991), the sorption behavior of radionuclides (studied with batch techniques) was compared with the sorption behavior under flowing conditions. Comparison of sorption coefficients obtained by batch and column techniques shows reasonable agreement for Sr, Cs, and Ba. Neptunium (Np) and Pu experiments show a fraction of the radionuclide eluting through columns with a sorption coefficient smaller than the one obtained in the batch studies. The most likely reasons for these discrepancies are pseudocolloid formation, precipitation, slow speciation kinetics, or slow mass transfer kinetics. These possibilities will be studied separately for Np and Pu.

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. A technique was designed to study radionuclide transport through saturated solid-rock columns that are larger than the columns previously utilized in this task. Two samples from the core obtained from the SMF were selected to test the new technique: one sample from the Topopah Spring Member (G4 274.7'- 275.5') and the other from the Calico Hills unit (G4 1530.3' - 1532.3').

A collaborative agreement between J. Conca (Washington State University) and LANL was established. Conca initiated the assessment of the capability of the Unsaturated Flow Apparatus (located at the Earth and Environmental Science Laboratory in Richland, Washington) for the study of transport through unsaturated welded and nonwelded Yucca Mountain tuffs. Four solid rock columns (two made of tuff from the Topopah Spring Member and two made of tuff from the Calico Hills unit) were prepared and sent to Conca for study.

Staff discussed a potential collaboration with P. Wierenga in the area of unsaturated transport. Wierenga was interested in collaborating with LANL to study unsaturated transport but declined the collaboration with YMP because of a previous contract with the NRC (with funding from the Nuclear Waste Fund).

Staff purchased and set up the soil measurement system's apparatus to study unsaturated transport through tuff, utilizing vacuum. This effort, in conjunction with the collaboration with Conca, will enable assessment of the potential of available systems to perform unsaturated transport experiments.

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. A strategy to study colloid transport was developed and presented to the principal investigators of LANL/YMP tasks.

2.2.2.13 Study 8.3.1.3.6.2 - Diffusion

The Study Plan is being revised to incorporate YMPO and DOE/HQ comments.

Staff received and inventoried core from the SMF.

Activity 8.3.1.3.6.2.1 - Uptake of radionuclides on rock beakers in a saturated system. A report describing the uptake of radionuclides by intact tuff from solutions prepared with water from the NTS Well J-13 is in preparation.

Activity 8.3.1.3.6.2.2 - Diffusion through a saturated tuff slab. Three experimental designs were prepared with core received from the SMF to initiate diffusion studies with tuff from the Topopah Spring Member and the Calico Hills unit.

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 DOE/HQ review comments, was submitted to the YMPO on June 18, 1991. Comment resolution is in progress.

Activity 8.3.1.3.7.1.1 - Analysis of physical/chemical processes. A dual porosity/dual permeability (DPDP) model is being investigated for possible incorporation into the computer code FEHMN. This model allows the overlay of a fracture network on a grid of matrix material. The fractures and matrix in a particular finite-element node can interact, and fracture-fracture interaction and matrix-matrix interaction between adjacent nodes can also occur. This model can be used to better understand the effects of fracture flow on moisture movement and radionuclide transport in the unsaturated zone.

A YMP colloid strategy was developed. As part of this effort, meetings with the USGS were held to ensure that colloid sampling of Yucca Mountain ground waters is performed over the next few years. Three-dimensional calculations of colloid transport were run, based on the 3D flow field used for several dissolved species transport calculations run by LANL staff.

A talk entitled "Water-Level Rise in a Vertical Fracture due to Tectonically Induced Compressive Stress" (Kelkar and Zyvoloski, 1991) was presented at the AGU Spring 1991 Meeting in Baltimore, Maryland.

Activity 8.3.1.3.7.1.2 - Geomechanical/geophysical model of Yucca Mountain and integrated geochemical transport calculations. A report was

prepared (Birdsell et al.) presenting the results of radionuclide transport calculations using TRACRN, which is being certified under the LANL Software QA Plan (SQAP). Therefore, results must be taken as unvalidated and produced by uncertified code. The results provide an examination of the sensitivity of radionuclide transport calculations to dimension of solution, geostatistics of K_d, selected source terms and recharge rates.

A modeling strategy was developed to test the applicability of the minimum K_d experimental sorption strategy developed by LANL staff. A tiered set of calculations will be performed to test the minimum K_d approach under the assumption of slow, steady matrix flow. A conservative set of calculations (K_d=0) will be used initially to determine breakthrough to the water table at various flow rates. These results will be scaled for each radionuclide based on available inventory and/or solubility. The scaled breakthrough results will be compared with regulatory limits to determine if the particular nuclide poses a problem. For those nuclides that may pose a problem, the minimum sorption coefficient (either for the entire mountain or for individual units) required to sufficiently retard the nuclide will be determined. This process will be repeated with heterogeneous hydraulic conductivity distributions, unsteady recharge, and the DPDP model.

"TRACR3D: A Model of Flow and Transport in Porous Media, Model Description and User's Manual" (Travis and Birdsell, 1991) was published to supply the information necessary to understand the mathematical and numerical models employed by the TRACR3D code. It also includes a user's manual with several examples of problems. TRACR3D is the precursor to the code TRACRN, which is being certified in accordance with the LANL SQAP.

Activity 8.3.1.3.7.1.3 - Transport models and related support. Software QA was a major component of the work during this reporting period. Primarily, this work has concentrated on the formal certification of TRACRN, a ground-water flow and transport code used in the retardation sensitivity analysis study and the geochemistry program as a whole.

During the reporting period, TRACRN was given the authorization by the LANL CCB to begin the certification process. TRACRN was classified as pre-existing development software with a reverse engineering development approach. The code is in the requirements and design phase, and the draft Software Requirements Document was completed.

Concurrently, work has been done on the design and implementation phases. The file list and modularizing the code were completed, and the Software Design Document and the Models and Methods Summary were written. Implementation of netCDF interface tables in TRACRN is about 90 percent complete, and the User's Manual is about 50 percent complete. The Verification and Validation (V&V) Plan and Procedures document has been started, along with the support modules for some of the V&V problems.

Work continued on software QA for CTCN (Colloid Transport Code Nuclear). The numerical solver, LSODPK, and the graphics output, NCSA Image tool, used in CTCN were certified.

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

Study Plan 8.3.1.3.7.2 is in preparation by LANL.

A change request was submitted to the SCPB to identify four activities within this study to better define the different approaches to data and model validation. The new activities were titled (1) Intermediate-Scale Experiments, (2) Field-Scale Experiments to Study Radionuclide Transport at Yucca Mountain, (3) Natural Analog Studies of Radionuclide Transport, and (4) Data on Radionuclide Transport From Other DOE Sites (Anthropogenic Analogues). Descriptions were prepared for these activities and are in review.

Pre-Title II design activities for the ESF required developing Test Planning Package 91-5 and input to the ESF Design Requirements to provide a complete test program for design. This study was not included in the original ESF design because limited access to the Calico Hills unit was assumed in the SCP's concept of an ESF (two shafts).

Discussions were held with LBL on collaborating with LANL in developing and implementing this study.

Several LANL investigators presented talks at the NWTRB Meeting on Natural and Archeological Analogs held in Reno, Nevada, on April 16-17. Presentations were made by J. Canepa, Role of Analogs in the Radionuclide Transport Program; E. Springer, Anthropogenic Analogs--Radionuclide Transport at DOE Sites; and D. Bish, Yucca Mountain as a Natural Analog.

2.2.2.16 Study 8.3.1.3.8.1 - Gaseous radionuclide transport calculations and measurements

This study was inactive due to a lack of funding.

2.2.3 Rock Characteristics (SCP Section 8.3.1.4)

2.2.3.1 Activity 8.3.1.4.1.1 - Development of an integrated drilling program

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

2.2.3.2 Activity 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

Study Plan 8.3.1.4.2.1 was reviewed by the YMPO and the comment resolution process was initiated.

Activity 8.3.1.4.2.1.1 - Surface and subsurface stratigraphic studies of the host rock and surrounding units. The results of X-ray fluorescence (XRF) and isotopic analyses of test wells USW G-1 and USW G-3 were presented at the IHLRWM Conference in Las Vegas in April (Spengler and Peterman, 1991).

XRF analyses were conducted on the reference chemostratigraphic section collected near Highway 95 and at Paintbrush Canyon. Results have been documented in a draft paper entitled "Trace Element Variability in Altered and Unaltered Tuffs at Yucca Mountain, Nevada" (Spengler et al.). The paper will be presented at the 1992 IHLRWM Conference in Las Vegas, Nevada, April 12-16, 1992.

A paper entitled "Assessing the Natural Performance of Felsic Tuffs Using the Rb-Sr and Sm-Nd Systems--A Study of the Altered Zone in the Topopah Spring Member, Paintbrush Tuff, Yucca Mountain, Nevada" (Peterman et al., 1991) was published.

Activity 8.3.1.4.2.1.2 - Surface-based geophysical surveys. No progress during the reporting period due to lack of funding.

Activity 8.3.1.4.2.1.3 - Borehole geophysical surveys. The following talks on physical properties and logging results from Yucca Mountain were presented to: (1) USGS, Branch of Geophysics seminar, Golden, Colorado; (2) ACNW, NRC in Bethesda, Maryland; (3) a colloquium at the USGS in Reston, Virginia; and (4) the 1991 IHLRWM conference in Las Vegas.

YMPO comments on a draft report about physical properties of ash-flow tuff were received May 1991. The author responded to comments and it was then submitted to the Journal of Geophysical Research.

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

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

The NRC has deferred their review of Study Plan 8.3.1.4.2.2, Activities 1, 2, and 4, pending potential DOE revisions for consistency with current ESF planning. Activities 3 and 5 of Study Plan 8.3.1.4.2.2 were revised and are in comment verification at the YMPO.

Activity 8.3.1.4.2.2.1 - Geologic mapping of zonal features in the Paintbrush Tuff. The accuracy of field measurements made in the Tiva Canyon Member was in the process of being assessed against existing laboratory measurements. Plotting and compilation of field notes of maps south and west of the central part of Yucca Mountain continued.

Staff participated in the inspection and correlation of lithophysal zones in core from selected coreholes as part of the evaluation of the TSw1/TSw2 contact. In addition, staff also presented a talk entitled "Available Information on the Distribution of Lithophysae at Yucca Mountain" (Spengler) to members of the SOC and the core evaluation team at the May 7 SOC meeting.

An abstract entitled "A Low-Angle Breccia Zone of Hydrologic Significance at Yucca Mountain, Nevada" (Spengler and Rosenbaum) was submitted to GSA for presentation during the theme session on geology, hydrogeology, and tectonics of southern Nevada in relation to the potential storage of high-level nuclear waste at the Annual Meeting in San Diego in October 1991.

Activity 8.3.1.4.2.2.2 - Surface-fracture network studies. YMP participants continued field work on fracture outcrop studies at the NTS. Six sites were revisited where additional data were collected, and six new field stations were completed in the Tiva Canyon and Topopah Spring Members of the Paintbrush Tuff.

A format for a data compilation report was developed and the entering of descriptive fracture data collected from more than 35 localities was begun. This task involved entering quantitative measurements, semi-quantitative measurements and qualitative observations noted at each locality, including locality information such as exposure descriptions, lithology, and stratigraphic unit; and numerous fracture characteristics, including, but not limited to, fracture orientation, spacings, expression, shape, lengths and heights, and surface structures. The field data was entered into a format for easy reference by other YMP participants. Fracture orientation data was computerized for statistical analyses. Interpretative summaries were written for each field station. The 35 localities are in several units of the Tiva Canyon and Topopah Spring Members of the Paintbrush Tuff.

Activity 8.3.1.4.2.2.3 - Borehole evaluation of faults and fractures. No progress during reporting period due to lack of funding.

Activity 8.3.1.4.2.2.4 - Geologic mapping of the exploratory shaft and drifts. Plans to excavate a test pit on the Arizona side of Hoover Dam were canceled as a result of the State of Nevada issuing the air-quality permit which was necessary to deepen the pit at Fran Ridge. Plans were underway to deepen the prototype north pit at Fran Ridge, and clean the area around the pit for surface-fracture studies.

Staff completed Engineering Reconnaissance Reports for six possible ESF shaft sites and four possible ESF ramp portal sites as part of the ESF access selection studies. Staff also completed Engineering Reconnaissance Reports for the currently selected North and South Ramp Alignments for ESF design studies.

Personnel continued coordination with the ESF designers and Test Coordinators Office to include Underground Geologic Mapping needs in the tunnel boring machine (TBM) trailing gear design and in the tunnel utility layout. A mapping platform must be included in the design, and the utilities (ventilation, compressed air, water, and power) should be located in the lower left or right quadrant or invert of the tunnel.

Activity 8.3.1.4.2.2.5 - Seismic tomography/vertical seismic profiling. The computer program, ANRAY90, was applied to well log information from test wells USW G-4, and UE-25c#1, c#2, and c#3. It is apparent from the modeling results to date that the near surface high-velocity zones could significantly shield the deeper zones from the seismic energy. This implies that unless the offset distances are relatively close to the well, seismic energy will not

reach the deeper zones. It also implies that cross-hole measurements that avoid the near surface welded tuffs may be the only practical means to image below welded tuffs.

A paper entitled "The Resolution of Tomographic Imaging Techniques" (Peterson) was reviewed internally and will be modified to include more details of anisotrophy correction.

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

This Study Plan is being revised to incorporate comments received from the YMPO and DOE/HQ. The initiation of drilling activities under this study is an out-year activity.

Activity 8.3.1.4.3.1.1 - Systematic drilling program. Samples of welded and nonwelded tuff were collected from surface outcrops at Yucca Mountain using a hand-held, gasoline-powered core drill as part of a collaborative effort by SNL, the USGS, and Pacific Northwest Laboratory (PNL) staff. Additional samples that include stratigraphic units not exposed in the immediate vicinity of the potential repository site were requested from existing drill core and rotary cuttings in the SMF. Collectively, these samples provide a composite vertical profile (stratigraphic coordinates) at spacings of approximately 1 to 4 meters through all units constituting the unsaturated zone and a small number of horizontal traverses in selected units at sample spacings of 20 to 200 meters. The 658 samples are being used for scoping studies of spatial continuity under this activity and for prototype testing of material properties and technique development by Study 8.3.1.2.2.3 (Characterization of Percolation in the Unsaturated Zone--Surface-Based Study, Matrix Hydrologic Properties Testing activity). Material properties being determined include porosity, dry and wet bulk density, particle density, saturated conductivity, and imbibition.

Additional compilation and evaluation of existing drillhole information on both formal stratigraphic and microstratigraphic units at Yucca Mountain has been undertaken. Selected intervals in several existing core and rotary holes have been relogged at the SMF, with particular emphasis placed on the continuity and character of some of the microstratigraphic units exhibiting unexpected rock properties as determined from the outcrop sampling study. The geologic logging also served as a prototype technique development and training exercise for SNL staff in preparation for the Systematic Drilling Program Activity. In addition to expanding and substantiating some of the findings of the outcrop study, this work has identified the cause of several anomalous thickness features that have appeared in computer models of some micro units being developed by Study 8.3.1.4.3.2 (Three-Dimensional Rock Characteristics Models).

A paper summarizing some preliminary interpretations of the outcrop-sampling data, entitled "Microstratigraphic Units and Spatial Correlation of Hydrologic Properties in Tuff, Yucca Mountain, Nevada" (Rautman et al.), has been accepted for presentation at a theme session on Yucca Mountain at the 1991 Annual Meeting of the GSA. A related paper describing some of the implications of the outcrop-sampling data for geologic modeling, entitled "Deterministic Geologic Processes and Stochastic Modeling" (Rautman and Flint), has been submitted to the 1992 IHLRWM Conference in Las Vegas, Nevada.

A portable gas permeameter has been developed to allow direct field measurement of in situ permeabilities to provide additional scoping data on the spatial variability of poorly consolidated and other nonwelded tuffs. For additional discussion, refer to Subactivity 1.6.2.1.1 (Development of a Theoretical Framework for Calculational Models). The device has also been used on a prototype basis to obtain closely spaced laboratory measurements on slabs of rock. Additional laboratory measurements to study small-scale continuity will be conducted after calibration of the device is completed. A series of orifice tips is being developed to provide direct permeability measurements at varying scales spanning three orders of magnitude. A paper incorporating a brief description of the gas permeameter, "Field Research Program for Unsaturated Flow and Transport Experimentation" (Tidwell et al.) has been prepared and submitted to the 1992 IHLRWM Conference in Las Vegas, Nevada. Some results from the prototype testing phase of development have been summarized in a paper entitled "Influence of Measurement Scale on Effective Media Property Estimates" (Tidwell et al.), which has been submitted for presentation at the Fall Meeting of the AGU in San Francisco, California.

The YMP SOC convened in May to address the long-standing issue of alternative interpretations of the contact between thermal/mechanical units TSw1 (high lithophysal content) and TSw2 (low lithophysal content, repository horizon) in existing core holes. The SOC representatives examined all available core through the critical interval and concluded that a revised interpretation was warranted. The elevations of the interpreted contact in drill holes UE-25 a#1, USW G-1, and USW G-2 were raised by amounts that may exceed 100 meters. These revisions of the contact elevations allow a reinterpolation of the upper contact of the potential repository host rock that may result in significant design changes. The remodeling of the contact was conducted by Study 8.3.1.4.3.2 (Three-Dimensional Rock Characteristics Models).

A report entitled "Structures in Continuously Cored Deep Drill Holes at Yucca Mountain, with Notes on Calcite Occurrence" (Carr) has been prepared and is undergoing internal USGS review.

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. The contact between thermal/mechanical units TSw1 and TSw2 was remodeled using new data from existing drill holes developed by the YMP SOC. Three-dimensional gridded terrain models (GTMs) were produced, and a number of cross sections and contour maps showing the new contact and changes from previous models were developed from those GTMs. The reinterpretation of this contact generally raises the elevation of the surface separating high-lithophysal material from the lower-lithophysal tuff that constitutes the host unit for the potential repository. Raising the contact expands the volume of rock suitable for potential repository excavation, particularly in the northern portion of the site area. The configuration of this expanded volume potentially allows portions of the potential repository floor to be raised as well, resulting in lower and more consistent grades both within the repository and on the northern access ramp. Information regarding the revised model was provided to a YMP-level Technical Integration Group considering design specifications for the ESF/Repository/Ramp interface.

Evaluation of geostatistical and other modeling methods continued. Programs from a large library of state-of-the-art geostatistical subroutines (GSLIB) obtained under contract from the Stanford (University) Center for Reservoir Forecasting (SCRF), an industry-research group that includes SNL, have been used in the analysis of outcrop-sample data obtained as a joint effort by Study 8.3.1.4.3.1 (Systematic Acquisition of Site-Specific Subsurface Information) and Study 8.3.1.2.2.3 (Characterization of Percolation in the Unsaturated Zone--Surface-Based Study, Matrix Hydrologic Properties Testing activity). The indicator simulation algorithm from GSLIB has been used by SNL staff to produce both conditional and unconditional simulations of lithology in an alluvial fan/debris flow complex on the NTS. Simulations conditioned to abundant outcrop (trench wall) data almost exactly reproduced the "exhaustive" mapped data. Unconditioned simulations that used only the proportion of different lithologies and the observed spatial continuity patterns produced realizations bearing a striking resemblance to the actual geology. The unconditional simulations also emphasize the importance of adequate conditioning data to represent properly the deterministic features of the geology. Although this work was only partially funded by the YMP, the results demonstrated the utility of the simulation methodology and increased confidence in the approach. Additional validation of the simulation approach to heterogeneity and flow modeling was obtained at the annual review meeting of SCRF, where participants from major international petroleum companies discussed applications to reservoir flow and production forecasting.

A paper entitled "Characterization Uncertainty and Its Effects on Models and Performance" (Rautman and Treadway, 1991) was presented at the second IHLRWM Conference in Las Vegas, Nevada. This study used non-parametric geostatistical simulation to quantify characterization uncertainty. A similar, but somewhat more comprehensive description of the same simulation experiment, entitled "Geologic Uncertainty in a Regulatory Environment: An Example from the Potential Yucca Mountain Nuclear Waste Repository Site" (Rautman and Treadway) has been accepted for publication in the journal Environmental Geology and Water Science. A more methodological paper entitled

"Geostatistical Techniques for Describing and Modeling Heterogeneities in Rock Properties" (Rautman) was presented at a University of Arizona symposium on Characterization of Transport Phenomena in the Vadose Zone; a short summary of the paper was published in the workshop proceedings (Rautman, 1991). A version of this methodology paper with emphasis on applications to issues of data adequacy was also given as a technical presentation to the May 21, 1991, Technical Project Officers (TPOs) meeting in Las Vegas. Another paper, "Use of Conditional Indicator Simulation to Quantify Uncertainty" (Hansen), which describes some numerical experiments using synthetic input data, has been prepared and is in internal SNL review.

The limitations of existing geometric modeling capabilities at SNL have become increasingly apparent during recent work involving both the remodeling of the TSw1/TSw2 contact and a more general modeling of a larger region in collaboration with USGS staff to incorporate additional, more detailed stratigraphic data not previously available. The existing modeling technique was originally described in Ortiz et al. (1985). Some of the limitations inherent in the existing system were described more recently in "Evaluation of Geographic Information Systems for Three-Dimensional Ground-Water Modeling, Yucca Mountain, Nevada" (Turner et al., 1991). SNL staff have been evaluating replacement software and hardware configurations that offer the potential for integration with developing geostatistical methodologies, such as those in the GSLIB library. A potential vendor of geologically oriented software with experience serving the needs of the mining industry has been selected, and a contract is being negotiated.

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

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

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 is in the final stages of DOE comment verification, and is nearly ready for submittal to the NRC.

2.2.4.3 Study 8.3.1.5.1.3 - Climatic implications of terrestrial paleoecology

Study Plan 8.3.1.5.1.3 is in YMPO review.

Activities 8.3.1.5.1.3.1-3 showed no progress during the reporting period; these are out-year activities.

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 sent to the NRC on June 24, 1991.

Activity 8.3.1.5.1.4.1 - Modeling of soil properties in the Yucca Mountain region. Dust samples collected in 1989 were prepared for major-oxide analysis.

Activity 8.3.1.5.1.4.2 - Surficial deposits mapping of the Yucca Mountain area. Field verification of surficial deposits was conducted in conjunction with preparing strip maps of Quaternary faults at Yucca Mountain. Orthophoto quadrangles (1:6,000) were obtained from the YMPO in August 1991, to be used for compilation of surficial geology.

Activity 8.3.1.5.1.4.3 - Paleoenvironmental history of Yucca Mountain. Personnel conducted field work in conjunction with preparing strip maps of Quaternary faults at Yucca Mountain.

2.2.4.5 Study 8.3.1.5.1.5 - Paleoclimate-paleoenvironmental synthesis

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

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

The internal SNL review of the Study Plan 8.3.1.5.1.6 was completed and submitted to the YMPO for review. A summary of the conference paper entitled "An Overview of the Yucca Mountain Global/Regional Climate Modeling Program" (Sandoval) was submitted for presentation at the 1992 IHLRWM Conference at Las Vegas, Nevada.

Activity 8.3.1.5.1.6.2 - Regional climate modeling. For the first phase of the present climate validation task, three years of regional climate simulations covering two periods, January 1982 to December 1983 and January 1988 to April 1989, were generated with the regional climate model MM4 using data from the European Center for Medium-Range Weather Forecasts. The analysis of model results consisted of two steps. In the first step, model results were compared with data for the period acquired from the National Climate Data Center. These data were collected from about 390 stations throughout the western United States. The model reproduced the seasonal cycle of temperature and precipitation well. Monthly and seasonal temperature biases were generally less than a few degrees. The effects of topography on the distribution of precipitation were also well reproduced. Overall, the model simulated precipitation better in the cold season than in the warm season and better over coastal regions than in the continental interior. Although modeled and observed snow depth values differed significantly over some regions, the simulated cycles of snowpack formation and melting were realistic.

The second step of the analysis focused on the southern Great Basin. Model-produced surface air temperatures and precipitation were compared with observations from five stations in southern Nevada. Monthly and seasonal temperature biases were generally negative and largely explained by differences in elevation between the observing stations and model topography. The model-simulated precipitation captured the extreme dryness of the Great

Basin well. Precipitation biases were generally negative in the summer and positive in the winter. At Yucca Mountain, simulated precipitation, soil moisture content, and infiltration were maximized in the winter. Evaporation peaked in the spring after temperatures began to increase. Further details of this analysis are given in the report entitled "Toward the Simulation of Future Climate Scenarios Over the Southern Great Basin" (Bates et al.). After the internal SNL review is completed, it will be submitted for publication in the Bulletin of the American Meteorological Society.

Activity 8.3.1.5.1.6.3 - Linked global-regional climate modeling. No progress reported during this reporting period. This is an out-year activity.

2.2.4.7 Study 8.3.1.5.2.1 - Characterization of the Quaternary regional hydrology

The YMPO review of Study Plan 8.3.1.5.2.1, revision 2, was completed. Resolution of the review comments was in progress. DOE responses to 10 comments from the State of Nevada on this Study Plan were returned to the State on September 19, 1991.

Activity 8.3.1.5.2.1.1 - Regional paleoflood evaluations. A report entitled "Evidence of Prehistoric Flooding and the Potential for Future Flooding at Coyote Wash, Yucca Mountain, Nevada" (Glancy) was submitted for USGS approval.

Activity 8.3.1.5.2.1.2 - Quaternary UZ hydrochemical analysis. An Interim Change Notice submitted to the YMPO in 1990 proposed that this activity be deleted and the scope of this work be accomplished under Study Plan 8.3.1.2.2.7. A change request for the SCPB is needed but has yet to be submitted to the YMPO CCB.

Activity 8.3.1.5.2.1.3 - Evaluation of past discharge areas. YMP personnel developed and tested techniques for efficient scanning of geologic maps at all levels of complexity and for all available map scales. All the geologic data at the 1:250,000 scale have been scanned. More complex geologic data at larger scales have been scanned where detailed geologic data are needed.

About 75 percent of the fault data for the study area has been processed through ARC/INFO. Drainage data for the entire region have been developed, scanned, and plotted as ARC/INFO coverage.

Processing was completed on a series of digital data sets, describing gravity, aeromagnetics, and related geophysical data distributed on a CD-ROM by National Oceanic and Atmospheric Administration's (NOAA) National Geophysical Data Center. Copies of selected aeromagnetic and topographic data have been extracted for the study area.

A field trip was conducted in late July and early August to collect samples from springs in the Oasis Valley, Spring Mountains, and the NTS. Samples were collected for water quality, isotope data, flora and fauna. These data are indicative of the present environment. The data will be used

as proxy data to determine actual processes occurring in the past and estimates will be made about the water quality of the ancient deposits.

An abstract of a report entitled "Determining Areas of Large Permeability and Large Well Yield in Regional Aquifers Using Hydrochemical, Hydrological, and Structural Discontinuity Analysis" (Kolm and Downey, 1990) was published.

Activity 8.3.1.5.2.1.4 - Analog recharge studies. Three field trips were conducted to the study sites. Spring and summer maintenance work was combined with evapotranspiration (ET) field work. Equipment installation and operation were completed during five weeks of field study at the analog sites. Analysis of summer field work will continue throughout the winter. Technical procedures/scientific notebooks completed for the evapotranspiration field work included: (1) Measurement of Evapotranspiration using Eddy Correlation Methods, (2) Estimation of Leaf Area Index in Plant Canopies, (3) Measurement of leaf-water potential using a Pressure Chamber, (4) Measurement of Evapotranspiration using Bowen Ratio Methods, and (5) Measurement of Transpiration using Chamber Methods.

Late snows produced runoff at Stewart Creek and at Kawich Creek. Fall maintenance work indicated below-normal summer precipitation in the Stewart basin and above-normal precipitation in the Kawich basin. Both basins received about normal annual precipitation based on a 6-year average, 1986 through 1991.

Initial evaluation and scoping was done on the development of hydrologic response units at Kawich and Stewart. ARC/INFO has been used to manipulate the elevation, slope and aspect information stored in INFO files. This information, taken from USGS topographic maps, must be reduced from tens of thousands of polygons into several hundred polygons. Each polygon represents an area which responds to precipitation as a homogeneous hydrologic unit.

Comparisons between measured solar radiation at the analog sites and a simplified clear sky model for direct and diffuse insolation on horizontal surfaces has provided information useful in the precipitation-runoff modeling system which is to be used in estimating recharge at the analog sites.

Bulk precipitation samples were collected from the Organ Pipe Cactus National Monument and Safford sites in April and July. All of the instrumentation for the long-term meteorological monitoring have been received and calibrated. Installation will take place in the near future. Development of instrumentation for hydrologic monitoring, heat flux, and wet-dry collectors is proceeding rapidly so that it can probably be installed this fall.

A report entitled "Chemical Analyses of Water from Selected Wells and Springs in the Yucca Mountain Area, Nevada, Southeastern California" (McKinley et al., 1991) was published.

The Master's thesis that was contracted through the University of New Mexico, entitled "Soils and Geomorphology of the Quaternary Alluvial Sequence of the Western Piedmont of the Ajo Mountains, Organ Pipe Cactus National Monument, Pima County, Arizona" (Simpson), has been completed.

Activity 8.3.1.5.2.1.5 - Studies of calcite and opaline-silica vein deposits. Work continued on strontium isotopic analyses of vein carbonates from deep drill holes at Yucca Mountain and stable isotope work continued on existing drill-core samples recently obtained from the SMF.

Staff scientists presented three papers at the 1991 American Nuclear Society (ANS) High-Level Radioactive Waste symposium: "Isotopic Discontinuities in Ground Water Beneath Yucca Mountain, Nevada" (Stuckless et al., 1991); "An Evaluation of Evidence Pertaining to the Origin of Vein Deposits Exposed in Trench 14, Nevada Test Site, Nevada" (Stuckless, 1991); and "Strontium Isotopes in Carbonate Deposits at Crater Flat, Nevada" (Marshall et al., 1991).

Uranium isotopic analyses continued on mineral separations of calcite from Crater Flats localities as well as microsamples from Trench 14 blocks that have been studied petrographically by Vaniman and others at LANL. Three ages from block HD-15 range from about 85 to 370 ka and support the stratigraphic relationships worked out by Vaniman, but all three samples will have to be analyzed for thorium in the residuum on order to facilitate an age correction. Dating of the Solitario Canyon and Windy Wash fault samples will be postponed until a staff geochronologist is hired.

Trench 14 was deepened to 20 feet and calcite-opal veins pinched out to 5-6 cm, as predicted. Staff of the USGS and LANL observed the trenching activities and sampled the new exposures of veins and tuff.

A paper entitled "Isotopic Composition of U and Sr in Ground Water and Hydrogenic Deposits, Yucca Mountain, Nevada -- Evidence Against Upwelling Water" (Peterman et al.) was revised, resubmitted, and accepted by Science.

Staff completed experimental work on leaching techniques to isolate calcite hosted lead from lead in the insoluble silicate residue. Strontium isotopic analyses were performed on spring deposits from Death Valley.

The following abstracts were submitted for the 1991 GSA National Meeting in San Diego, California: "The $\delta^{13}C$ and $\delta^{18}O$ Values of Epigenetic Calcite Within Yucca Mountain, Nevada: Paleohydrologic Implications"; (Whelan and Stuckless); "Strontium Isotope Characterization of Ground-Water Flow Systems in Southern Nevada" (Peterman et al.); "Lead Isotopes in the Carbonate-Silica Veins of Trench 14, Yucca Mountain, Nevada" (Zartman and Kwak); "A Model for the Formation of Pedogenic Carbonate Based on Strontium Isotope Data from Southwest Nevada" (Marshall and Mahan); and "Isotopic Evidence for a Per Descensum Origin for Hydrogenic Veins in Faults Near Yucca Mountain, Nevada" (Stuckless et al.).

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

YMPO review of Study Plan 8.3.1.5.2.2 was completed and comment resolution was initiated.

Activity 8.3.1.5.2.2.1 - Future surface hydrology. YMP staff began evaluation of comments on Study Plan 8.3.1.5.2.2.

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 - Evaluation of possible future changes in climate and regional geologic framework on regional SZ hydrology. Topographic data were reprocessed to provide slope aspect and shaded relief displays. These were used for choosing appropriate grid size for future ground-water models. Further processing of topographic data is required to confirm geographic registration of the data.

The soil survey of southern Nye County has been entered into ARC/INFO, and edited, labeled and attributed. These surveys form a data base to obtain recharge parameters for basin-scale models when assigned attributes.

2.2.5 Erosion (SCP Section 8.3.1.6)

No work was carried out on erosion. This area is not currently funded.

2.2.6 Postclosure Tectonics (SCP Section 8.3.1.8)

2.2.6.1 Study 8.3.1.8.1.1 - Probability of magmatic disruption of the repository

The DOE received 9 comments on this Study Plan from the State of Nevada on August 8, 1991.

Activity 8.3.1.8.1.1.1 - Location and timing of volcanic events. No progress during the reporting period due to lack of funding.

Activity 8.3.1.8.1.1.2 - Evaluation of the structural controls of basaltic volcanic activity. Calculations of the probability of magmatic disruption of the potential repository were completed using a range of models of structural controls of volcanic activity. These include the random model of Crowe et al. (1982) and structural models proposed by contractors for the State of Nevada.

Field studies were conducted at the Lathrop Wells volcanic center with USGS participants to examine northwest-trending faults that may provide structural controls for the location of the center.

A talk on use of analogs in volcanism studies for the Yucca Mountain site was presented at the workshop on the Role of Natural Analogs in Geologic Disposal of High-Level Nuclear Waste, sponsored by the Center for Nuclear Waste Regulatory Analyses and the NRC Office of Regulatory Research. Analog data were presented for the structural controls of volcanic activity.

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. The System 151 Image Processor is fully operational and can be used to produce digital images from geologic maps.

Discussions were held with participants from RSN and EG&G on obtaining digitized topographic data for the volcanic centers of the Yucca Mountain region. LANL staff arranged to acquire digital terrain data for volcanic centers of the Crater Flat area and the Lathrop Wells volcanic center using the orthophotographic data obtained and developed by EG&G. These data will be used to refine volume data for probability calculations.

A meeting was attended on Disruptive Events with Golder Associates in Seattle, Washington. LANL staff presented current results of probability modeling of the risk of future volcanism for the Yucca Mountain site.

2.2.6.2 Study 8.3.1.8.1.2 - Effects of a magmatic disruption of the repository

A draft of Study Plan 8.3.1.8.1.2 is in preparation.

Activity 8.3.1.8.1.2.1 - Effects of Strombolian eruptions. A literature search was initiated on the physical process of generation, ascent, storage, and eruption of basalt magma in an extensional environment. Eruption modeling was conducted to extend these concepts to Strombolian eruptions.

Lithic fragments in scoria deposits of volcanic centers of the San Francisco volcanic field and the Vulcan's Throne area of Grand Canyon National Monument were examined in the field.

Activity 8.3.1.8.1.2.2 - Effects of hydrovolcanic eruptions. A dissected vent with an early phase of hydrovolcanic activity was identified for further study. This vent is exposed on the south wall of the Grand Canyon near Vulcan's Throne.

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

Study Plan 8.3.1.8.2.1 is still in revision.

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 was made during the reporting period; this is an out-year study.

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

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

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

A draft of Study Plan 8.3.1.8.3.3 is in preparation.

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 was made in this study 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

DOE responses to 5 comments from the State of Nevada on this Study Plan were returned to the State on July 24. Responses to 3 comments from the NRC were returned on August 23.

Activity 8.3.1.8.5.1.1 - Volcanism drill holes. An independent company has initiated drilling at one of the aeromagnetic sites. LANL staff will attempt to obtain cuttings from this drill rig to determine if the results can be used for the volcanism program.

Activity 8.3.1.8.5.1.2 - Geochronology studies. A contract was initiated with D. DePaolo, Chairman of the Department of Geological Sciences at the University of California, at Berkeley, to conduct an independent review of the geochronology studies for the volcanism project. DePaolo spent two days examining the field relations and geochronology data for the Lathrop Wells, Crater Flat, and Cima volcanic fields in May and presented eight recommendations in the review.

Staff discussed $^{40}Ar/^{39}Ar$ geochronology studies with M. Harrison of the University of California, Los Angeles, and P. Zeitler, Lehigh University. Both expressed reservations at applying of this method to fine-grained basalt samples because of the problem of recoil effects. Zeitler agreed to participate in future geochronology studies.

Paleomagnetic samples were drilled and sampled for dike systems at the Paiute Ridge site and the Lathrop Wells volcanic center. Samples at the latter location were collected for sites that have not been sampled and studied in work conducted by the USGS. Paleomagnetic samples were also drilled and collected at the A and I cone centers in the Cima volcanic field.

Activity 8.3.1.8.5.1.3 - Field geologic studies. Samples were collected at the Lathrop Wells volcanic center for surface exposure age estimates using the $^{3}He/^{4}He$ method. The samples sites include a Ql_3 lava dated independently by the thermoluminescence (TL) method and the summit of the Lathrop Wells scoria cone.

The 4x4 truck-mounted backhoe was moved to Las Vegas in preparation for field studies. Field studies were completed at Snake River Plains, Idaho, to test the operation of the backhoe system and to obtain samples of soils baked by lava flows for TL age determinations.

Preparatory work was completed for construction of surface-disturbing soil pits at the Lathrop Wells volcanic center. Biological and archaeological surveys of selected sites were completed, and safety procedures for field work and backhoe operation were finalized. Quality assurance surveys of the volcanism task were completed, and a grading package completed and approved. A test planning package (TPP 91-32) was completed and issued as a controlled document.

The first surface-disturbing work was successfully completed on July 9-10 at the Lathrop Wells volcanic center. Seven soil pits were dug in the first phase, and a second phase was completed during August 29-30 (Figure 1.2). Sampling was completed of the 3.7-Ma basalt centers of Crater Flat for petrology and geochronology studies.

A report entitled "Preliminary Geologic Map of the Sleeping Butte Volcanic Centers" (Crowe and Perry, 1991) described the geology and geochronology data for the Sleeping Butte volcanic centers, two Quaternary centers located 45-km northwest of Yucca Mountain. In "Cation-Ratio Dating: Why Does it Work?" (Reneau et al., 1991), elemental distributions were used within rock varnish to demonstrate that the concentrations of Ca, K, and Ti are not independent of Mn concentration, as originally implied by Dorn (1983) and to argue against significant preferential elemental leaching from varnish. It then explored alternative hypotheses to explain the empirical relationship of decreasing cation-ratio with increasing surface age.

Activity 8.3.1.8.5.1.4 - Geochemistry of scoria sequences. A contract was emplaced with an isotopic laboratory at the University of Colorado to obtain isotopic data for strontium (Sr), neodymium (Nd), and lead (Pb) from basalt samples. Twelve samples, including test standards, were submitted to the laboratory. Isotopic data was received for the isotopic systems of Sr and Nd for the Lathrop Wells volcanic center.

INAA data for the identified field eruptive units at the Lathrop Wells center were examined to test eruption models.

Basalt samples were collected for analytical studies at soil pit sites dug at the Lathrop Wells volcanic center.

Activity 8.3.1.8.5.1.5 - Geochemical cycles of basaltic volcanic fields. Samples were collected at the G, H, and I cones in the Cima volcanic field for regional petrology studies.

2.2.6.9 Study 8.3.1.8.5.2 - Characterization of igneous intrusive features

Preparation of Study Plan 8.3.1.8.5.2 continued.

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. Reconfiguration and testing of the digital temperature-logging system, thermal conductivity laboratory, and temperature calibration laboratory continued. Acquisition of the new hardware/software and reconfiguration of laboratory and field facilities will require extensive revision of the controlling technical procedure.

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

No progress was made 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 reviewed by the YMPO and comment resolution is nearly completed.

Activities 8.3.1.9.2.1.1-4 showed no progress during the reporting period due to lack of funding.

Activity 8.3.1.9.2.1.5 - Mineral and energy assessment of the site, comparison to known mineralized areas, and the potential for undiscovered resources and future exploration. Data on mines and types of deposits in the southwest Nevada volcanic field and surrounding area were collected and plotted on a computerized geologic base map. A draft colored geologic map with overlay of mines and prospects was completed. A draft of the compendium of deposits with model types (ore-deposit model) was completed. A geologic map of the mineral resources of the area surrounding Yucca Mountain, including a large part of the southwestern Nevada volcanic field, has been completed and will soon be distributed. A major compilation of existing information, "Mines, Prospects, and Mineral Occurrences in Esmeralda and Nye Counties, Nevada, Near Yucca Mountain" (Bergquist and McKee, 1991) was published.

A draft report containing information on hydrocarbons in the vicinity of Yucca Mountain was completed and submitted for technical review.

A draft report on the geophysical assessment of mineral resource potential was completed. A report on analytical capabilities related to mineral resource appraisal was in progress.

2.2.7.2 Study 8.3.1.9.2.2 - Water resource assessment of Yucca Mountain

Study Plan 8.3.1.9.2.2 was sent to the NRC for review.

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

No progress was made in this study 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 was made in this study 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

The Meteorological Monitoring Plan, revision 1, was replaced by the Meteorological Monitoring Plan (Study Plan for Meteorological Data Collection at the Yucca Mountain Site), revision 0. See Section 2.2.8.3 below.

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

The plan for the synthesis of meteorological monitoring data has been incorporated into the Meteorological Monitoring Plan. See Section 2.2.8.3 below.

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

The Study Plan was approved by DOE on April 1, and sent to the NRC for review on May 16, 1991.

2.2.8.4 Study 8.3.1.12.4.1 - Characterize the potential extreme weather phenomena and their recurrence intervals

The plan to characterize the potential extreme weather phenomena and their recurrence intervals has been incorporated into the Meteorological Monitoring Plan (Study Plan for Meteorological Data Collection at the Yucca Mountain Site), revision 0. See Section 2.2.8.3 above.

2.2.9 Offsite installations and operations (SCP Section 8.3.1.13)

No work was performed on Offsite Installations and Operations in FY 1991 due to lack of funding. This area is inactive.

2.2.10 Surface characteristics (SCP Section 8.3.1.14)

2.2.10.1 Study 8.3.1.14.2.1 - Exploration program

A final version of Study Plan 8.3.1.14.2.1 was prepared after comment resolution and sent to YMPO for approval on August 21, 1991.

Responsibility for this study, as well as Studies 8.3.1.14.2.2 and 8.3.1.14.2.3, has been assumed by the USGS/USBR, and all three studies have been combined into a single study (with an accompanying Study Plan). Hence, it is anticipated that SNL will have no work in this area in the future.

2.2.10.2 Study 8.3.1.14.2.2 - Laboratory tests and material property measurements

See discussion for Study 8.3.1.14.2.1 above.

2.2.10.3 Study 8.3.1.14.2.3 - Field tests and characterization measurements

See discussion for Study 8.3.1.14.2.1 above.

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 ESF program is imminent.

Activities 8.3.1.15.1.1.1-2 showed no progress during this reporting period due to lack of funding.

Activity 8.3.1.15.1.1.3 - Thermal conductivity characterization. All procedures required to perform scoping studies in this activity have been completed. The three technical procedures approved and issued during this reporting period include one for calibration of temperature sensors and two governing specific thermal-conductivity measurement techniques (guarded heat-flow-meter and thermal comparator). In addition, an experiment procedure was approved and issued that provides the overall guidance for conduct of a scoping study on the effects of sample saturation on the thermal conductivities of multiple samples of welded, devitrified tuff and zeolitized tuff.

2.2.11.2 Study 8.3.1.15.1.2 - Laboratory thermal expansion testing

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 ESF program is imminent.

Activity 8.3.1.15.1.2.1 - Thermal expansion characterization. One technical procedure (calibration of temperature sensors) required to perform work for this activity was approved and issued, as reported for Activity 8.3.1.15.1.1.3. In addition, a technical procedure for operation of a scanning electron microscope was approved and issued; this procedure would be used as part of work to characterize samples on which thermal-expansion behavior is measured.

One of the prerequisites for performance of thermal-expansion measurements has been the design and construction of a chamber/test arrangement that can maintain 100 percent relative humidity (for T < 100°C) while not adversely affecting instrumentation in the dilatometer. Such a chamber has been built and used successfully for measurements on nonporous standards. An initial run for a zeolitized tuff sample has been made; the results are promising, although length changes in the temperature range of 85 to 105°C are difficult to interpret relative to expected behavior. Additional measurements on tuff samples will be performed before finalization of the technical procedure governing the thermal-expansion measurements.

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 has been approved by DOE and was sent to the NRC on June 21, 1991.

Activity 8.3.1.15.1.3.1 - Compressive mechanical properties of intact rock at baseline experiment conditions. Prototype experiments run at the baseline set of conditions (i.e., 10^{-5} s^{-1}, room temperature, atmospheric pressure, saturated) have been completed and the technical procedures necessary for future testing at baseline conditions are being drafted by personnel at New England Research, Inc. (NER).

Activity 8.3.1.15.1.3.2 - Effects of variable environmental conditions on mechanical properties. Prototype experiments have been run, technical procedures have been written, and four experiments have been completed at a nominal strain rate of 10^{-9} s^{-1}. These experiments are part of a series of experiments studying the time-dependent deformation of the potential repository-horizon welded tuff.

A report entitled "Tensile Strength Testing of Topopah Spring Tuff" (Teufel and McNamee, 1991) was published. The report details the experiments run to determine the appropriate test type for measuring tensile strength of the welded tuff.

The results of a scoping series of experiments were presented at the 1991 IHLRWM Conference in Las Vegas, Nevada. The presentation was entitled "Mechanical Anisotropy of Yucca Mountain Tuffs" (Price et al., 1991).

Two abstracts, "The Influence of Strain Rate and Sample Inhomogeneity on the Moduli and Strength of Topopah Spring Member Tuff" (Price et al.) and "Modulus Dispersion and Attenuation in Tuff, Sandstone, and Granite" (Haupt et al.), have been submitted for consideration to be presented and published at the 33rd U.S. Symposium on Rock Mechanics. The conference will be held on June 8-10, 1992, in Santa Fe, New Mexico.

2.2.11.4 Study 8.3.1.15.1.4 - Laboratory determination of mechanical properties of fractures

Study Plan 8.3.1.15.1.4 is in SNL internal review.

Activity 8.3.1.15.1.4.1 - Mechanical properties of fractures at baseline experiment conditions. Both the mechanical properties (normal and shear stiffness and frictional shear strength) and the transport properties (fluid and solute transport) of fractures in rock are strongly influenced by the roughness and the degree of mismatch between the surfaces. As part of a project to determine the variability of the roughness and the degree of mismatch of the surfaces of natural fractures, the topographies of 17 natural fractures from various rock types were profiled by SNL staff. The rocks were of igneous (both intrusive and surface volcanic, including tuff from Yucca Mountain) and sedimentary origin. Software has been developed to analyze these data for the roughness of each surface and its scaling (size-dependent) properties and the degree of mismatch between the two opposing surfaces. These data will be compiled, included in a report on a simple mathematical model of rough fractures, and maintained for future analysis.

Activity 8.3.15.1.4.2 - Effects of variable environmental conditions on mechanical properties of fractures. To relate frictional constitutive properties, which are measured on smooth surfaces of tuff, to dilating fractures, it is necessary to measure the response of rough surfaces to various loads and displacements. In order to enhance our capability to test natural fractures, SNL staff members have fabricated some new fixtures for the rotary shear machine that can accommodate arbitrary sample shapes. A technique is being developed to grind a circular test area on such a sample for rotary shear testing.

Several SNL staff members comprise the Fracture Properties Working Group, which met four times during the last six months to discuss testing plans and the status of the Study Plan. These meetings included discussions with staff at the University of Colorado on some relatively large-scale laboratory experiments being performed on fractures with rough surfaces.

2.2.11.5 Study 8.3.1.15.1.5 - Excavation investigations

Work under this study cannot be conducted until the accesses and initial portions of the ESF Main Test Level have been constructed. As a result of the revised ESF design, based on the results of the ESF Alternatives Study, substantial portions of this Study Plan will have to be revised prior to starting work. The NRC has informed DOE that a review of the Study Plan will be deferred until a later date.

2.2.11.6 Study 8.3.1.15.1.6 - In situ thermomechanical properties

This study is not funded. The principal impacts of this budget shift is that Study Plan 8.3.1.15.1.6 has been delayed until such time as ESF construction is imminent. The NRC has informed DOE that a review of the Study Plan will be deferred until a later date.

2.2.11.7 Study 8.3.1.15.1.7 - In situ mechanical properties

This study is not funded. The principal impacts of this budget shift is that Study Plan 8.3.1.15.1.7 has been delayed until such time as ESF

construction is imminent. The NRC has informed DOE that a review of the Study Plan will be deferred until a later date.

2.2.11.8 Study 8.3.1.15.1.8 - In situ design verification

Study Plan 8.3.1.15.1.8 was submitted to the YMPO for review.

2.2.11.9 Study 8.3.1.15.2.1 - Characterization of the site ambient stress conditions

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

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

Study Plan 8.3.1.16.1.1 was accepted by the NRC on May 8, 1991. DOE responses to nine comments on this Study Plan by the State of Nevada were returned to the State on June 6, 1991.

Activity 8.3.1.16.1.1.1 - Site flood and debris hazard studies. Some rainfall and minor runoff occurred at Yucca Mountain during the summer of 1991. Convective storms throughout the region were less frequent and of generally lower magnitude than those of 1990, which was the most active runoff year since 1984. Streamflow at Yucca Mountain during 1991 was limited to just a few drainages and the runoff magnitudes were low.

The probable maximum flood (PMF) investigation was generally on schedule and progressing satisfactorily. The PMF magnitudes for drainages that include proposed surface facilities have been calculated for clear-water flows and a draft report listing those magnitudes has been written and is currently being reviewed internally. The magnitudes of clear-water flows are being adjusted for likely sediment entrainment. Those adjusted flow rates will be utilized in the preparation of maps showing estimated zones of inundation near planned surface facilities. The flood-inundation phase of the study was initiated. Ongoing monitoring of weather conditions and situations conducive to flooding continued.

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

No progress on this study 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

No progress during 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 ash fall at the site

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

2.2.13.2 Study 8.3.1.17.2.1 - Faulting potential at the repository

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

2.2.13.3 Study 8.3.1.17.3.1 - Relevant earthquake sources

A revision of Study Plan 8.3.1.17.3.1 was submitted to the YMPO on May 1, 1991, for verification of comment resolution.

2.2.13.4 Study 8.3.1.17.3.2 - Underground nuclear explosion sources

No progress was made during the reporting period. This is an out-year activity.

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

Study Plan 8.3.1.17.3.3 is in YMPO review.

Activity 8.3.1.17.3.3.1 - Select or develop empirical models for earthquake ground motions. No progress during reporting period; this is an out-year activity.

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 have been halted because of reductions in funding. A small effort has been ongoing to modify the canisters used for emplacing accelerometers downhole for monitoring of 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 made to analyze data on UNE-generated ground motions. A statistical analysis and an evaluation of travel-path effects and differences between surface and subsurface ground motions will be made. The primary prerequisites for both analytical categories are verification and validation of all computer software to be used. The process for verification and validation has begun, but progress has been quite slow.

A Problem Definition Memo (PDM) was approved by SNL management that describes the tasks to be performed to accomplish statistical analyses of UNE-generated ground-motion data at Yucca Mountain.

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

All YMPO review comments on Study Plan 8.3.1.17.3.4 were resolved and revision of the Study Plan was initiated prior to resubmittal for YMPO approval.

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

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

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

Study Plan 8.3.1.17.4.1 was accepted by the NRC on May 14, 1991.

Activity 8.3.1.17.4.1.1 - Compile historical earthquake record. No progress during the reporting period due to lack of funding.

Activity 8.3.1.17.4.1.2 - Monitor current seismicity. The 55-station Southern Great Basin Seismic Network (SGBSN) ran with minimal downtime. The analog data reception node in Golden failed once and was repaired; another failure is unlikely to be repairable.

Site selection for 25 new SGBSN stations within a 25-km radius of Yucca Mountain was completed. Applications for permits for all 25 sites were completed and permits were received for six sites.

Three sites for United States National Seismic Network (USNSN) stations were selected and applications for permits for two USNSN sites were completed (Shoshone Peak and Gold Mountain). The Shoshone Peak USNSN station was ready

for installation, awaiting final permits and permission from the YMPO. All USNSN receiving node computer hardware was installed, tested, and working.

A draft report entitled "Seismicity and Focal Mechanisms for the Southern Great Basin of Nevada and California" (Harmsen) was submitted for internal review in August.

Activity 8.3.1.17.4.1.3 - Evaluate potential for induced seismicity at the site. No progress during the reporting period due to lack of funding.

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

Technical responsibility for Study 8.3.1.17.4.2 will be transferred from SNL to the USGS as of October 1, 1991. This transfer of responsibility will consolidate and simplify the management of the tectonics program for the YMP.

Activity 8.3.1.17.4.2.1 - Identify appropriate trench locations in Midway Valley. Non-surface-disturbing mapping of surficial units in Midway Valley began in FY 1990 and continued. Preparation of maps, description of units, and field verification of mapping units continued in FY 1991. This mapping resulted in definition of ten surficial mapping units for Midway Valley, seven of which are alluvial units. Description of the stratigraphy of each of these mapping units and their lateral variability will be a prime focus of work during FY 1992. In addition, initial recommendations were made for locations of two trenches and 26 soil pits. Of the recommendations, 13 soil pits are planned as the next phase of surface-disturbing field work.

The environmental permits required for excavation of trenches as part of this activity were obtained by DOE in July 1991. A 100-meter-long trench, Trench A/BR-3, was excavated to the northwest of Exile Hill within Midway Valley during July 1991 (Figure 1.1). This trench was oriented east-west, perpendicular to a strongly developed vegetation photolineament that could be a northern extension of the Bow Ridge fault. Ground-breaking for this trench and deepening of Trench 14 to the south represented resumption of surface-disturbing work for the YMP after a 5-year hiatus.

The trench dug to a depth of about 2-3 m and was logged at a scale of 1:25 with recognition of two major stratigraphic units throughout the length of the trench: a lower, older alluvial unit with a buried soil that has been stripped to the top of the Bk or K horizon, and an upper, younger sheetwash- and eolian-dominated unit with a moderately developed soil profile. Various lithofacies and soil profiles were mapped. Variations in alluvial facies were mapped based on dominant clast size and type of matrix: clast-supported versus matrix-supported.

No evidence for faulting was found within the trench. The lack of faulting brings into question the location of the Bow Ridge fault north of Trench 14. Little space is available for the fault trace east of the trench and west of bedrock on Exile Hill. The Bow Ridge fault could lie to the west, although this would represent a substantial reorientation of the fault from its dominant north-south trend. This portion of the fault may not have ruptured during the time represented by the deposits found in the trench with

their age span (>100,000 years). Alternatively, a northwest-trending fault, such as the Sever Wash fault, could have offset the Bow Ridge fault in a right-lateral sense. Cross-cutting relationships between north-south and northwest-trending faults have not been well documented at the northern end of Yucca Mountain and Midway Valley.

Two reports, "Summary and Evaluation of Existing Geological and Geophysical Data Near Prospective Surface Facilities" (Gibson et al.) and "Preliminary Mapping of Surficial Geology of Midway Valley" (Wesling et al.), and two abstracts were prepared to document this work. Papers that follow the abstracts will be presented at the annual GSA National Meeting in October 1991.

Activity 8.3.1.17.4.2.2 - Conduct exploratory trenching in Midway Valley. No progress during the reporting period. This is an out-year activity.

2.2.13.11 Study 8.3.1.17.4.3 - Quaternary faulting within 100 km of Yucca Mountain, including the Walker Lane

Preparation of Study Plan 8.3.1.17.4.3 continued and is scheduled for submittal to the YMPO in November 1991.

Activity 8.3.1.17.4.3.1 - Conduct and evaluate deep geophysical surveys in an east-west transect crossing the Furnace Creek fault zone, Yucca Mountain, and the Walker Lane. The following papers were published: "TUBOSEIS, PART A--An Interactive Program for Construction and Editing Models of Seismic Refraction Travel Time Data Using a Color-Graphics Terminal" (Chuchel, 1990a); "TUBOSEIS, PART B--Diskette of FORTRAN Source Code and Test and Data Files [Program listing]" (Chuchel, 1990b); "Aeromagnetic Map of the Beatty 1/2 x 1 Degree Quadrangle, Nevada-California" (Glen and Ponce, 1991); and "Revision of an Aeromagnetic Survey of the Lathrop Wells Area, Nevada" (Langenheim et al., 1991).

Work continued on a 200+ page, 10-chapter Bulletin summarizing geophysical studies under the YMP, which will be a follow-up of the Geophysics "White Paper" released last fall.

A paper entitled "Comparison of Vibroseis and Explosives Source Methods for Deep Crustal Seismic Reflection Profiling in the Basin and Range Province" (Brocher) was submitted to the Journal of Geophysical Research. The paper was accepted by the journal on June 21, 1991.

A draft paper entitled "Geophysical Characterization of Mineral and Energy Resources at Yucca Mountain and Vicinity, Nevada" (Langenheim et al.) was completed and submitted for review. A summary of a proposed report entitled "Structure of Crater Flat and Yucca Mountain, Southeastern Nevada, as Inferred from Gravity Data" (Oliver and Fox) was submitted to the ANS for presentation at their April 1992 meeting.

Work continued on the gravity compilations of the Beatty sheet and a report on five detailed gravity and ground magnetic properties across Fortymile Wash.

Activity 8.3.1.17.4.3.2 - Evaluate Quaternary faults within 100 km of Yucca Mountain. Air-photo interpretation was completed and results checked against published and unpublished geologic maps for the following 1:100,000 quadrangles: Cactus Flat, E 1/2 Pahute Mesa, SW 1/4 Timpahute Range, W 1/2 Pahranagat Range, W 1/2 Indian Springs, W 1/2 Las Vegas. Base maps were submitted at 1:62,500 and 1:24,000 scales for reduction to 1:100,000 scale in preparation for compilation.

Two maps on the photogeologic interpretation of Quaternary faults west and south of the NTS were released to YMP distribution in August (Reheis, 1991; and Reheis and Noller, 1991).

Activities 8.3.1.17.4.3.3-5 showed no progress during the reporting period due to lack of funding.

2.2.13.12 Study 8.3.1.17.4.4 - Quaternary faulting proximal to the site within northeast-trending fault zones

An internal USGS draft of Study Plan 8.3.1.17.4.4 was completed.

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

The Study Plan is currently in YMPO review.

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 is in review at the NRC.

Activity 8.3.1.17.4.6.1 - Evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain. Preparation of strip maps of the Paintbrush Canyon, Windy Wash, Bow Ridge, Sever Wash, Ghost Dance, Solitario Canyon, and unnamed faults in Crater Flat continued. Mapping of the faults continued through late spring and summer. In September, staff completed a week-long field review of strip maps of faults at Yucca Mountain and Crater Flat. The review team was accompanied by personnel from the Nevada Bureau of Mines and Geology, U.S. Bureau of Reclamation, and the YMPO. Preparation of an outline of the report describing results of strip mapping of faults was initiated.

Digitization of existing maps and transfer of field data for faults in Crater Flat to the new base map was completed. In addition, field checking of a photogeologic map of scarps and lineaments at Yucca Mountain was completed.

Abstracts entitled "Quaternary Movement on the Paintbrush Canyon-Stagecoach Road Fault System, Yucca Mountain, Nevada" (Whitney and Muhs), and "Strike Slip Faulting and Oroclinal Bending at Yucca Mountain, Nevada: Evidence from Photogeologic and Kinematic Analysis" (O'Neil et al.) were submitted for the GSA Annual Meeting, San Diego, California, in October 1991.

Activity 8.3.1.17.4.6.2 - Evaluate age and recurrence of movement on suspected and known Quaternary faults. No progress during reporting period.

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.

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

No progress was made in this study 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

The Study Plan is in preparation by the USGS.

2.2.13.18 Study 8.3.1.17.4.10 - Geodetic leveling

Study Plan 8.3.1.17.4.10 was approved by the DOE and was sent to the NRC on February 14, 1991.

Activity 8.3.1.17.4.10.1 - Relevel base-station network, Yucca Mountain and vicinity. A new quadrilateral survey was begun on the Stagecoach Road Fault. The "0" point of this quadrilateral was determined. All four marks on STAGE quadrilateral were set and descriptions were in the process of being written. During the next fiscal year, STAGE and the other quadrilaterals will have baseline (mark to mark) measurements observed.

Activities 8.3.1.17.4.10.2-3 showed 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 study.

2.2.13.20 Study 8.3.1.17.4.12 - Tectonic models and synthesis

A draft for Activities 4 and 5 of Study Plan 8.3.1.17.4.12 was completed in August. This draft was combined with a previously prepared draft of Activities 1, 2, and 3. Editing and final preparation of a draft Study Plan for YMPO review was then completed.

Activity 8.3.1.17.4.12.1 - Evaluate tectonic processes and tectonic stability at the site. Field reconnaissance and office studies aimed at evaluation and improvement of the tectonics program continued.

Staff reviewed progress on the draft map entitled "Tectonic Map of the Death Valley-Yucca Mountain region." In its present form, the 1:250,000 scale map encompasses approximately 35 15-minute quadrangles. The map spans the California-Nevada boundary, and includes the Death Valley and Yucca Mountain areas. A decision was made to cease further expansion of the map, to prepare an explanation for the current draft, and to submit the map and explanation for release as a colored map. Considerable work remains to get the draft ready for publication, including preparation of the explanation, continued field review of the original published data from which the map was generalized, and technical review of the draft. The map is expected to facilitate comprehension of a very large data base, and contribute to understanding of the relation between Quaternary tectonism at Death Valley and that at Yucca Mountain.

Activities 8.3.1.17.4.12.2-3 showed no progress during the reporting period; these are out-year activities.

2.3 REPOSITORY OVERVIEW

2.3.1 Geomechanical analyses (Section 8.3.2.1.4.1)

Laboratory scale experiments are being developed to provide a data base from which constitutive models for joint behavior may be further developed and also tested. Preliminary experiments are being constructed from plexiglass materials. This will allow stress and strain tracking within the model using optical means. The experiment set-up is being modeled using discrete-element (discontinuum) and finite-element (continuum) methods.

SNL supported the YMPO-commissioned Software Advisory Group. The initial task of the group, to rewrite Section 19 of the QA Requirements Document (QARD), was completed and submitted to the YMPO for review. The requirements are now in Supplement I of the QA Requirements Plan.

2.3.2 Seismic analyses (SCP Section 8.3.2.1.4.2)

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

2.3.3 Ventilation analyses (SCP Section 8.3.2.1.4.3)

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

2.3.4 Safety analyses (SCP Section 8.3.2.1.4.4)

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

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

SNL geomechanics analysts and experimentalists met with members of the Rock Mechanics Review panel to discuss ongoing and planned work. Discussions centered on the redirection of work due to budgets for field testing.

At the University of Colorado at Boulder, work on laboratory characterization of natural fracture surfaces has continued. The profilometry techniques to profile the surface of natural fractures of tuff have been developed and preliminary shear and normal stiffness measurements have been obtained.

Design Investigation Memo (DIM) 259, "Rock Mass Strength Criteria Assessment," to study, evaluate, and recommend rock mass strength criteria for the YMP Reference Information Base, was written and work was initiated. A report documenting the results of the study is being drafted.

A report entitled "Three-Dimensional Analysis of the G-Tunnel High-Pressure Flatjack Development Test" (Jung) documents the results of a series of three-dimensional analyses of the G-Tunnel high-pressure flatjack development test. The analyses constitute the first attempt to apply three-dimensional discrete joint modeling techniques to analyze YMP experiments.

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

Submission of "Underground Area Requirements for a Potential Nuclear Waste Repository at Yucca Mountain" (Ryder and Zerga) for internal SNL technical review was delayed pending the incorporation of results from a recently completed investigation on emplacement density scaling techniques. When completed, the report will present a general approach to area estimation, as well as numerical examples comparing the area requirements for two waste receipt schedules (oldest-fuel-first and levelized), a 2010 emplacement start date, and several design-basis areal power densities (APDs).

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 "A Thermomechanical Far-Field Model of Yucca Mountain" (Brandshaug, 1991a) was published. The report presents far-field thermal and mechanical results obtained from two-dimensional finite element models of the potential repository at Yucca Mountain. The thermal model simulates transient heat transfer resulting from the emplacement of heat-generating nuclear waste in the host rock, and includes a simplified model of pore-water boiling in its solution. The mechanical model simulates the tuff at Yucca Mountain as an elastic/plastic, isotropic, heterogeneous continuum with one ubiquitous vertical joint set.

A report entitled "Determination of Equivalent Thermal Loadings as a Function of Waste Age and Burnup" (Mansure and Petney, 1991) was published. This report summarizes an effort to develop a method for determining equivalent thermal loadings for each type of spent fuel planned for emplacement at the potential repository at Yucca Mountain. Equivalent thermal loads were defined as those loadings that would produce worst-case thermomechanical effects similar to those predicted for a baseline waste description. Two methods of scaling waste emplacement for waste age and burnup were considered: equivalence of total energy transferred to the host rock over a given period of time, and equivalence of maximum rock temperature response at the center of the modeled potential repository region.

Following the publication of the report, a reinvestigation of scaling techniques for waste age and burnup was completed. The results of this study indicate that the Equivalent Peak Temperature Rise (EPTR) concept presented by Mansure and Petney (1991) in fact represents a subset of a method known as the Equivalent Energy Density (EED) concept. The EED concept bases its scaling of emplacement densities on the criterion that the equivalence of integrated energy release of an arbitrary and a baseline waste description over a given period of time (deposition period) corresponds to an equivalence of worst-case thermomechanical effects. The results of this study have been documented in "Equivalent Energy Density Concept: A Preliminary Reexamination of a Technique for Equating Thermal Loads" (Ryder). Included in the discussions of this reexamination are examples showing the dependence of the calculated scaled emplacement densities on the physical scale-of-interest within the potential repository block. In addition, the importance of tradeoff evaluations resulting from the choice of scale-of-interest is emphasized based on temperature profiles for design-basis areal power densities of 57 and 80 kW/acre. This report is currently in internal SNL technical review.

A report entitled "Areal Power Density: A Preliminary Examination of Underground Heat Transfer in a Potential Yucca Mountain Repository and Recommendations for Thermal Design Approaches" (Hertel and Ryder) has received YMPO approval and is being prepared for final publication. This report summarizes a series of sensitivity studies that calculated the expected temperatures near a potential repository at Yucca Mountain. These studies were used to establish an efficient loading scheme for the spent fuel

canisters and maximum areal power densities given assumptions regarding canister loadings, waste ages, underground extraction ratios, and minimum canister spacings. Based on the results of this study, a recommendation to increase the potential repository design-basis thermal loading from 57 to 80 kW/acre has been made. Pending further investigation of the impacts of such an increase on other aspects of potential repository design and operations, this recommendation must be considered preliminary and is not, at this time, up for formal action by YMPO's CCB.

In support of an October 1991 NWTRB meeting on thermal design of the potential repository, a consistent set of calculations examining host-rock thermal responses to design-basis areal power densities ranging from approximately 20 to 80 kW/acre were defined and are complete. These analyses examine both near- and far-field responses using an analytical solution based on the linear superposition of heat-generating points and cylinders. The geometry used to represent the potential repository is a modified version of that published in the Site Characterization Plan/Conceptual Design Report (SCP/CDR). Drift spacing is held constant at approximately 53 ft (corresponding to the current maximum extraction ratio of 30 percent) and canister spacings adjusted accordingly to provide the appropriate scaled local areal power densities. Fully stepped emplacement of the spent fuel inventory is explicitly modeled and defense high-level waste considered segregated in dedicated drifts immediately adjacent to the main access drifts. The results from these investigations will be presented to the NWTRB in October and later incorporated into a report.

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

A report entitled "A Sensitivity Study of the Thermomechanical Far-Field Model of Yucca Mountain" (Brandshaug, 1991b) was published. This report presents the results of sensitivity studies conducted regarding the predicted thermal and mechanical behavior of the far-field model of Yucca Mountain published in this report, which was referenced in Design Activity 1.11.6.1. The model input parameters investigated include areal power density, thermal conductivity, specific heat capacity, material density, pore-water boiling, finite element meshes, Young's modulus, Poisson's ratio, coefficient of thermal expansion, in situ stress, rock matrix cohesion, and rock joint angle of internal friction. Uncertainties associated with these parameters were investigated with respect to the predicted rock temperatures, stresses, matrix failure, and joint failure throughout the far-field model.

2.4.1.19 Design Activity 1.11.6.4 - Strategy for containment enhancement

Effort was suspended on this activity. Personnel and budget resources were reallocated to support the NWTRB meeting on thermal loading of the potential repository.

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

In support of the Exploratory Studies Facility Design Requirements (ESFDR) document, work progressed on four of the eleven performance-related analyses of intact and rock mass properties. Studies and evaluations for three of the four analyses were completed and reports were published.

In a report entitled "Assessment of the Potential Effects of Creep Deformation of the Tuffs Upon the Exploratory Shaft Liner" (Bauer et al.) the potential for creep deformation of tuff upon the ES shaft liner was assessed. For the welded tuff, creep deformation of the matrix material could be that of the expected elastic strains. For the densely welded tuff, more work is warranted to study the potential for time-dependent deformation on fractures.

A report entitled "Preliminary Evaluation: Three-Dimensional Far-field Analysis for the Exploratory Shaft Facility" (Asgian et al., 1991) provided estimates of temperatures, stresses, and strains for many locations of interest in and near the ESF. Determinations of temperatures at key locations within the ESF and potential repository area and the thermally induced component of stress at specific locations can be made using these estimates. This work satisfied two separate analysis requests.

Two reports, "Drift Design Methodology and Preliminary Application for the Yucca Mountain Project" and "Drift Design Methodology for a Radioactive Waste Repository in Hard Rock" for Comprehensive Rock Engineering (J. Hudson, editor), were both approved for publication by the YMPO. In these reports, a design methodology for assessing drift stability is presented. The assessment

is based on site conditions, together with empirical and analytical methods. Analytical numerical methods are emphasized because empirical data are unavailable for excavations in welded tuff either at elevated temperatures or under seismic loads. The methodology incorporates analysis of rock masses that are systematically jointed, randomly jointed, and sparsely jointed. In situ, thermal, and seismic stresses are considered. Methods of evaluating the analytical results and estimating ground support requirements for the full range of expected ground conditions are outlined. The results of a preliminary application of the methodology using the limited available data are presented. The methodology is expected to evolve as excavation of the ESF demonstrates the controlling deformation mechanisms and allows site-specific evaluation of in situ properties.

Work continued on "Assessment of the Potential Extent of Fracturing for the Pad, Collar, and Shaft for the ESF."

A presentation entitled "Thermal Structural Effects on Underground Excavations" (Bauer) was made to the NWTRB.

2.4.3.2 Design Activity 8.3.2.4.1.2 - Design activity to verify air quality and ventilation

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

2.4.4 Preclosure design and technical feasibility (SCP Section 8.3.2.5)

2.4.4.1 Design Activity 4.4.3.1 - Operations plan to accompany the advanced conceptual design

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

2.4.4.3 Design Activity 4.4.4.1 - Repository design requirements for license application design

SNL PIs and staff met with the YMP staff contacts on a monthly basis to provide a review and status report of ongoing work.

An effort to coordinate pre- and postclosure performance assessment analyses into an integrated plan was initiated. The effort began with a review of requirements listed in the ESFDR and 10 CFR 60 to determine which of those requirements could be addressed by analyses. The effort continued with

a definition of the nature of the analyses needed to address the requirements. This work will be documented in the performance assessment plan.

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 was made during the reporting period; this is an out-year study.

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

Three basic efforts were performed to support this activity. These included work on the degradation model itself, preliminary laboratory analyses to support the model, and the reporting of the results.

In the first area, efforts focused on the thermal-mechanical stability of both a seal element in a tuff matrix and a cementitious mineral phase within the calcium-silicate-hydrate matrix. Model development has been completed and appropriate material properties were assessed. Preparation of a report is underway and it is expected to be completed in the first half of FY 1992.

In the second area, efforts focused on the preparation and testing of cementitious-based samples. Samples of high-silica concrete and grout were prepared. These samples, cast in two-inch PVC pipes sealed at the ends, were cured for 28 days. The samples were cut into wafers and prisms for the thermally accelerated experiments and then subjected to environments simulating Yucca Mountain. Two types of hydrothermal experiments were defined and initiated by SNL. Single point experiments involve reacting cement and ground water at 200°C in sealed tubes for a specified period, after which time the tube is cooled and the contents removed and analyzed. The other more complex experiments involve reacting cement and ground water at 200°C in a Dickson rocking autoclave device that allows periodic sampling of the fluid during the test duration. Two rocking autoclave experiments and thirty-two single point experiments were planned. At the end of this reporting period, the laboratory testing was ongoing. Completion is scheduled for the first quarter of FY 1992.

To support this laboratory testing effort, numerical analyses were initiated. These analyses will evaluate the extent of water/cement equilibrium existing at the end of the experiment, estimate the dominant forms of elements dissolved in the fluid, identify the final assemblage of minerals that should be present if all reactions are allowed to proceed to a state of equilibrium, and calculate the mass and compositions of the reaction products. The analyses were initiated at the end of this reporting period and are scheduled to be completed in the first quarter of FY 1992.

In the third area, a paper was presented and an abstract prepared. "Estimating Geochemical Behavior of Concrete to be Placed at Yucca Mountain"

(Hinkebein and Gardiner, 1991) was presented at the 1991 IHLRWM Conference in Las Vegas, Nevada. An abstract (Krumhansl and Hinkebein) was prepared for the Materials Research Society (MRS) Conference to be held in the first quarter of FY 1992.

2.5.1.3 Study 1.12.2.3 - In situ testing of seal components

Substantial progress was made during the reporting period on the preliminary definition of sealing field tests. The primary focus of the work performed for this study was the preparation of a report that defines and describes proposed tests to evaluate the performance of sealing components. The basis for selecting field tests was the performance and emplacement uncertainties defined in the SCP. It is proposed that two types of sealing-component testing be performed. Seal-characteristics tests include the small-scale in situ test, the intermediate-scale borehole seal test, the fracture grouting test, the surface backfill test, and the heated block/grout test. Performance-confirmation tests include the filter/single embankment test, the backfill test in the Calico Hills unit, the bulkhead test in the Calico Hills unit, the large-scale shaft seal test, and the borehole sealing test.

To support the development of the field tests, numerical analyses were performed, including hydration analyses of cementitious materials, thermomechanical analyses of a grouted fracture, and the hydrologic flow analyses of a borehole and shaft seal. Documentation will be completed during the first quarter of FY 1992.

Two extended abstracts (Fernandez et al.) were prepared and submitted to the 1992 IHLRWM Conference in Las Vegas, Nevada.

Information compiled as part of this study was used to support the ESF Preliminary Test Planning Package 91-5 and the ESDR Testing Requirements. This information was prepared by SNL and provided to LANL.

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 basic efforts were performed during this reporting period. These were development of a strategy to seal exploratory boreholes, which includes the development of design requirements, and the development of requirements to emplace sealing components.

In the first area, borehole video logs were reviewed and a classification scheme was developed to categorize the quality of the hole conditions, available technologies were reviewed, performance and structural calculations were completed, corrosion calculations for the casing were completed, and documentation was begun. The report will be completed at the beginning of FY 1992.

In the second area, the feasibility for emplacing sealing components were reviewed with the intent of developing additional performance requirements for

sealing component emplacement. This work included (1) reviewing backfilling technologies to seal underground openings - manual, gravity, mechanical transport, pneumatic, and hydraulic techniques were reviewed; (2) evaluating properties of crushed rock - results from laboratory and field activities were evaluated and logic developed to select a gradation for crushed tuff. Assuming a gradation for crushed tuff, unsaturated and saturated hydrologic properties for crushed tuff were estimated; (3) developing preliminary performance criteria for backfill - SCP postclosure performance criteria (not associated with backfill) were reviewed and several potential backfill criteria identified; and (4) reviewing technologies to field sealing tests - backfilling techniques were reviewed and suitability for fielding tests was assessed. Identification of miscellaneous requirements was also initiated. These requirements included grout placement requirements to achieve a specified performance, materials handling of the crushed tuff, ventilation, water, and electrical requirements, and equipment and construction methods needed to field the experiments.

Design Subactivity 1.12.4.1.2 - Perform trade-off studies to support advanced conceptual design development. Numerical analyses were performed to evaluate the flow of water in backfilled drifts. An analysis using the computer code NORIA-SP was designed to determine the length of drift that would be required to drain water entering the drift at a constant rate. It was assumed that the backfill had a high hydraulic conductivity. The second analysis used DCM3D to determine the effect of a material contrast within the backfilled drift on drainage of water entering the drift. The preliminary results from the runs indicated that having a material contrast within the backfill (achieved by emplacing a lower conductivity material against the typical higher conductivity backfill) can be effective in diverting flow into the rock rather than down the drift.

Design Subactivity 1.12.4.1.3 - Develop advanced conceptual design for seals. No progress during the reporting period; this is an out-year activity.

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

Design Subactivity 1.12.4.2.1 - Define subsystem design requirements. No progress during the reporting period; this is an out-year activity.

Design Subactivity 1.12.4.2.2 - Perform trade-off studies to support license application design development. No progress during the reporting period; this is an out-year activity.

Design Subactivity 1.12.4.2.3 - Develop license application design for seals. 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

Preliminary design selection criteria are being constructed based on systems engineering requirements. Selection criteria are based both on the requirements and on the ability of particular design architectures to be predictable over the long time spans required. Emphasis is being placed on predictability as the most important parameter. Decision analysis (Baysian Utility Theory) will be used (Keeney & Raiffa) as modified for use in NQA-1 environments. A literature search has provided nuclear Probabilistic Risk Assessments that serve as a good model for evaluation of selection criteria. Writing has begun on a proposed methodology and on the Selection Criteria themselves.

A preliminary thermal analysis has been done on a consolidated waste package design with drift emplacement to evaluate near field temperatures.

The draft Technical Data Base Handbook outline was reviewed and the GEMBOCHS (Thermodynamic Data Base) section was revised. A summary of the parameter categories and parameters in GEMBOCHS was also prepared by LLNL staff. This information was forwarded to YMPO through the Technical Data Advisory Group.

Staff participated in the DOE EBS Workshop held in Denver, June 18-20, and presented a paper entitled "Developing EBS Design Concepts Using a Systems Engineering Approach." J. Bates of ANL made a presentation which specifically addressed methods to reduce radionuclide release from waste packages and to inhibit alteration of waste forms in a vapor environment.

The draft System Studies Plan, prepared by SNL for YMPO, was received by the LLNL staff. The comments and questions raised by LLNL have been discussed with SNL, and a letter summarizing this informal review was prepared.

A draft report, "Incentives for Selection of Spent Fuel for Delivery to the Federal Radioactive Waste Management System (FWMS) - A Preliminary Analysis," edited by PNL, was submitted to LLNL for review. This report integrates the results of LLNL's Spent Fuel Receipt Scenarios Study into the overall FWMS. Comments resulting from LLNL's review were forwarded to PNL.

The following paper was submitted to the Focus '91 Nuclear Waste Packaging Conference in Las Vegas, September 29 - October 2: "Engineered Barrier System and Waste Package Design Concepts for a Potential Geological Repository at Yucca Mountain" (Short et al.).

2.6.1.2 Study 1.10.4.1 - Characterize chemical and mineralogical changes in the post-emplacement environment (also SCP Study Plan 8.3.4.2.4.1)

This Study Plan has been reviewed by YMPO and DOE/HQ. Comments were sent to the LLNL PI in 1990. A revised draft incorporating these comments has yet to be prepared.

The paper entitled "The Effect of Dislocation Density on the Dissolution Rate of Quartz" (Blum, 1991) was approved by YMPO and published.

Activity 1.10.4.1.1 - Rock-water interactions at elevated temperatures (also SCP Activity 8.3.4.2.4.1.1). No progress during the reporting period due to lack of funding.

Activity 1.10.4.1.2 - Effect of grout, concrete, and other repository materials on water composition (also SCP Activity 8.3.4.2.4.1.2). A change request to the SCPB to incorporate man-made materials activities into the Waste Package Environment Testing area was sent to the YMPO CCB on May 28. The change request was returned to LLNL for minor revision.

Staff attended a meeting on adverse impacts of man-made materials on Engineered Barrier System (EBS) materials performance held June 28 in Los Alamos, New Mexico. The meeting also covered the long-term performance of the potential repository, and the determination of sorption coefficients for radionuclides in Yucca Mountain. A list of materials expected to be used in the ESF was compiled by the architect/engineer contractor, REECo, and was distributed at the meeting. As a follow-on, members of the Metal Barrier staff were asked to comment on the conceivable effects of items from this list on the performance of EBS materials. These opinions are being consolidated and transmitted to the YMPO.

Activity 1.10.4.1.3 - Composition of vadose water from the waste package environment (also SCP Activity 8.3.4.2.4.1.3). Water/rock reactions occurring in the vadose zone were modeled using EQ3/6. Using the results of hydrologic models, the variation in the activity of water in the vadose zone in the near field was estimated. The activity of water was independently controlled in EQ3/6 by setting the fugacity of inert gas in the system model. The preliminary results, for cases where the activity of water is greater than 0.8, were similar to results obtained for simulations of fully saturated systems. However, the preliminary simulations do not account for possible changes in the relationship between the concentration of a dissolved constituent and its activity that might occur as a result of the interactions between water and mineral surfaces. These results were presented at the YMPO technical exchange meeting on water chemistry held at NTS in July. As a result of this meeting, specifically the interest expressed in modeling and experimentally accessing water in the unsaturated zone, preliminary calculations were made of the quantity of unsaturated water that could be expected to be removed from intact potential repository horizon Topopah Spring Tuff via centrifugation. The results of the calculations show that, at most, a few mL of water could be expected to be removed from each sample (6 cm in diameter, 8 cm long) when centrifuged at 18,000 rpm.

Activity 1.10.4.1.4 - Dissolution of phases in the waste package environment (also SCP Activity 8.3.4.2.4.1.4). Installation of the HPLC

(liquid chromatograph) was finished. A calibration method was developed for organic acid anions which are potential complexing agents for metals in the vicinity of the potential repository.

The paper entitled "Dissolution and Precipitation Kinetics of Gibbsite at 80°C and pH 3: The Dependence on Solution Saturation State" (Nagy and Lasaga) was approved by YMPO on September 6.

Activity 1.10.4.1.5 - Effects of radiation on water chemistry (also SCP Activity 8.3.4.2.4.1.5). 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 (also SCP Activity 8.3.4.2.4.1.6). Staff attended the YMPO Geochemistry Technical Exchange at NTS on July 28-30. Two talks were presented, entitled "Impact of the Waste Package on Water Chemistry" (Bruton), in which preliminary account was taken of the effect of the activity of water on rock-water interaction that was simulated using the EQ3/6 codes, and "Preliminary Estimate of the Effect of Water of Hydration on Cation-Exchange Equilibria in Clinoptilolite" (Viani), in which the effects of elevated temperature and evaporative concentration of ground water on cation exchange in clinoptilolite were discussed.

Activity 1.10.4.1.7 - Numerical analysis and modeling of rock-water interaction (also SCP Activity 8.3.4.2.4.1.7). Work has begun to compare the two-site ideal Vanselow model for ion-exchange on clinoptilolite with the regular solution model proposed by Pabalan (from SWRL-NRC).

Calculations have been completed to estimate the effect of hydration on the thermodynamic properties of clinoptilolite. Thermogravimetric data were used to deduce the quantity of hydration water in each of the homo-ionic clinoptilolite component end members. The average molar free energy and other properties of hydration water were estimated from calorimetric data for hydrated and dehydrated clinoptilolite. The new heat capacity, entropy, and standard chemical potential for end member components of clinoptilolite derived using this data have been given to the Data Base Task to generate test versions of DATA0 and DATA1. The effects of accounting explicitly for water of hydration will be judged by comparing EQ3/6 results using the test data base with runs using the current data which assumes that each end member has the same number of waters of hydration. This work contributes to LLNL's ability to assess the effectiveness of Yucca Mountain zeolites to chemically retard radionuclide transport.

Staff attended an International Programs meeting with Swedish representatives in Las Vegas on May 28-30 discussing a joint venture on geochemistry and hydrology tasks.

Staff began to investigate the distribution of the thermodynamic activity of water around an emplaced waste package. This information is needed to plan the modeling of fluid-rock interactions in the near field environment under variable water saturation and temperature conditions.

Estimates of thermodynamic data for clinoptilolite taking explicit account of the water of hydration (hetero-hydrate model) were used to simulate

the effects of elevated temperature on the composition of clinoptilolite and its ability to sorb Cs and Sr. Simulation results were compared to predictions using thermodynamic data estimates in which clinoptilolite hydration water was not explicitly accounted for (iso-hydrate model). The temperature effects that were predicted using the data based on the hetero-hydrate model were moderated in comparison with predictions based on the iso-hydrate model. The results were presented at the Geochemistry Technical Exchange meeting on water chemistry held July 28-30 at the NTS.

A presentation on Natural Hydrothermal Analogs was given at the NWTRB meeting on Natural and Archaeological Analogs held in Reno, Nevada, on April 16-17. These presentations reviewed the need to carry out a natural analog study, the approach to the study, and an overview of potential analog sites in the Taupo Volcanic Zone in New Zealand.

2.6.1.3 Study 1.10.4.2 - Hydrologic properties of waste package environment (also SCP Study Plan 8.3.4.2.4.2)

This Study Plan has been reviewed by YMPO and DOE/HQ. Comments were sent to the LLNL PI in 1990. A revised draft incorporating these comments has yet to be prepared.

Activity 1.10.4.2.1 - Single-phase fluid system properties (also SCP Activity 8.3.4.2.4.2.1). 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 (also SCP Activity 8.3.4.3.4.2.2). Work continued on the fracture healing study. The pore pressure lines were thoroughly cleaned to eliminate any possibility of silicon oil to contaminate the measured Si concentration in the water condensed from the steam which flows through the sample. A blind test using an aluminum sample was done. The blind test confirmed that the high silica concentration in the water condensed from the steam that flowed through the tuff sample, as reported previously, was due to the rock sample. Scanning Electron Microscope (SEM) photos of the fracture surfaces of the tuff sample were taken. The post-experiment surface contains micron-size particles of silica minerals. The pre-experiment surface lacks such small particles. The post-experiment surface is smoother than the pre-experiment surface.

A demonstration test was run to illustrate fracture flow versus matrix flow. A one-dimensional imbibition test was done on a rod of plaster-of-Paris. Two blocks of plaster-of-Paris were then cast. The two blocks were separated by an aperture, which was determined by the modelers based on the result of the 1-D imbibition test. Water with blue dye was ponded on top of the "fracture." The flow of water along the fracture and the imbibition of water into the matrix were consistent with the model predictions.

Work was done on integrating the various hydrological modeling studies into a comprehensive conceptual and theoretical framework of the thermo-hydrological features and processes which are critical to performance of the potential repository.

Hydrothermal model calculations on thermal loading were conducted for the NWTRB meeting on thermal loading of the potential repository to be held in October. These calculations address several general objectives: (1) what are the accuracies of potential repository thermal models which only consider heat conduction, (2) how does the potential repository dry-out volume vary with Areal Power Density (APD) and with the Local Areal Power Density (LAPD) along emplacement drifts, (3) how do heat flux and ground surface temperature vary with APD, and (4) how do gas-phase velocities (which arise due to hydrothermally-driven natural convection) vary with APD. These hydrothermal calculations are being conducted at several different scales, with the large scale and intermediate scale model requiring the use of the Equivalent Continuum Model (ECM) assumptions, and the small scale model discretely accounting for nonequilibrium fracture-matrix flow behavior.

The large scale calculations represent the potential repository as a disk shaped heat source with a diameter of 3 km; the thermal load of the potential repository is assumed to be uniformly distributed throughout the 3 km diameter disk. All major hydrostratigraphic units in the unsaturated zone at Yucca Mountain are included in this model. Various initial steady-state conditions are considered, including the "nominal" recharge flux case as well as cases of increased recharge flux. Various spent fuel ages from 10-yr-old spent fuel to 80-yr-old spent fuel are being considered. For the reference case, the 30-yr-old fuel is being emphasized.

The intermediate scale calculations explicitly incorporate the emplacement drift geometry and spacing. The intermediate scale models also include all major hydrostratigraphic units in the unsaturated zone at Yucca Mountain. For the intermediate scale models, it is assumed that the thermal load for an emplacement is averaged along the axis of the drift. This assumption closely corresponds to drift emplacement configurations where the waste packages are oriented along the axis of the drift. This assumption is also applicable to borehole emplacement; particularly after the saturation and temperature fields between neighboring waste packages have coalesced (which occurs within five years of waste emplacement).

The large scale and intermediate scale modeling do not represent the "hydrothermal umbrella" effect because they do not account for "cold spots" between emplacement panels. Therefore, both the intermediate and large-scale model calculations provide conservative lower bounds on dry-out volumes of the potential repository. Moreover, because they do not account for nonequilibrium fracture-matrix interaction, these models significantly under-predict the extent of condensate shedding due to the "hydrothermal umbrella" effect.

It is planned to conduct nonequilibrium fracture-matrix calculations wherein the impact of APD and LAPD on discrete nonequilibrium fracture flow will be investigated. The emphasis will be placed on relatively large aperture fractures. The objective of the small scale model is to demonstrate the potential benefits of higher APDs on mitigating fracture-dominated flow from reaching the potential repository horizon.

V-TOUGH modifications were incorporated into version 4.1 and the changes have been submitted to the on-line SCCS software configuration management system. The recent modifications allow V-TOUGH to run on the NERSC center

CRAYS which will soon be using the UNICOS operating system. Other modifications include additional error checking and a feature which allows the user to turn off gas flow for specified gridblocks.

The preconditioned conjugate gradient linear equation solver (obtained from LANL) is being implemented into the V-TOUGH code. Staff finished porting the two-dimensional curvilinear mesh generator for V-TOUGH from the CRAY to the Sun computer. The curvilinear mesh generator is now fully integrated with TOUGH pre- and post-processing routines, and testing is nearly completed.

A pre-processor was developed that takes the output from a one-dimensional steady-state V-TOUGH model and creates the initial primary variable conditions for a two-dimensional V-TOUGH model which uses the same vertical grid and hydrostratigraphic information as the one-dimensional model. The capability of extracting heat flux, vapor flux, and liquid flux was added to the EXTBIN post-processor.

A post-processing package called EXTOOL (extractor tool) was developed for V-TOUGH and LLNL's flow and transport simulator. This tool was originally developed in parallel with enhancements to V-TOUGH which write time history files of primary and secondary output variables based on user-selected options. The new time history routine in V-TOUGH can handle a much broader range of output variables than in previous versions of V-TOUGH (and TOUGH). These variables can be selected based on a "menu" of options and output "triggers." EXTOOL allows the modeler to very quickly (and conveniently) extract data from the time history file and to display it either in xy plots or in contour plots. EXTOOL is also compatible with existing output files which were formatted for the CONTSAC and PLTSAC post-processors. A window has been added to EXTOOL that displays the various graphics options. Other modifications include EXTOOL version 2.1 being able to operate on 3-D grid information. Users can now draw a plane or a line through a 3-D grid and obtain either a contour plot or an X-Y plot. Version 3.1 was modified so that it no longer is dependent on files created by V-TOUGH and version 3.5 was modified so that it has the ability to read a "colortable" file which provides for color contours. The option of plotting multiple y-axes on the same xy plot has been added to EXTOOL. The purpose of this extension is to allow plotting of three or four dependent variables versus x on the same xy graph. The ability to plot four small graphs on the same page has been also added.

Staff developed and are testing the capability of converting an EXTOOL (or PLTSAC) xy graph to a Framemaker MIF file. They also developed subroutines for LLNL's flow and transport simulator that write output files which are compatible with the EXTOOL post-processing and graphics package.

The revised version of the Hydrology Chapter of the Near Field Environment Report was completed. The original version of this chapter has been modified, and the first draft is about to be released as a paper entitled "The Impact of Hydrology on the Engineered Barrier System of the Potential Yucca Mountain Repository Site" (Buscheck et al.).

The draft of the V-TOUGH Individual Software Plan (ISP) was completed and is now being reviewed. The ISP will bring V-TOUGH into compliance with LLNL's Software Quality Assurance Plan (SQAP). It also serves as the Acquisition Plan which is required by the SQAP.

The configuration management system for V-TOUGH has been established. This system meets the requirements of TIP-YM-11. Three folders were set up for V-TOUGH: one for general maintenance, one for the time history change, and one for general V-TOUGH information. All work on V-TOUGH is now being logged and controlled in the appropriate folder. All modules of V-TOUGH versions 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, and 3.1 have been placed under configuration management.

V-TOUGH has been modified to eliminate the need to use one of the two preprocessors for compilation. The "makefile" was modified to more easily produce the executable for the SunWorkstations or one source file for other platforms, including the NERSC CRAYS using the CTSS operating system, the NERSC CRAYS using the UNICOS operating system, the OCF CRAYS using UNICOS, any UNIX 64-bit-word machine or any UNIX 32-bit-word machine.

The following four papers were presented at the 1991 IHLRWM Conference in Las Vegas, April 29-May 2: "Laboratory Determined Suction Potential of Topopah Spring Tuff at High Temperatures" (Daily and Lin, 1991); "Microwave Measurements of the Water Content of Bentonite" (Latorre and Glen, 1991); "Theory of Matrix and Fracture Flow Regimes in Unsaturated, Fractured Porous Media" (Nitao, 1991); "Variation of Permeability with Temperature in Fractured Topopah Spring Tuff Samples" (Lin, 1991).

The following two papers were submitted to the Focus '91 Nuclear Waste Packaging Conference in Las Vegas, September 29 -October 2: "The Demands Placed on Waste Package Performance Testing and Modeling by Some General Results of Reliability Analysis" (Chesnut); "The Impact of Episodic Nonequilibrium Fracture-Matrix Flow on Geological Repository Performance" (Buscheck et al.).

The following paper was presented at the AGU meeting in Baltimore, Maryland, on May 30: "Role of Steam in Fracture Healing of Topopah Spring Tuff Samples" (Lin).

Activity 1.10.4.2.3 - Numerical analysis of flow and transport in laboratory systems (also SCP Activity 8.3.4.2.4.2.3). The development of the Nonisothermal Unsaturated Flow and Transport (NUFT) Code continues. NUFT has already proven to be extremely useful in conducting isothermal nonequilibrium fracture-matrix calculations. Because of its efficiency, isothermal calculations using the NUFT code can be easily accommodated by a SPARC 1 Sun Workstation. Work on linear equation solvers using the Preconditioned Conjugate Gradient (PCG) method for both the V-TOUGH and NUFT codes continues. First-degree preconditioning using natural ordering of the variables as well as the combinative preconditioning scheme has been implemented.

2.6.1.4 Study 1.10.4.3 - Mechanical attributes of the waste package environment

A comment resolution meeting for Study Plan 8.3.4.2.4.3 was held on July 8-9 at LLNL. A revised draft incorporating all comments from this meeting was completed and submitted to YMPO on September 27.

Activity 1.10.4.3.1 - Waste package environment stress field analysis (also SCP Activity 8.3.4.2.4.3.1). As part of LLNL's support to the ESSE activity, LLNL completed a draft evaluation of the Postclosure Rock Characteristics Guideline in 10 CFR 960. Core Team comments were received and the evaluation was revised accordingly. A final guideline evaluation ready for internal review, was delivered to SAIC on June 28. LLNL core team and review representatives attended the July 17-19 comment resolution meeting in Las Vegas, and a revised text incorporating comments for the Postclosure Rock Characteristics Guideline was returned to SAIC on July 22.

2.6.1.5 Study 1.10.4.4 - Engineered barrier system field tests (also SCP Study Plan 8.3.4.2.4.4)

Development of the Study Plan has been given low priority by YMPO.

Activity 1.10.4.4.1 - Repository horizon near-field hydrologic properties (also SCP Activity 8.3.4.2.4.4.1). The ESF planning package was submitted to the YMPO on April 30.

The following paper was presented at the 1991 IHLRWM Conference in Las Vegas, April 29-May 2: "Yucca Mountain Near Field Environment Considerations for Engineered Barrier System Design and Performance" (Wilder, 1991a).

The following three papers were submitted to the Focus '91 Nuclear Waste Packaging Conference in Las Vegas, September 29 - October 2: "Field Air Injection Test to Determine the Effect of a Heat Cycle on the Permeability of Welded Tuff" (Lee and Ueng); "Thermocouple Psychrometer Measurements of In Situ Water Potential Changes in Heated Welded Tuff" (Mao and Wang); and "Temperature Measurements from a Horizontal Heater Test in G-Tunnel" (Lin et al.).

The following papers were published during the reporting period: "Air Injection Field Measurements to Determine the Effect of a Heat Cycle on the Permeability of Welded Tuff" (Lee and Ueng, 1991); "Temperature Measurements from the Prototype Barrier System Field Test" (Lin et al, 1991); "Thermocouple Psychrometer Measurements of In Situ Water Potential Changes in Heated Welded Tuff" (Mao and Wang, 1991); "Performance Implications of Waste Package Emplacement Orientation" (Wilder, 1991b); "Engineered Barrier Systems and Canister Orientation Studies for the Yucca Mountain Project, Nevada" (Wilder, 1991c); "In Situ Changes in the Moisture Content of Heated Welded Tuff Based on Thermal Neutron Measurements" (Ramirez et al., 1991); and "Prototype Engineered Barrier System Field Tests - Final Report" (Buscheck et al., 1991).

Activity 1.10.4.4.2 - Repository horizon rock-water interaction (also SCP Activity 8.3.4.2.4.4.2). 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 (also SCP Activity 8.3.4.2.4.4.3). 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. A peer review was completed of Oak Ridge National Laboratory (ORNL) report entitled "Characteristics of Potential Repository Wastes."

Staff attended an American Society for Testing and Materials (ASTM) meeting (Committee C26.13 Repository Waste), held in Colorado Springs, Colorado, July 29-30, where discussions on establishing an ASTM standard spent fuel characteristics guidelines were held.

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.

Subactivity 1.5.1.1.2 - Integrate glass waste form information. A draft of the Waste Form Characterization Report was completed. The report contains details of glass performance characteristics and a simple glass dissolution model.

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. Several flow through cells have been loaded at LLNL with UO_2 and schoepite, and rates of dissolution are being obtained. A common UO_2 sample is being shared between PNL and LLNL to ensure that measurements at both laboratories are comparable.

Flow-through dissolution tests were carried out on UO_2 and schoepite ($UO_3.2H_2O$) at 25°C. Four carbonate/bicarbonate solutions were used, with initial pH ranging from 8 to 10; however, it was observed that with time, all pHs approached a value of ~9.65. This was also seen in initial tests with spent fuel at PNL. The pH behavior is due to loss of CO_2 from solution as argon containing various amounts of oxygen is bubbled through the leaching solutions. Such an effect is predictable because carbonate/bicarbonate solutions have a finite equilibrium fugacity of CO_2 in the gas phase, but it was expected that the changes would be much slower than was actually seen. The solution absorbs CO_2 from or evolves CO_2 to the atmosphere, depending on the particular solution involved. This problem is being corrected by slowly sparging the solutions with gas containing appropriate concentrations of CO_2. The limited experience at LLNL and PNL with this approach to date indicates that it will be an effective method for stabilizing the pH. An atmosphere containing a specific concentration of CO_2 (depending on the particular solution composition) will be used hereafter. The dissolution rate was apparently not dependent on oxygen partial pressure over the test range of 0.002 to 0.2 atm. The dependence of the rate on the carbonate/bicarbonate

concentration (2×10^{-4} to 2×10^{-2} molality) is to the 0.7-0.8 power (apparent reaction order). The results at the higher concentrations are in agreement with recent PNL values but at the lower concentrations, LLNL values are lower than those of PNL. Future tests will clarify the causes of the differences. The next set of these experiments is being prepared.

Early interpretation of the experiments shows: (1) the dissolution rate of UO_2 increases with increasing carbonate/bicarbonate concentration, (2) dissolution rate depends on O_2 fugacity at high (0.2M) carbonate/bicarbonate concentration but not at low concentration (0.002M), and (3) tests on schoepite and dehydrated schoepite also show that dissolution rate increases with increasing carbonate/bicarbonate concentration and is unaffected by O_2 fugacity, as expected since uranium in schoepite is fully oxidized.

At PNL, stabilization of the 2×10^{-4} molality Na_2CO_3 solution at pH = 10 requires the CO_2 concentration in the cover gas to be about 1 ppm. Rather than purchasing a pre-mixed gas, the carbonate solution was sparged with atmospheric air after passing it through Ascarite absorbent to remove the CO_2. During testing that was conducted to determine the suitability of the Ascarite method, the water supply bottle was switched from polyethylene to glass. Following this change, the uranium concentration in the column effluent dropped immediately by a factor of about 10 and continued to drop over the next 10 days by another factor of about 10. Silicon dissolved from the glass bottle was apparently responsible for the decreased dissolution rate. Inductively Coupled Plasma Mass Spectrometry (ICP-MF) of the solution indicated the Si concentration to be about 1.5 ppm. The supply bottle was switched back to polyethylene and the test was restarted using a fresh sample of fuel.

One additional flow-through column was started during May. It was loaded with spent fuel fragments that were archived from one of the Series 3 tests previously terminated. Water from Well J-13 at Yucca Mountain, which is the same water used in the semi-static Series 3 test, is being pumped through this column. Preliminary evaluation of the early results from this test indicates that the dissolution rates in the flow-through test are approximately equal to those observed for the soluble radionuclides in the last cycle of the Series 3 test.

Following approval of the test plan and two technical procedures in March, a Readiness Review at PNL was completed, and experimental work on Flow Through Dissolution of Spent Fuel was started in April. Spent fuel samples of ATM-103 were obtained from the Materials Characterization Center at PNL and used to load three flow through columns for room temperature dissolution testing. One of the columns was loaded with fuel fragments 1 - 3 mm in size; the other two columns were loaded with individual fuel grains (10 to 30 μm in size) prepared by crushing and screening the fuel followed by washing to remove the very fine subgrain particles. Dilute carbonate/bicarbonate solutions are being pumped through the columns at flow rates of about 0.2 mL/min. Samples of column effluent are collected periodically and analyzed for uranium. Some of the effluent samples will also be analyzed for fission products such as ^{187}Cs and ^{90}Sr.

These three columns are operating at PNL with the same test conditions (2×10^{-3} molality carbonate/bicarbonate, pH = 9, 50°C) and the same type of

fuel specimen, to investigate reproducibility, and have been generating approximately equal results. All three appear to have approached steady-state uranium concentration within ~15 percent of the mean value. Therefore, two of the columns were changed to a new set of test conditions (2×10^{-4} molality carbonate/bicarbonate, pH = 8, 75°C). A fresh fuel specimen was placed in one of the columns whereas the original specimen was left in the other. Variable flow-rate tests were started with the third column while maintaining the original set of test conditions.

In addition to the spent fuel testing, unirradiated UO_2 pellets supplied by LLNL were crushed, screened, and washed (to remove the fine powder) at PNL to produce particles in the 44 to 105 μm size range for flow through testing. A portion of this material was returned to LLNL. The purpose is to provide identical test material for comparison of the slightly different flow through testing methods being employed for the spent fuel tests at PNL and the UO_2 tests at LLNL.

The new ceramography lab at PNL is completely operational and ~ 10 samples have been polished and examined. The x-ray diffraction (XRD) results have been confirmed by spot checks using electron diffraction. No phases other than UO_2 and U_4O_9 were observed.

The variable flow-rate tests at PNL are nearing completion with generally satisfactory results. The results indicate that the concentrations of uranium 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 will continue for a brief additional period, but the testing emphasis will be changing toward completion of the test matrix provided in the test plan.

Because of some unexpected results obtained both at PNL and at LLNL using unirradiated UO_2 specimens, another source has been identified of well-characterized unirradiated UO_2 at PNL, and new test specimens have been prepared. A portion of this UO_2 material, prepared in both pellet and particle forms, was shipped to LLNL on August 20; both programs will be conducting tests on the same well-characterized material.

A developmental flow-through test was set up at PNL to measure the surface potential of unirradiated UO_2 using the streaming potential method while simultaneously measuring dissolution rate. A run was started which duplicated a previous flow-through test measuring the effects of Ca and Si additions to dilute bicarbonate solution. Dissolution rate responses matching those observed in the previous test were measured while successfully measuring stable streaming potentials. These encouraging results confirm the feasibility of simultaneously measuring surface potential and dissolution rate in a single test. Such tests were recently proposed in an addendum to the current flow-through test plan.

An addendum to the current test plan to measure specimen surface potential during flow-through dissolution tests being conducted with unirradiated UO_2 was written by PNL and submitted for review to LLNL. The purpose of the surface potential measurements is to provide additional data which could be useful in understanding mechanisms by which water chemistry variables affect the measured dissolution rates.

The following paper was submitted to the Material Research Society Conference to be held in Strasbourg, France, November 4-7: "Gap and Grain-Boundary Inventories of Cs, Tc, and Sr in Spent LWR Fuel" (Gray et al.).

Subactivity 1.5.2.1.2 - Oxidation of spent fuel. The drybath tests to determine oxidation front penetration rates continue as planned. Characterization samples of ~100 mg each are being removed for the tests. About 35 subsamples have been removed for examination to this point. Leaching samples of ~3 g have been removed from each two crucibles at 195°C. Almost all the samples have passed the O/M ratio of 2.25. Scanning Electron Microscopy (SEM) examination of some of the samples at high Δ(O/M) indicate no contamination with fluorine as found in the commercial spent fuel (CSFM) tests. XRD is continuing on two series of fuels that show promise for the most complete results this year. The XRD series are being run, and ceramography is being performed. After an initial variation in oxidation rate, the O/M versus time curves seem to be leveling off at ~2.4 irrespective of initial fuel condition or oxidizing temperature. At these O/M ratios, only UO_2 and U_4O_9 crystal lattice structures have been observed so far. A few electron diffraction samples are being run to determine if an additional amorphous phase is present. All preliminary indications are that after initial transients, this first stage in the oxidation process is independent of fuel condition. Preliminary reconsideration of some older oxidation data generated in an EPRI/Tennessee Valley Authority program implies that a second oxidation stage occurs above an O/M ratio of 2.4 and that accelerated tests at temperatures between 250 and 300°C would have to be conducted to obtain information on this second stage in a laboratory time frame. That is, below 200°C, preliminary indications are that this second stage would not appear in a laboratory time frame, and below 150°C, it may not appear in thousands of years. Due to the rapidity of the oxidation at high temperatures, the weight gain would need to be followed on a continuous basis in the thermo-gravimetric analysis system.

A full interim weighing was conducted, and one sample was lost when a crucible bail failed; however, no additional samples were contaminated. The Δ(O/M) data continue to support the predicted behavior. First, it appears that spent fuel variations only affect oxidation in a transitory manner. Secondly, the first stage of oxidation ends atΔ(O/M) ~0.4 and is essentially a U_4O_9 lattice structure with additional oxygen. The time to reach this Δ(O/M) has an Arrhenius behavior. Finally, oxidation of the fuel to a higher O/M ratio will eventually occur. From the preliminary data, it is projected that the first stage of oxidation (to an O/M ratio of about 2.4) should not be complete at potential repository temperatures before 1000+ years.

The following paper was presented at the 1991 IHLRWM Conference in Las Vegas, April 29-May 2: "Spent Fuel Waste Form Characteristics: Grain and Fragment Size Statistical Dependence for Oxidation Response" (Stout et al., 1991).

The following paper was submitted to the Focus '91 Nuclear Waste Packaging Conference in Las Vegas, September 29 - October 2: "Effects of an Oxidizing Atmosphere in a Spent Fuel Packaging Facility" (Einziger).

The paper entitled "Leaching Action of the EJ-13 Water on Unirradiated UO_2 Surfaces Under Unsaturated Conditions at 90°C: An Interim Report" (Wronkiewicz et al., 1991) was completed.

The paper entitled "Grain Boundary Oxidation of PWR Spent Fuel in Air" (Thomas and Einziger) was approved by YMPO on September 10, 1991, and will soon be published.

Subactivity 1.5.2.1.3 - Corrosion of zircaloy. The paper entitled "An Interpretation of the High-Stress, Low-Temperature Cracking of Zircaloy-4 Spent Fuel Cladding" (Smith) was approved by YMPO on September 6, and will soon be published.

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 carbon-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 288 weeks. The N3 tests (ATM-10, a West Valley actinide-doped glass) continued and have been in progress for 206 weeks. The approved Activity Plan entitled "D-20-27 Unsaturated Testing of WVDP and DWPF Glass" (Bourcier), for controlling both sets of tests, was received and is being implemented.

An article "Colloid Formation during Waste Form Reaction: Implications for Nuclear Waste Disposal" (Bates et al.) intended for journal publication was revised based on internal comments at ANL and some recent studies of the leaching of fully radioactive DWPF glass. The revised report was sent to LLNL for additional comment.

Static leach testing of WVDP and DWPF glass

This work was not funded during this reporting period.

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

In a response to a request from LLNL to help update the data base in support of EQ3/6, a list of mineral phases identified during glass testing was compiled by ANL. The list included phases formed during vapor phase alteration, static and unsaturated testing, and as colloidal material in test solutions. Information was compiled from tests using SRL 131, 202, and 165 glasses; WV 44, 50, and ATM-10 glasses; and from natural glasses.

Review comments on the ANL Topical Report entitled "Parametric Effects on Glass Reaction in the Unsaturated Test Method" (Woodland et al.) were addressed, and the report was submitted to YMPO for approval on August 14.

Parametric studies of WVDP and DWPF glasses

Data from the four-year tests with ATM-1c and ATM-8 glasses are still being evaluated. In particular, a set of sequential filtering steps was done to study the size distribution of particulate material in solution. The filters and filtrates are being analyzed for radionuclide levels.

The paper entitled "The Hydration of Borosilicate Waste Glass in Liquid Water and Steam at 200°C" (Ebert et al.) has been reviewed and comments returned to the PI.

Subactivity 1.5.2.2.2 - Materials interactions affecting glass leaching

Studies of glass surface layers and precipitation

A sample of vapor hydrated West Valley 50 glass was analyzed using Analytic Electron Microscopy (AEM). The purpose of this examination was to characterize the Ca, Th, phosphate phase formed in the reacted layer and compare the phase with that found in the material filtered from the liquid in the N3 tests. The phase that formed in the hydrated layer matched well with brockite. This matches the phase found on the filter, which suggests that the material in solution is a result of degradation of the reacted layer rather than reprecipitation from solution. The importance of this finding is that brockite is an americium sink, and is the source of americium detected in the N3 test solutions.

To further evaluate the effect of solution composition on reaction affinity, AEM examination of SRL 131 glass reacted in 60 and 120 ppm Si solution was continued. These samples were generated in scoping tests to establish the test matrix to be used in Activity D-20-28. All of the 1000 and 2000 m^{-1} (surface area/volume) samples were successfully sectioned and examined. While the test periods are short, the glass is Si poor and reacts relatively rapidly. Layer thickness ranged from ~1 μm to 100 Å. Essentially, the layers formed in deionized water (DIW) and 60 ppm Si were identical in structure and in thickness. The layer consists of an outer fibrous precipitated band of clay followed by a gel which takes on a very porous nature near the interface with the glass. The samples reacted in a 120 ppm Si solution showed essentially no layer formation and nearly no precipitation of fibrous material from solution.

The Scanning Ion Mass Spectroscopy (SIMS) system has been developed at ANL to profile transuranic elements in reacted glass samples. The SIMS system can detect and resolve ^{237}Np, ^{238}U, ^{239}Pu, and ^{241}Am at weight percents of 0.02, 1.0, 0.02, and 0.0002, respectively. The system is now ready to profile actinide concentrations in reacted glasses and will be applied to archival samples.

Work is continuing to analyze the Surface to Volume Ratio. Reaction Time samples using AEM. This work will be presented in the article "AEM Analyses of SRL 131 Altered as a Function of SA/V" (Mazer et al.) at the Material

Research Society meeting to be held in Strasbourg, France, November 4-7. The AEM was calibrated to perform quantitative analysis of reaction layers and secondary phases. K-factors were obtained by analyzing a suite of well-characterized glasses (that are being used in testing) and other mineral standards. From this series of analyses, a K-factor library was established, and the reference library was then used to analyze the reacted glasses. For major elements, the AEM-analyzed compositions were well within acceptable ranges. For minor elements, there was greater variation, and additional standards are being sought.

The AEM results show clearly the dual structure of layers that form in DIW and 60 ppm Si. In these leachates the extent of layer formation is similar. In 120 ppm Si, very little layer formation is observed. At equivalent $(SA/V)^* t$, different degrees of crystallization have occurred within the layers. For example, in the DIW leachate there is extensive crystallization of the outer portion of the inner layer at 2.5 days and 1000 m^{-1}, while there is no analogous crystallization for the sample reacted for 1.25 days at 2000 m^{-1}. Also, for the samples reacted in 60 ppm Si and DIW, the layer formed at 2.5 days and 1000 m^{-1} is thicker than expected when compared to the results for the 1000 m^{-1} samples. However, in 120 ppm Si the opposite trend is observed.

Work is continuing to characterize the layers with respect to composition and phase identification and to prepare the monolithic samples reacted at 50 and 100 m^{-1} for AEM examination. The goal is to integrate the solution data with the AEM results to better understand the affinity effect on glass dissolution.

Geochemical interactions

The fabrication of flow-through cells for the dissolution work was completed. The buffer compositions that were selected used 16 cells in the first series, 13 powders and 3 monoliths. The first test series began July 16 and was completed in September. The leach solutions were buffered at pH values of 4, 6, 8, 10, and 12 and doped with 2.5 millimolal concentrations of magnesium perchlorate and calcium perchlorate (separately). These tests were performed to determine the effects of solution composition (calcium and magnesium concentrations) on glass dissolution rate.

The flow-through tests having buffer solutions doped with calcium and magnesium were terminated after 6 weeks. Analytical results obtained at this time indicate the tests reached steady-state concentrations after about 30 days. Calcium and magnesium in the buffer solutions slowed down the dissolution rates relative to undoped buffers. Further analyses of these data will be performed after the remaining solutions have been analyzed.

Calculations of leachant buffer solutions to be used in future flow-through experiments were performed using the EQ3nr and GT codes and database. The buffer solution compositions are optimized for buffer stability and capacity to maintain a constant pH during glass dissolution. At low pH values, glass dissolution tends to increase pH, and the opposite is true at high pH. The buffers are poised so that they will neutralize the expected pH excursion caused by glass dissolution, and are based on estimated glass dissolution rates obtained in previous tests.

The calculations have shown that the effect of magnesium on dissolution rate is probably due to the formation of one or more magnesium silicate phases which armor the glass from further reaction. Even very small amounts of magnesium added to the leachant results in a high degree of supersaturation with respect to magnesium silicate and magnesium aluminosilicate phases (up to 25 log units of supersaturation). The solutions used in the glass dissolution experiments performed at Catholic University of America were also analyzed and a similar degree of supersaturation was discovered.

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 packages

Input/output interfaces for the YM Integrated Model (YMINM) are being defined. The intent of the YMINM is to provide management with a valid tool to make decisions regarding site characterization, design alternatives and resource allocations. The container behavior submodel is being developed concurrently to aid in delineating interface definition issues for the other submodels.

Staff hosted a Waste Package Performance Assessment Workshop with Golder Associates at LLNL on June 27-28. The purpose of the work at Golder Associates is to provide an independent study to develop and recommend a detailed plan for evaluation of the suitability of the Yucca Mountain site for a potential repository that is independent of DOE and utility industry initiatives. Their activity is funded by DOE through the Chicago Operations Office and Argonne National Laboratory (ANL). Personnel from Golder gave an overview presentation, then workshop participants discussed various aspects of developing models and predictive methods for rates of container breaching and rates for radionuclide transport.

The paper entitled "Models of Water Table Excursions Induced by Seismic and Volcanic Events at Yucca Mountain, Nevada" (Carrigan, 1991) was presented at the Spring AGU Meeting on May 29, in Baltimore, Maryland.

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. Staff used DBAPP and D0OUT to generate the R10 suite of thermodynamic datafiles (DATA0 files) for use with the EQ3/6 software package (release 3245.1090). Relative to R9, the R10 suite incorporates revised thermodynamic data for approximately 60 aqueous hydroxides, and correct dissociation-constant values for six diphosphate complexes.

Extensive restructuring and modification of DBAPP began. This update will 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.

Continued development of a software interface between GEMBOCHS and the GT geochemical modeling code. Continued restructuring of GEMBOCHS and D0OUT that will facilitate generation of composite data bases for the EQ3/6 package based on alternate suites of basis and auxiliary basis aqueous species.

Staff participated in the Technical Data Advisory Group Meeting in Las Vegas on July 18 and presented a summary of the flow of thermodynamic data into the GEMBOCHS data base.

The paper entitled "The LLNL Thermochemical Data Base - Revised Data and File Format for the EQ3/6 Package" (Delany and Lundeen, 1991) was published.

A paper is being prepared entitled "DBAPP: A Fortran-Equal Program that Facilitates Review and Modification of the GEMBOCHS Thermodynamic Database." This document will be submitted for review as a UCRL publication upon completion. A paper entitled "CHGBOCHS: An Automated Ingres-Email-Interleaf Filing System for Change Requests Associated with the GEMBOCHS Thermodynamic Database" is in its final revision. This document will be submitted for review as a UCRL publication upon completion. On September 20, "The LLNL GEMBOCHS Database and Software Library: YMP-TDB Quarterly Report," 3rd Qtr., was submitted to YMPO. On September 20 a review was completed of the Nuclear Energy Agency (NEA) draft document entitled "A Comparison of Radionuclide Sorption Databases Used in Recent Performance Assessments" (McKinley and Scholtis).

Laboratory work in support of Activity 1.5.3.2

Attempts were made to measure high-temperature americium hydrolysis and carbonate stability constants as a practical application of the High Temperature Guided Wave Spectroscopy apparatus. This instrumentation had been previously developed via lanthanide-ligand model systems.

The initial study attempted a measurement of americium hydrolysis at four temperatures from T=22-95°C. Up to 11 spectra were collected at each temperature, each having a different metal/liquid concentration ratio. Over the control regime of a hydroxylamine buffer system (pH = 5.26-6.75), the observed range of the americium 503-nm peak electronic absorption was only 0.003 absorbance and no monotonicity with pH was evident. The Guided Wave spectrometer was thus not sufficiently sensitive to quantitate americium hydrolysis below a pH of 6.8. The ^{243}americium in these experiments was 10^{-4}M with 0.5M ($NaClO_4$) ionic strength.

A subsequent study of americium carbonate complexation utilized the same [AM] and ionic strength as the hydrolysis experiment, but in a bicarbonate medium with controlled overpressures of CO_2. It appeared that these experiments were plagued throughout by precipitate formation. At room temperature the spectral shift of the 503-nm peak with increasing [CO3] seemed fairly reasonable. Replicate spectra and zero-absorbance baseline regions were somewhat more unstable than is customary, and the system may have been on the edge of precipitation even here.

In contrast, at all temperatures explored above (50, 75, and 95°C), extremely unstable and fluctuous spectra were observed for all pH values sampled (as low as 4.7). As these experiments generated absorbance

measurements of only ~0.02 absorbance units with the Guided Wave spectrometer, a reasonable conclusion is that temperature-controlled laser techniques at [AM]<<10_{-4}M would be necessary to obtain the desired carbonate stability constants.

A paper on the high temperature Guided Wave spectrometer and the results from the investigation of the praseodymium acetate system was presented at the ANS International Topical Conference on Methods and Applications of Radioanalytical Chemistry II. An article is being prepared for The Journal of Radioanalytical and Nuclear Chemistry based on the results of this meeting. Praseodymium, a non-radioactive stand-in for americium, was used in the development stages of the high temperature spectrometer.

LLNL staff met with personnel from LBL and LANL to discuss integrated research concerning solubility and speciation data determination. YMPO staff also participated in the meeting held in Las Vegas on July 2.

The paper "Remote Photoacoustic Measurements of Actinide Species in Aqueous Solutions Using an Optical Fiber Photoacoustic Spectrometer" (Russo et al.) was submitted to the MRS Symposia, Scientific Basis for Nuclear Waste Management XIII, Boston, Massachusetts, November 26-29.

The following papers were published during the reporting period: "Remote Photoacoustic Measurements in Aqueous Solutions Using an Optical Fiber" (Russo et al., 1991); "Development of High-Temperature UV-VIS-NIR Spectroscopy for the Measurement of Free Energies of Complexation at Elevated Temperatures" (Robouch et al., 1991); "An Elevated Temperature Titration Calorimeter" (Smith et al., 1991); and "Chemical Thermodynamics of Technetium IV" (Rard, 1991).

The paper entitled "High-Temperature Spectroscopy for Nuclear Waste Applications" (Grant et al.) was submitted to YMPO for approval on July 25.

The paper entitled "Humic Material in Well Water from the Nevada Test Site" (Minai et al.) has been reviewed. The author has incorporated the review comments and a revised version was submitted to YMPO for approval on September 25.

Subactivity 1.5.3.2.2 - Develop geochemical modeling code. A user guide to satisfy the documentation requirements of NUREG-0856 is being prepared for each of the three codes in the EQ3/6 package: the EQPT data file preprocessor, the EQ3NR speciation-solubility code, and the EQ6 reaction-path code. These will correspond to the software as released in Version 3245.1090. The EQPT manual is completely new, and the EQ3NR manual is a major revision of a version published in 1983.

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. The paper "Spent Fuel Waste Form Characteristics: Grain and Fragment Size Statistical Dependence for Dissolution Response" (Stout et al., 1991) was presented at the IHLRWM Conference in Las Vegas, April 29-May 2.

The following two papers have been returned to YMPO with review comments addressed: "Characterization of Spent Fuel Approved Testing Material - ATM-104" (Guenther et al.) and "Characterization of Spent Fuel Approved Testing Material - ATM-105" (Guenther et al.).

The paper entitled "Estimating the Time for Dissolution of Spent Fuel Exposed to Unlimited Water" (Leider et al.) has been reviewed and comments returned to the PI.

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. Staff attended the Performance Assessment Review Meeting April 2-3 in Las Vegas and presented a summary of the LLNL glass performance model. The PA review meetings are held yearly to assess the development of the Yucca Mountain Performance model.

Staff attended the Program Review for High-Level Waste Technology Development Activities in Washington, D.C., on April 10-11, and also met with ANL personnel to discuss plans for glass model development and related glass testing. Staff attended the NWTRB Meeting in Reno on April 16 and presented a talk on the use of natural analogs in validating a glass performance model.

W. Bourcier met with A. Barkatt (Catholic University of America), J. O'Keefe and S. Alterescu (NASA Goddard) on April 19 to discuss their experimental work on tektite dissolution behavior. Their work showed the strong effect of magnesium in slowing down the rate of dissolution of both tektite and nuclear waste glasses. More work will be performed to determine the mechanism for the reduction in reaction rate. Some work to characterize the reacted glass surfaces from future tests may be performed at LLNL and ANL.

An abstract entitled "Toward a Consistent Model for Glass Dissolution" (Strachan et al.) was submitted for publication in Radioactive Waste Management. This paper will be a joint product of modeling work at PNL and LLNL with the purpose of providing a focus for future model development and experimental efforts.

New versions of the reaction path code GT and associated graphics programs are available. The new code contains provisions for stable isotopes and an improved kinetics treatment. Plans are in place to upgrade the existing software to the new version. The latest EQ3/6 data base file (data0.com.R10) was converted to GT format.

The Activity Plan D-20-66 "Glass Dissolution Tests to Provide Fundamental Kinetic Data on Glass Dissolution Rates and Mechanisms" (which governs the flow-through tests at LLNL) and QA grading sheets were submitted for approval. The Test Plan for the flow-through tests was completed and is also waiting for approval.

The following two papers were presented at the 1991 IHLRWM Conference in Las Vegas, April 29-May 2: "Disposal of Vitrified Waste in an Unsaturated Environment" (Bates, 1991); "Mechanistic Interpretation of Glass Reaction: Input to Kinetic Model Development" (Bates et al., 1991).

The paper entitled "Prediction of Long-Term Release Rates of Radionuclides from Nuclear Waste Glass" (Bourcier) was submitted to Chemistry and Migration Behavior of Actinides and Fission Products in the Geosphere at the Migration '91 meeting to be held in Jerez, Spain, October 28-30.

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. Staff participated in a YMPO meeting on source term for total systems analysis at LBL on July 16. Needs, interface, and conceptual consistency for a source term from the engineered barrier system for use in a mountain-scale and regional-scale model were discussed.

A specification for a simplified source term model was provided to SNL for use in their Total System Analyzer model. The simplified model parametrizes the results of the most important processes affecting the source term, and does not attempt to track finer details. SNL staff commented that the "simplified" model was at about the right level of summary information to be useful in their larger-scope model.

Staff attended the NWTRB Panel on Risk and Performance Analyses held in Washington, D.C., May 20-22, and presented papers entitled "Preclosure Performance Assessment" (Jardine) and "Source Term Development" (O'Connell).

The following paper was presented at the 1991 IHLRWM Conference in Las Vegas, April 29-May 2: "Preliminary Calculations of Release Rates from Spent Fuel in a Tuff Repository" (Apted et al., 1991).

The following paper will be presented at the Focus '91 Nuclear Waste Packaging Conference in Las Vegas, September 29-October 2: "Diffusive Barrier Simplified Analysis -- Design and Sensitivity Applications" (Ueng and O'Connell).

Subactivity 1.5.3.5.2 - Development of uncertainty methodology. A presentation was made to the ESSE Core Team Meeting in Las Vegas on April 10 entitled "Engineered Barrier System Release Rates and Controlling Factors."

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) was submitted to YMPO for approval on September 5.

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

This activity is currently in the prototype and planning stage. The revised Scientific Investigation Plan (SIP) for waste package performance assessment has been approved for interim use and has been submitted to YMPO.

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 1991.

The following paper was presented at the 1991 IHLRWM Conference in Las Vegas, April 29-May 2: "Effects of Heterogeneity on Actinide Diffusion Rates in Tuffaceous Rock" (Buchholtz ten Brink et al., 1991).

Subactivity 1.5.5.1.2 - Radionuclide distribution in tuff cores. General planning and experimental design continued during this report period. Emphasis was placed on developing capabilities for testing and modeling combined fracture/matrix flow, colloid transport, and chemical sorption in the heterogeneous environment expected near the waste package.

The following Technical Implementing Procedures were prepared: "Depth Profiling on the Ion Microscope," "Data Reduction for Depth Profiles," and "Dektak IIA Surface Profiling System."

Construction continued on the flow-through chemical-hydrological system that will measure interactions of actinide-bearing solutions with rock core samples at in situ pressures and elevated temperatures. Solution delivery and collection systems were constructed, tested and modified. Flow tests of both the pressurized and unpressurized portions of the fluid lines were undertaken. The pump line was tested and modified to reduce pulsation and volume. Constant pore pressure and differential pressure can now be maintained while a measurable flow rate of water is achieved. Diaphragms were obtained, installed and tested to separate the pore-fluid from the metal measuring devices, such as pressure gauges and transducers. The confining pressure lines were completed and tested: performance was satisfactory. Wiring of the end caps, construction and installation of in-line filters, and incorporation of heating elements have progressed to the testing stage. Instrument-control and data acquisition of hydrological parameters (e.g., resistivity, pressure differential) was computerized by connecting to a Macintosh II computer with the program LABVIEW.

Slippage of the testing schedule occurred due to the need to identify and remedy problems such as a leaking diaphragm, creep in teflon gauges, filter deformation, and pulsation in the fluid lines. The fluid transport and detection components will be further tested using the test-core prior to experiments utilizing fractured core from the potential repository horizon and radioactive pore fluid. Fractured "dummy" core and repository-horizon core was prepared for the flow-through experiments. In addition, adjacent samples

were inspected and submitted for characterization of fractures, pore structure and pore size.

Development continued on characterizing the suspended particles or colloids that exist in the solution which evolves from interaction of the waste with ground waters. Training, learning software, testing of capabilities, realignment of the laser, and repairing malfunctions were the primary activities associated with the auto-correlation photon spectrometer (PCS) during the report period. Calibration against commercial standards indicated good agreement for the size distribution of particles in the 1 μm to 3 μm size range. In order to reduce the potential for contamination of fluid samples prior to particle-size analysis, a laminar-flow hood was installed and a milli-Q water system was repaired and installed in the PCS lab.

Previous LLNL work indicated that diffusion of radionuclides occurred along a heterogeneous front in Topopah Spring Tuff, emphasis during this period continued to be development of capabilities to characterize the submicron to millimeter scale pore and fracture structure in the rock. All supplies were acquired for three-dimensional imaging of pore-spaces and micro-fractures and for autoradiography, which will be used to identify the relative locations of larger pore or fracture features and actinide locations. Core samples were prepared for analysis, however, FY 1992 funding uncertainties and attrition of staff prevented completion of the analysis.

The ability to measure actinide concentration gradients in rock, glass, and fuel at very small spatial intervals is crucial for obtaining information about the migration rate of the actinides in the near field. Consequently, efforts were begun to generate a library of standards and determine useful yields and relative sensitivity factors (RSF) for materials analysis with SIMS. Analysis and data reduction of depth profiling of U and Th ion implant in Si, SiO_2, Al_2O_3, MgO, TiO_2, Fe_3O_4, and ZrO_2, Mg-Al spinel, Ca-Ti, perovskite, natural quartz, olivine, enstatite, augite diopside, akermanite, grossular and andradite, granite, and feldspar was completed. Discrepancies in the results were resolved when discussions with the laboratory that provided the implants indicated that differing implant procedures were used in some of the samples. It appears that the sensitivity factors for most minerals present in the Topopah tuff are similar; this validates the use of a single sensitivity factor in the previous analysis of tuff samples where sample areas included a variety of minerals.

Testing was completed for the prototype version of software necessary to calculate RSF from standards and is currently in use. An EGA card, an optical disk drive and an x-y display unit were installed in the instrument-controlling IBM PC to correct problems encountered on the IMS hardware.

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 study.

2.6.4 Waste package production technologies (SCP Section 8.3.4.4)

On May 10, R. Staehle, University of Minnesota, met in a technical exchange with LLNL technical staff to discuss cumulative damage functions. Staehle is funded by DOE/HQ as part of the PASS program. The topic of this seminar was "Four Step Approach to Predicting the Performance of Radioactive Waste Containers."

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)

Internal QA grading packages were completed: (1) E-20-13, Degradation Mode Surveys, (2) E-20-15, Selection Criteria, (3) E-20-16, Model Development, (4) E-20-17, Experimental Technique Development, (5) E-20-18, A, B, C, D, E, H, Parametric Studies, LLNL (6) E-20-18, F and G, Parametric Studies, ANL (6) E-20-18, F and G, Parametric Studies, ANL, and (7) E-20-19, Selection of Container Material.

The following three papers were presented at the 1991 IHLRWM Conference in Las Vegas, April 29-May 2: "An Electrochemical Approach to Predicting Corrosion Performance of Container Materials" (McCright et al., 1991), which discussed electrochemical testing to determine the critical potentials for localized corrosion initiation of Alloy 825; "Degradation Mode Surveys of High Performance Candidate Container Materials" (Gdowski and McCright, 1991), which discussed the recently completed degradation mode surveys on the high-nickel alloys and titanium/titanium alloys. This paper also covered some background on the SCP Conceptual Design candidate materials and plans to compile a modified candidate list. "Gaseous Release of Carbon-14: Why the High Level Waste Regulations Should be Changed" (Van Konynenburg, 1991), which discussed the problems of carbon-14 release from spent fuel waste packages. This paper urged a reconsideration of some of the federal regulations governing the controlled release of radioactive nuclides.

The following six papers were submitted to the Focus '91 Nuclear Waste Packaging Conference in Las Vegas, September 29 - October 2: "Candidate Container Materials for Yucca Mountain Waste Package Designs" (Clarke et al.); "Progress in Evaluating the Corrosion of Candidate HLW Container Metals in Irradiated Air-Steam Mixtures" (Reed (ANL) and Van Konynenburg); "Effect of Ionizing Radiation on the Anticipated Waste Package Environment at Yucca Mountain" (Reed and Van Konynenburg); "Electrochemical Polarization Measurements on Pitting Corrosion Susceptibility of Nickel-Rich Alloy 825" (McCright and Fleming); "Stochastic Models for Predicting Pitting Corrosion Damage of HLRW Containers" (Henshall); and "Status Report - Fabrication and Closure Development of Nuclear Waste Disposal Containers for the Yucca Mountain Project" (Domain et al.).

Papers entitled "Corrosion Models for Performance Assessment of High-Level Radioactive-Waste Containers" (Farmer, 1991) and "Corrosion Considerations of High-Nickel Alloys and Titanium Alloys for High-Level Radioactive Waste Disposal Containers" (Gdowski, 1991) were published.

The paper entitled "Cost Estimate of High-Level Nuclear Waste Containers for the Yucca Mountain Project" (Russell and Domain) was approved by YMPO on July 17, and will soon be published. The paper entitled "Modeling of Gaseous $^{14}CO_2$ Release from Perforations in Spent Fuel Disposal Containers" (Pescatore and Sullivan) was sent to YMPO for approval on September 4.

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. Discussion continued on how to apply the selection criteria to the candidate material list update. Cortest Laboratories proposed to develop an expert system using the selection criteria. An Activity Plan was begun to cover the container material update work.

LLNL staff met in session on July 30 and 31 to evaluate the candidate materials against all of the selection criteria. These candidates included the so-called SCP-6 (the ones described in the SCP and annotated in the report UCID-21472 -- namely, 304L stainless steel, 316L stainless steel, nickel-base Alloy 825, unalloyed, high purity copper (CDA 102), 7 percent aluminum bronze (CDA 613), and 70/30 copper nickel (CDA 715) plus materials that had originally been considered in the 1983 candidate selection report (UCRL-53449) plus other materials that have been the focus of recently produced degradation mode surveys. During the two-day session, the evaluation was applied in a three-stage process: first, the candidate materials were evaluated individually according to the 34 separate criteria in UCRL-ID-104552. Second, the scores achieved in each of the separate criteria were multiplied by the appropriate weighting factor for that criterion. The weighted scores were tabulated.

Detailed evaluations were completed on (1) 304L stainless steel, (2) 316L stainless steel, (3) Alloy 825, (4) pure copper, (5) 7 percent aluminum bronze, (6) 70/30 copper nickel, (7) carbon steel, (8) nickel-base Alloy C-4, and (9) titanium grade 12. The evaluation was based on the YMP Conceptual Design, a thin-walled container fabricated from a single material. For many of the criteria, there was no readily available supporting information so that the best professional judgment was used, and a collective judgment was arrived at from the four participants. Alloy 825, Alloy C-4, and Titanium Grade 12 scored the highest overall of the materials evaluated. These materials are therefore recommended for advanced studies as part of the Advanced Conceptual Design (ACD). Carbon steel failed because of its low perceived general corrosion rates under relevant Yucca Mountain environmental conditions; copper failed because of its low mechanical strength and perceived difficulty in processes for welding remotely. The two 300 series stainless steel canisters obtained nearly failing scores for their susceptibilities to localized corrosion and stress corrosion cracking under relevant Yucca Mountain conditions. In other design concepts, some of these materials would have been

suitable, particularly as one layer of a multiple barrier. It is expected that additional design concepts will be recommended for ACD. A formal report on the selection process is being prepared. This will include the scoring procedure and details of the process.

The Babcock & Wilcox, Inc. container cost estimate report entitled "Cost Estimate of High Level Nuclear Waste Containers for the Yucca Mountain Project" (Russell et al., 1991), was revised and transmitted to YMPO to satisfy resolution comments in time for the Total System Life Cycle Cost (TSLCC) meeting on July 16.

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. Two letters of direction from DOE Operations Office/San Francisco (SANLs) were completed for work at ANL. One SANL was for an augmentation in the scope of work on radiation induced effects in the near field environment and container material performance. The other SANL is for a restart of work on the propagation of slow growing cracks in the candidate materials. This work was contractually halted because of budget reductions during FY 1990. However, ANL was able to keep the tests operating. The SANL will permit an orderly completion of the work and preparation of final reports on these subjects by the end of FY 1991.

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. Work is progressing under subcontract at ANL on the radiation effects on the environment near the waste package container and the resulting effects on the container material performance. Much of the work involves the effect on copper and Cu-base alloys since these materials are the more seriously affected. The work is divided into two parts: (1) Yield of NOx/NH3 in high water vapor to air systems. The yield of ammonia and condensable nitrogen oxides in gaseous systems that consist of high water vapor-air ratios are determined. High water vapor concentrations are likely during the initial phase of potential repository history and, based on preliminary data that have been obtained, will affect the NO_x/NH_3 yields. These experiments are being performed according to previously established procedures and provide needed input to establishing the nature of the environment that surrounds the waste package. Developmental aspects have been completed. (2) Modeling/Calculation of radiolytic yields in the waste package. The range of existing data on the radiation chemistry of moist air systems is summarized and related to a broad range of waste package design considerations.

The paper entitled "Survey of Degradation Modes of Nickel-Chromium-Molybdenum Alloys, Sections 1-5" (Gdowski) has completed YMPO review.

2.6.5.5 Activity 1.4.2.3 - Degradation modes affecting candidate austenitic materials

Progress is discussed under Section 2.5.5.4.

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

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

One of the major goals of modeling pitting corrosion is to predict the effect of environmental variables on the pitting response. In the context of stochastic pitting models, the goal is to model the effect of environment on such stochastic parameters as the birth probability of a pit, the death probability of a pit, the critical embryo age required to produce a stable pit, and the stochastic growth probability. The first steps toward modeling the effects of the environment on stochastic pit initiation has begun. The environmental variables considered in this initial analysis were: (1) applied potential, (2) chloride ion concentration, (3) temperature. Other important variables, such as pH, will be included in future analyses. Both a linear dependence and an exponential dependence of the birth probability on the applied potential were considered, since the published literature is not clear on this relationship. Sample calculations of the pitting survivability have been made for different values of applied potential, and these are compared with experimental data from Shibata (1990). The comparison shows a qualitatively reasonable simulation. The limited data can be fit reasonably well by either an exponential or low-power relationship.

An interesting question to explore with the model is whether a threshold exists in the potential (the so-called critical potential) at which pitting occurs or whether the pit initiation rate just becomes very slow as the potential is reduced. The question is particularly relevant for nuclear waste containment because of the extremely long times involved. The stochastic model has been used to explore the effect of the applied potential on the median induction time required to initiate a pit. Two forms of pitting equations have been used in the model--incubation time is inversely proportional to (potential minus critical potential) and incubation time is inversely proportional to the exponential of the potential. The first form would produce no pits, even over geologic time spans, if the potential is subcritical. The second form would produce pits at very long times, even at low potential.

The effects of chloride on the pit initiation behavior were also explored using the stochastic model. An increase in the slope of the survival probability plot with increasing chloride concentration was produced by the model, as expected. More quantitatively, the relationship between the induction time and chloride was examined. From the literature, this relationship is suggested as an inverse function, and the simulation indicates that this is a reasonable, though not perfect, description.

Efforts have been concentrated on establishing the effects of applied potential [E_{app}], chloride ion concentration [Cl^-], and temperature [T], on the "damage function" histogram (number of pits versus pit depth). The equations described in the previous two progress reports were again used to describe the effects of these variables on the stochastic parameters for pit

nucleation. It is important to note that environmental effects on pit growth are not included in these calculations and that growth is assumed to be linear with time. The effects of environment on pit growth will be the subject of future research. As an example of the results from the current model, damage function histograms were obtained where the number of pits is plotted against the pit depth for two arbitrarily chosen values of [Cl^-]. The distributions obtained have essentially the same shape for the two chloride levels; however, the number of pits for any particular depth is greater at higher chloride concentration. The increase in the number of pits with increasing [Cl^-] was shown in another plot of the median number of pits after 400 time steps versus [Cl^-]. The shape of the curve suggests that the median number of pits increases exponentially with the increasing [Cl^-]. This is not surprising since the change in birth probability with changing [Cl^-] dominated the simulations and birth probability depends exponentially on [Cl^-].

The environment to which the waste containers will be exposed certainly will not be constant. Therefore, it is necessary to be able to model the effects of a changing environment on the pitting response. This effort has begun by allowing for linear changes in the environmental variables E_{app}, [Cl^-], and T during the stochastic simulation. Nonlinear changes could easily be accommodated and will be explored in the future. Again, the environmental changes currently affect only the nucleation behavior; pit growth is unaffected.

Finally, the influence of temperature on pit initiation was explored with the stochastic model. Data in the literature show that the effect of temperature on pitting behavior is complex, and the pitting induction time may increase or decrease with increasing temperature. The reason that the model is able to simulate this type of behavior is that temperature affects the stochastic parameters in different ways, such that their effect on the induction time is different. Specifically, an increase in temperature increases the pit birth rate and death rates while decreasing the time required to produce a stable pit. However, the increase in the pit death rate increases the induction time, thereby providing the model with a means to simulate complex temperature dependencies.

Stochastic modeling of pitting corrosion continued in the area of simulating changes in the environment. Only linear changes in environment have been simulated. More complex environmental histories are now simulated by the Monte Carlo model for the environmental variables of applied potential, E_{app}, temperature, T, and chloride ion concentration, [Cl^-]. Exponential expressions were chosen because they may be more realistic for describing the changes of these variables with time in the potential repository.

Work continues on developing a mathematical expression for the critical pitting potential [E_{crit}] of Alloy 825 as a function of temperature, pH, and chloride ion concentration. During the past month, previous experimental determinations were examined to identify the linear portions of the E_{crit} vs. log [Cl^-], E_{crit} vs. T, and E_{crit} vs. pH plots.

Revision was completed on the report drafted in June entitled "Modeling Localized Corrosion of High-Level Radioactive Waste Containers" (Henshall). This preliminary document has now been issued as a letter report. A seminar was presented to the YMP staff on July 24 based on this report.

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. This activity is not part of the current work scope. It is scheduled to be accomplished at a later date.

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. 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

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. The following paper was presented at the 1991 IHLRWM Conference in Las Vegas, April 29-May 2: "Effects of Heterogeneity on Actinide Diffusion Rates in Tuffaceous Rock (Buchholtz ten Brink et al., 1991).

A literature search was completed on the adsorptive behavior of goethite at elevated temperatures and experiments started to characterize goethite surface chemical properties in the temperature range 25°C to 75°C.

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)

The "Retrieval Strategy Report for a High-Level Nuclear Waste Repository" (Flores) was submitted to the YMPO for review and approval. Approval was granted and the report is being published.

2.7.2 Public radiological exposure - normal conditions (SCP Section 8.3.5.3)

2.7.2.1 Performance Assessment Activity 2.1.1.1 - Refinement of site data parameters required for Issue 2.1

The Radiological Environment Monitoring Program was restarted in January 1991. Activities included air sampling, placement of thermoluminescent dosimeters and radon measuring devices, and ground and soil surveys. Routine monitoring activities continued through the third quarter.

2.7.2.2 Performance Assessment Activity 2.1.1.2 - Development of performance assessment activities through the preclosure risk assessment methodology program

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

2.7.2.3 Performance Assessment Activity 2.1.1.3 - Advanced conceptual design assessment of the public radiological safety during the normal operations of the Yucca Mountain repository

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

2.7.3 Worker radiological safety - normal conditions (SCP Section 8.3.5.4)

2.7.3.1 Activity 2.2.1.1 - Refinement of site data parameters required for Issue 2.2

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

2.7.3.2 Activity 2.2.1.2 - Advanced conceptual design assessment of the worker radiological safety during the normal operations of the Yucca Mountain repository

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

2.7.3.3 Activity 2.2.2.1 - Refinement of site data parameters required for Issue 2.2

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

2.7.3.4 Activity 2.2.2.2 - Development of performance assessment activities through the preclosure risk assessment methodology program

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

2.7.3.5 Activity 2.2.2.3 - Advanced conceptual design assessment of the worker radiological safety during the normal operations of the Yucca Mountain repository

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

2.7.4 Accidental radiological release (SCP Section 8.3.5.5)

2.7.4.1 Performance Assessment Activities 2.3.1.1 and 2.3.2.1 - Refinement of site data parameters required for Issue 2.3

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

2.7.4.2 Performance Assessment Activity 2.3.1.2 - Determination of credible accident sequences and their respective frequencies applicable to the Yucca Mountain repository

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

2.7.4.3 Performance Assessment Activity 2.3.1.3 - Development of candidate design-basis accidents for the Yucca Mountain repository

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

2.7.4.4 Performance Assessment Activity 2.3.2.2 - Consequence analyses of credible accidents at the Yucca Mountain repository

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

2.7.4.5 Performance Assessment Activity 2.3.2.3 - Sensitivity and importance analyses of credible accidents at the Yucca Mountain repository

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

2.7.4.6 Performance Assessment Activity 2.3.2.4 - Documentation of results of safety analyses and comparison to applicable "limiting" values

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

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 ground-water travel, as well as for other purposes, currently depends heavily on the acquisition of experimental data. The SCP activity

under which such data are acquired is Activity 1.6.2.2.2, and the current work is summarized there.

2.7.5.2 Activity 1.6.2.2 - Verification and validation

Subactivity 1.6.2.2.1 - Verification of codes. A document summarizing the results of the Performance Assessment Calculational Exercises, PACE-90, (Barnard and Dockery, 1991) was published in July. The PACE-90 effort contributed both to code development and to preliminary assessment of the total repository system; it was a multiparticipant, multidisciplinary exercise of DOE capabilities. The report contained information on the PACE-90 problem definition, hydrogeologic stratigraphy and parameter development, and calculational results for a nominal flow case. Elements of these deterministic calculations were performed by SNL, LANL, LBL, LLNL, and PNL. The results showed that, if the parameters and models used in the calculations are valid, radionuclide transport through Yucca Mountain via liquid pathways is extremely slow. None of the models estimated release of nuclides to the saturated zone in amounts great enough to be of regulatory concern. However, sensitivity studies for the problem set indicated a need for additional numerical and analytic analyses, including the effect of transient liquid pulses through the system; the ability of fractures, matrix rock heterogeneities, or lateral discontinuities to form fast flow paths or flow barriers; the ability of potential fast paths to transport a significant amount of radioactive material; and the rates of flow and transport in the saturated zone to the accessible environment.

Results of PACE-90 were presented at the 1991 IHLRWM Conference (Barnard and Dockery, 1991), at the Performance Assessment Review meeting in Las Vegas, and at the NWTRB meeting on performance assessment on May 20-21. The PACE calculations furthered the development of codes because they required additional capabilities in certain codes; they were also a verification exercise in that they required comparisons of the results of different codes when the codes were all applied to the same problem.

The PACE calculations were also used as a basis for developing problems for both the ESSE and the Total-System Performance Assessment (TSPA) calculations. Although some resources from code development and verification were used to support the ESSE and the TSPA, the results of the work are presented under progress report discussions in Section 2.7.5.4, Subactivity 1.6.4.1.3 and Section 2.7.6.6.

Several information exchanges took place between SNL staff and workers for the EPRI on development of capabilities for total-system performance assessment. SNL provided the EPRI with copies of the codes TOSPAC and NORIA, documentation, and some initial training on the use of the codes.

The heat-conduction code, COYOTE II, has been under consideration as a possible alternative to NORIA. Many of the code enhancements proposed for NORIA, including four-node elements, dynamic memory allocation, etc., are already features of COYOTE II. Because there was still some question concerning the applicability of COYOTE II to unsaturated-flow problems, several scoping calculations were set up. COYOTE worked well on a one-dimensional infiltration problem. A solution set has been obtained for a

two-dimensional, two-layer problem with a steady infiltration rate; examination of the results is still pending.

Enhancements to FEMTRAN are being incorporated. The capability for the user to specify distributed sources was implemented and successfully tested on analytic solutions. The driver was modified to allow easy changes in array dimensions. Enhancements of FEMTRAN involving user-specified boundary conditions were completed and successfully tested against analytic solutions.

Time profiles for NORIA-SP were developed to determine which computing activity accounts for significant execution time. This information was used to guide code enhancements aimed at increasing the efficiency of the code.

Work continued on the formal documentation and benchmarking of the 2D method-of-lines code LLUVIA-II. Time-dependent results obtained using LLUVIA-II showed good agreement with a 2-D unsaturated flow problem used for the evaluation. Coding modifications with potential speedup are continuing.

A summary report on the code verification exercise, COVE 2A, has completed extensive iterations in internal technical review and is currently in management review. A report on the TOSPAC calculations for COVE 2A (Gauthier et al.) completed YMP review in June.

During the time while the TOSPAC User's Manual was in review at the YMP, TOSPAC, a total-system code with extensive capabilities for modeling flow in unsaturated media, was modified in order to perform quality-affecting calculations for ESF studies. To account for these modifications, the manual has undergone major changes and is receiving additional technical review.

Software QA

The principal effort in software QA focused on (1) entering codes into the configuration-management system and qualifying them for use in quality-affecting work, (2) revisions to procedures and plans, and (3) an audit of software-QA practices.

In May, the qualification process was begun for COYOTE II, a non-linear heat-transfer code, in order to incorporate it into the software configuration-management system, in accordance with QAIP 3-2. Tests on an example problem using BLOT, FASTQ, and COYOTE II were completed. Other parts of the qualification process for COYOTE II reached various stages of completion: installation, evaluation, writing check-out reports, and developing additional user documentation.

Documentation review of the user's manual for STRES3D, a thermo-mechanical-analysis code, was completed in June; the review established that the manual meets certain requirements for qualification established in QAIP 3-2. Review began on a similar review of documentation codes that the National Center for Atmospheric Research may use in quality-affecting climatology studies.

To improve procedures, work was performed to evaluate a software package that would control access to VAX codes used in quality-affecting analyses. Procedures were developed for backing-up and restoring tapes in the local

records center (LRC) because the maintenance of tapes is part of the requirements for software QA. New initiatives in this maintenance included investigations of commercially available library software for the LRC and procedures for analyzing the format of tapes stored there.

As part of the need to revise software-QA plans and procedures, SNL staff met with the YMP staff to resolve comments on the SNL-proposed revisions to the software plan (SQAP Rev. 01) and software procedures (QAIP 3-2, Rev. 01) in June. These revisions reflected proposed changes in the Quality Assurance Requirements Document. Both SQAP, revision 1, and QAIP 3-2 revision 1 were submitted for the YMPO in July and the QAIP 3-2 was approved for department use in August.

SNL staff participated in an internal audit of software QA practices. This exercise provided much of the preparatory work necessary for the YMP audit held at SNL in August. Preparations prior to the audit included checking the master log, the magnetic tapes, the procedures, and ensuring that all software documentation was placed in the Records Center. In the DOE QA audit (August 19-23), three issues were corrected as discovered. The one finding made was corrected with an ICN during the audit.

Subactivity 1.6.2.2.2 - Validation of models.

Caisson experiment

SNL and LANL YMP staff collaborated in designing a large-scale (caisson) flow and transport validation experiment. Responsibility for parts of the experiment was assigned at a meeting attended by staff from LANL and SNL held at SNL on May 21, 1991. SNL staff were assigned to choose and characterize the packing material for the caisson to allow for the collection of data useful for analysis for both chemical and hydrologic processes important to the validation of flow and transport models. In addition, SNL staff and subcontractors from the University of New Mexico (UNM) are to design geophysical techniques, such as EM imaging, DC resistivity, and TDR, for the detection of moisture within the caisson. Finally, SNL staff have the responsibility to study the geochemical interactions between the reactive tracers and the caisson material in well-controlled laboratory experiments. The data from these investigations will be used with the geophysical data in the coupled reaction/transport code LEHGC to model the movement of the tracer plume.

Properties of candidate materials for the caisson packing (inert and sorbent layers) were surveyed, including a literature search for data describing sorption of proposed tracers by the potential substrates. The hydraulic properties of silica sand proposed for the caisson were predicted using a mapping of particle-size distribution to hydraulic properties; it is intended that the hydraulic properties of the filling material be uniform throughout the caisson.

A preliminary experiment in a thin-slab chamber using a similar sand was conducted using both optical and x-ray data-acquisition methods to determine which techniques would work best during performance of meter-scale slab experiments in support of the large-scale validation experiment. Results indicate both methods work equally well (approximately 200 levels in moisture

content). The methods will be further developed to measure tracer concentration (dyes and iodine). The preliminary experiment also showed the formation of microlayers during packing of the sand slab. These layers are easily seen with full field-measurement methods and will undoubtedly play a major role in creating small-scale heterogeneities within the caisson when it is packed.

The hydraulic properties of the filling materials have been used to calculate flow rates for different boundary conditions and saturation states. A desired retardation factor for reactive tracers has been calculated from the flow rate and a desired solute tracer travel time. The amounts of candidate sorbents required to achieve the desired retardation factor are being calculated from estimated surface areas and K_d's of the reactive tracers (Ni and B). Candidate sorbents include clinoptilolite, goethite, and quartz sand coated with goethite or amorphous iron oxyhydroxide. These sorbents will occupy the finest grain-size fractions in the sorbing layer. An evaluation of several methods to coat the quartz grains with iron oxyhydroxide phases has been initiated.

Discussions of geophysical instrumentation with LANL YMP staff indicates that, based on TDR instrumentation installed in another experiment being conducted by LANL staff, it appears that only two-prong probes should be used. The signal generated by probes with three or more prongs is much more difficult for the cable tester and related hardware and software to process. Probes and cable testers are being ordered immediately to ensure their availability by the start of the experiment this Fall.

Fracture/matrix interaction

An experimental system was constructed to visualize flow and wetted geometry in unsaturated fractures in connection with matrix. The matrix on one side of the fracture is replaced with a clear glass or epoxy cast allowing sight into the fracture as an experiment proceeds. The system incorporates diffuse frontal lighting and digital imaging technology to record wetted structure as a function of time. A first experiment has been conducted with a horizontal fracture and water entry from the matrix. Pressure in the matrix is increased incrementally, and the wetted area in the fracture is recorded to obtain the moisture release functions for the fracture. Experiments are investigating hysteresis in this relation as well as the pressure at which the fracture aperture network is spanned and flow within the fracture can take place. Results of these experiments will be compared with a variety of percolation models proposed for use in deriving hydraulic properties from measured fracture surface properties. The experimental system also has been designed to be rotated within the gravitational field. A preliminary experiment in a vertical fracture with an initially dry matrix and water entry into the fracture from above demonstrated wetting front instability and the formation of gravity-driven fingering. Both the finger in the fracture and the subsequent wetting of the matrix were visualized, thus demonstrating the power of the experimental system for testing the key assumptions embodied in most conceptual models for flow and transport in unsaturated, fractured rock.

Fingering in fractures

Experimentation and analysis to date suggest gravity-driven fingering in unsaturated fractures may be important in all but very low-angle or tight fractures. After experimental observation of fingering in fractures (see previous section), emphasis has been on development of experimental apparatus and materials that enhance the ability to control boundary and initial conditions as well as material properties. Cooling fractures from Yucca Mountain have been cast for use in experimental systems this fall. The fabrication of fractures from simulated roughness profiles also was researched. A computer-driven milling machine is being programmed to mill two sides of a fracture (approximately 15 x 30 cm) in graphite. The graphite forms then will be used to cast fracture planes in glass or sinter glass beads to form a controlled-property matrix.

Development of techniques and materials

Analog rock materials are being developed so that experiments can be conducted using materials with controlled properties. A graphite mold was constructed for use in sintering glass beads; sodalime silicate glass beads were purchased; and a process with which to pack the beads in the mold (care must be taken to avoid the introduction of unwanted heterogeneity in the fabricated plates during the packing process) was developed. Several small-scale tests were conducted using the glass beads in an unconfined mold to aid in defining the optimum sintering process (temperature versus time relationship). Plates have been made from three different bead sizes; for each grain-size distribution, plates have porosities in three designated ranges: 30-35 percent, 20-25 percent, and 10-15 percent. Plates of similar porosity and grain-size distribution are made in pairs. A time/temperature/porosity relationship has been developed that allows precise specification of plate porosity given a defined furnace temperature and sintering time. A procedure for measuring plate porosity also has been developed and implemented. The design for a larger mold (30 x 20 x 0.9 cm) for sintering plates has been completed.

Experimentation continued toward the development of x-ray absorption as a technique for monitoring moisture content and solute concentration in fractured porous media. Efforts have primarily concentrated on enhancing image contrast, which is the difference in image density between points of differing water content. We are currently pursuing the use of a potassium iodide solution in our experiments. Iodine is a potentially useful tracer because of a favorable x-ray absorption edge and relatively stable geochemical characteristics.

In addition, the relative usefulness of x-ray absorbtion and transmitted light as techniques for measuring moisture content is being examined. Tests are conducted in thin slabs of unconsolidated sand subjected to several wetting and drying cycles. The goal of the tests is to quantify the accuracy and precision of the techniques. Gamma-ray and gravimetric techniques are used to evaluate accuracy. The final test in a series of three experiments aimed at evaluating the accuracy and precision of the two techniques in homogeneous media was completed. With these data collected, activities have been aimed at reducing and analyzing the collected data. Several software utilities have been written to facilitate data manipulation. An additional

experiment is planned to compare the techniques in a heterogeneously packed unconsolidated sand chamber.

A series of experiments to evaluate the sorption of FD&C Blue #1 dye by the sand used in the optical system have been initiated. The sensitivity and detection limit of a Gilford spectrophotometer for the dye was evaluated over the concentration range 1 ppm to 1000 ppm. Optimum sensitivity appears to be achieved over the range 3 to 15 ppm, but absolute sensitivity, detection limits, and precision have yet to be precisely established. The data have been collected, and preliminary estimates suggest a routine precision of +/- 1.5 percent (1r), limited principally by variations in cuvette positioning and transmissivity. A series of batch experiments was performed for dye concentrations ranging from 25 to 1000 g/ml at a sand/solution ratio of approximately 2.2 g/ml. After equilibrating the mixtures for 72 hours, the amount of dye sorbed by the sand was found by difference between the initial and final aqueous dye concentrations. The resulting K_d's ranged from 0.015 to 0.030. The experimental error is at least 0.005 (1 sigma). The data are consistent with slightly smaller K_d's at higher concentrations, but this relationship is not statistically significant due to the relatively high experimental imprecision.

The use of the uranyl (UO_2^+) ion as a fluorescent tracer has been evaluated. Results to date indicate that the sample/source/detector geometries and light sources used in standard spectrofluorometers are not suitable for use in the transport experiments planned at SNL. Improvement in the sensitivity of uranium detection in porous sands will require more powerful light sources, special sample holders, and computerized data reduction to correct for the natural fluorescence of the quartz sand.

A series of batch experiments investigating the sorption characteristics of uranium acetate on quartz sand was carried out. Five trials of various uranium concentrations spanned the range of 10 to 5,000 ppm; all were conducted at a sand/solution ratio of 1.13 g/ml. After equilibrating for 72 hours, the amount of uranium sorbed by the sand was found by difference between its final aqueous concentration and its concentration in a blank (i.e., no sand, enabling correction for sorption to the container walls). Results were equivocal, with negative K_d's arising at higher concentrations, implying either (1) dilution problems and a real K_d equal to zero, or (2) release of uranium from the sand to the solution. Uranium leaching experiments using the quartz sand and Na-acetate solutions are planned to determine if the second hypothesis is true.

Preparation of activity-specific technical procedures for tracer sorption studies continued. Published techniques for synthesis of goethite, a well-characterized substrate, were tested in the sorption laboratory. Technique development for analysis of B and Ni by graphite furnace atomic absorption spectrophometry was completed.

Efforts also have been initiated to establish a collaborative effort between SNL and the UNM Medical Center to evaluate the feasibility of using real-time x-ray imaging techniques to monitor the movement of fluids and solutes through fractured and unfractured volcanic tuff. A scoping study was performed at the UNM Medical Center in which a Siemen's "C" arm x-ray system was used to image the movement of a potassium iodide solution through a

60-micron fracture (formed by the mating of two sintered glass plates) and to image a dry slab of partially welded tuff. The system was found to work well with both analog and tuffaceous porous media. Of particular interest is the fact that flow was clearly visible in the fracture. The "C" arm appears to represent a powerful moisture-sensing tool capable of imaging volcanic tuff samples at a very high degree of temporal (on the order of an image every two seconds) and spatial resolution.

To aid in the evaluation of techniques used in the scaling of effective media properties, a need has been identified for an instrument that will allow rapid collection of effective media property data at a variety of scales. One such instrument, known as a mini-air permeameter, has been identified. The instrument simply measures the flux of compressed gas, subjected to a known constant head, through a small nozzle held against a rock sample or outcrop. Scale of the measurement may then be varied by changing the nozzle diameter. Efforts are currently aimed at fitting the unit for use in the field. This involved the purchase of a tripod, tribrack, and a number of other miscellaneous items. A prototype nozzle was designed and fabricated that will allow permeability measurements to be taken both in the lab on smooth rock surfaces as well as in the field on rough outcrop exposures. Efforts also have been made to obtain extensive slabs of tuff for initial laboratory tests using the gas permeameter. Plans have been made to have a block of densely welded tuff slabbed at a quarry in Grand Junction, Colorado. The block will be cut into slabs measuring approximately 0.9 m by 0.9 m by 2.5 cm. Slabbing will emphasize the anisotropy of the rock.

Calculations have been made that compare the speciation of plutonium that is predicted using two alternative thermodynamic data bases. One data base was produced with the support of the Waste Isolation Pilot Plant (WIPP) and is similar to that used in the EQ3/6 code; the second data base was produced by the NEA. The results of the calculations indicate that the latter data base is more consistent with the results of experimental solubility studies that have been carried out at LBL. The sensitivity analysis also examines the limitations that imprecisions in available experimental techniques place on efforts to validate a thermodynamic data base.

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 performed on this topic is discussed in progress report Section 2.7.5.4, Subactivity 1.6.4.1.3.

Subactivity 1.6.3.1.2 - Saturated zone flow analysis. SNL acquired the STAFF2D code to use as a module within a total-system analyzer (TSA) to calculate both flow and transport of radionuclides in the saturated zone. An initial estimate of ground-water velocities for the saturated zone was calculated using STAFF2D. Work is currently under way to develop a capability to use this code in detailed calculations of transport.

Other efforts are developing the capability for the simpler calculations needed for probabilistic total-system assessments. Linkages are being developed between the TOSPAC code and the TSA for saturated-zone analyses for the total-system analyses described in progress report Section 2.7.6.6.

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 that might be used in reallocation of performance assessment activities are discussed in progress report Section 2.7.5.4, Subactivity 1.6.4.1.3.

Subactivity 1.6.4.1.2 - Sensitivity and uncertainty analyses of ground-water travel time. Work performed under the topic is discussed in progress report Section 2.7.5.4, Subactivity 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 ground-water travel time are so closely related that this summary discusses nearly all of the work under this single heading.

The work performed for the Preclosure Ground-Water Travel Time task includes three major, interactive elements: conceptual-model development, tool development, and data analysis. A feedback mechanism among all of these elements allows continuing enhancement of each.

Conceptual-model development entails primarily identification of methods to handle the modeling of uncertainty using probability distributions (Kaplan, 1991a) and to interpret information on site processes as it becomes available. The methods proposed for use by SNL were presented at the 1991 IHLRWM Conference in Las Vegas in April, to J. Bartlett (Director, OCRWM) in May, and to the NWTRB, also in May. LBL staff have also been working on a report reviewing the current understanding of the physics of flow in the unsaturated zone and discussing the constraints that current flow models impose on the parameter space. Staff at Purdue University have been documenting conceptual alternatives to our current probability models. The alternatives include extending the point-estimate methods as a way to reduce the amount of information that must be incorporated into the initial stages of model development. Purdue is also investigating discrepancies in the correlation structure of data analysis reported in earlier studies. They have revisited the original U.S. Department of Agriculture (USDA) data and are in the process of demonstrating improved ways to look at the correlations.

Development of tools appropriate for data analysis has been very successful during the past 6 months. RS1/Explore software and programming tools, even though still in the prototype stage, have already been used extensively. A number of distributions were generated for parameters used in PA calculations for the ESSE and the TSPA. An unexpected result of the use of these tools has been the realization that this software provides a very efficient method of eliciting expert opinion. For several PA problems, experts were required to generate appropriate parameter ranges and distributions based on their own judgments. In each case, an initial distribution was obtained using RS1. Then the experts worked interactively with a PA analyst to refine the description of the uncertainty in the parameter. This was achieved by iteratively changing the visual image of the distribution until the expert was satisfied that the distribution accurately reflected his or her knowledge concerning the parameter. The tools are at the stage where we can rapidly train staff in their use. The tools can be adapted very quickly to different uses and user-specified versions can be generated.

With adequate resources, the software could be documented and entered into configuration management.

A number of activities were completed for the data-analysis element of this task. LBL has been in the process of producing a major document that addresses and documents a comparison of our understanding of geohydrologic parameters with appropriate analog sites. LBL is also working to identify data sources available from Yucca Mountain and analog sites that might be useful in modeling exercises, looking at correlation issues with these data, and investigating how fractal dimensions may be related to variograms for the purpose of future analyses of site data.

The major activity accomplished in data analysis during this time period was in conjunction with the ESSE. Two separate tasks were undertaken. One involved an evaluation of issues in geohydrology related to the performance of Yucca Mountain as a potential repository. The other was production of a geohydrologic data base with parameters and distributions that were then used in PA calculations.

The purpose of the geohydrology evaluation was to identify issues related to ground-water flow and critical to the determination of site suitability. Documentation supporting the tentative list of issues was compiled, and the list was provided to the group in charge of writing the ESSE document. Because the issues were treated only briefly in the ESSE report, SNL hopes to have the resources necessary to provide a detailed document on this subject in the near future.

The technical issues were identified using the Environmental Assessment (DOE, 1986), the conditions stated in regulatory guidelines, recommendations from expert panels and peer-review teams, and the current understanding of technical issues related to postclosure hydrology. Five issues were identified to encompass the present understanding of the geohydrology at the site that relate to qualifying and disqualifying conditions stated in the regulation. Information needed to resolve each issue was also included. The issues identified are the following:

1. What is the capability of the nonwelded and bedded tuffs above and below the potential repository to attenuate and redistribute transient moisture pulses? The technical basis for this is primarily related to the effects on our current models of the use of steady-state flow fields. The lack of water redistribution and potential concentration does not allow fast paths that could significantly influence transport to the water table.

2. Are the conceptual models used to describe fracture-matrix interactions valid? An understanding of which flow system dominates the unsaturated field and how the systems interact is obviously very important. This may be particularly true when the saturated-fracture-system contaminants flow into the stagnant pore system, resulting in retarded motion, or when fractures form internal boundaries in the flow field.

3. What effect does gas flow have on redistribution of moisture in the system? This is important in light of the concern with release of

^{14}C. It also may provide a mechanism for damping transient liquid pulses above the potential repository, since the mobility of the liquid and gas are coupled.

4. What are the hydraulic properties and hydrologic influence of the fault zones at the site? The discontinuity in the system caused by a fault may provide the most likely high-permeability path for the introduction of liquid water into the waste-package environment or the transport of nuclides in either the liquid or the gaseous phase.

5. What conditions or processes in the unsaturated zone might lead to the generation of preferential flow paths, and do they exist at the site? Composite fracture/matrix continuum models may be invalid if relatively high-velocity conditions exist within the preferential flow paths that result in transient, non-equilibrium conditions between fracture and matrix. Moreover, the answer to this question may indicate that the continuum approach may not be appropriate in the presence of preferential flow paths.

The geohydrologic-parameter distributions were generated using site and analog data and the RS1 software. A full suite of properties was provided for a four-layer hydrostratigraphy used as the basis for ESSE PA analyses. The data set was expanded and revised for a five-layer stratigraphic model used for the TSPA. This work is currently being documented, including information on data sources for Yucca Mountain and analog sites.

The data sets generated for the ESSE and TSPA have also been used to support studies of uncertainty and sensitivity in calculations of ground-water travel time (GWTT). Preliminary uncertainty and sensitivity analyses were performed for pre-waste-emplacement GWTT as defined in 10 CFR 60.113 (Kaplan, 1991b). The uncertainty analyses were performed to determine to what degree the site is likely to comply with the regulatory performance objective as a function of currently available information and to identify the circumstances under which a failure to meet that objective is possible. The sensitivity analyses were run to determine what information, if obtained during site characterization, is most likely to influence a prediction of performance with respect to the objective. The results of the analyses suggest that the expected value of a distribution of outcomes generated using a nonlinear transformation can, under certain circumstances, be an extremely poor predictor of performance against the criterion; that the dispersion in the response is, under certain conditions, a strong function of process and domain; and that the failure modes appear monotonically insensitive to all but a few input functions.

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 in this activity 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. An SLTR report outlining significant sequences of events and processes initiated by tectonic phenomena is in revision to incorporate comments resulting from scenario-screening meetings held earlier in 1991. As a result of these comments, extensive revision of the structure of the event tree is expected. Also, new elements have been added to address the potential effects on ground-water flow due to faulting extending from south of the potential repository along the trend of the Stagecoach Road fault zone and to address the possible changes that tectonic activity may induce in the high-hydraulic-gradient region to the north.

Subactivity 1.1.2.1.2 - Preliminary identification of potentially significant release scenario classes. Extensive revision of the event tree associated with basaltic volcanism has led to a report identifying potentially significant scenarios for release. Revisions were obtained during the last reporting period in conjunction with formulation of the ESSE analyses. A preliminary draft of the text for the report on the basaltic-volcanism event tree was distributed to LANL co-authors for comment and review. The report includes detailed descriptions of each of the elements within each scenario, as well as pictorial portrayals of these elements. The graphic representation is expected to be extremely important in allowing modelers to visualize the problem that must be analyzed.

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 progress report Section 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 progress report 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.) has completed SNL technical and management review and was submitted for YMP review. Summarizing work to date on the modeling of gas flow, this report includes a description of the gas-flow model, the derivation of the equations in it, and a description of its numerical implementation. Results of these calculations are incorporated in the total-system analysis described in

progress report Section 2.7.6.6. This work also addresses the coupling of a reasonable thermal model to the gas-flow model for Yucca Mountain.

Subactivity 1.1.3.1.3 - Development of a model of releases through basaltic volcanism. See progress report Section 2.7.6.6.

Subactivity 1.1.3.1.4 - Development of a model of releases through human intrusion. See progress report 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

The SCP calls for the construction of a complementary cumulative distribution function (CCDF) as the final step in the assessment of the performance of a potential repository. Although the final set of CCDFs will not be constructed for several years, the DOE has begun a process of iteratively producing CCDFs that use available information to estimate the total-system performance of a potential repository. This section reports work done toward the first in the series of iterations that will eventually produce the total-system analysis required for a license application. As described below, this work builds on previous total-system analyses and is intended to contribute not only to estimates of total-system behavior but also to model development (progress report Section 2.7.6.3) and to selection of scenario classes (progress report Section 2.7.6.1).

SNL coordinated the construction of a preliminary total-system performance assessment (TSPA) analysis. The analysis was based on information from PACE-90 (reported in progress report Section 2.7.5.2) and from the ESSE calculations. However, unlike the deterministic analyses of PACE-90, the TSPA will comprise a stochastic study where ranges in geologic, hydrologic, source term, and other parameters will be incorporated. The analysis will be documented in a report due in March 1992.

The goal of this work was to make an initial demonstration of how site data and results from detailed calculations could be abstracted for use in higher-level calculations. Because the analyses reflect our current understanding of the phenomena that may occur at the site, they will also, as a secondary goal, contribute to estimates of the site's contribution to

compliance with total-system regulations. The analyses can be considered the first of a series of preliminary total-system evaluations if the DOE elects to produce such studies periodically. The primary purpose of the exercise was, however, to demonstrate development of a tool that will be useful during the site characterization phase to better understand sensitive parameters and processes. The analyses were not comprehensive in terms of components modeled, nor were the data or models considered to be validated. The demonstration will not be adequate to allow a higher-level finding of the suitability of the site to be made. The TSPA has been coordinated with work ongoing at PNL. SNL and PNL will contrast and compare different philosophies for performing a total-system analysis. Their results will be reported separately. The geohydrology input parameters and the radionuclide source term used by SNL and PNL are the same, to allow comparison.

The TSPA analyses were constructed to produce an overall measure of system performance (such as a complementary cumulative probability distribution of radionuclide releases) from five components: geohydrologic conditions, human interference, gas flow, tectonism, and igneous intrusion resulting from basaltic volcanism. Climate change was treated as variations in ground-water infiltration rates.

The geohydrology analyses are considering flow and transport in the saturated zone; they are considering separately the matrix-dominated and fracture-dominated ground-water flow and transport processes in the unsaturated zone. The composite-porosity conceptual model for fracture-matrix interactions simulates matrix-dominated flow in the unsaturated zone. Fracture-dominated flow is modeled with discrete fracture networks and faults in an attempt to analyze the potential for fast paths to transport radionuclides at Yucca Mountain.

Human-intrusion analyses investigate direct release of radionuclides at the surface and into the aquifers underlying Yucca Mountain. Both scenarios arise from drilling operations. The surface-release problem combines the consequences of releasing all or a portion of the contents of one waste package with the occurrence probabilities of that event. The analyses of this problem are parameterized by the time of occurrence of the release. Probabilities are estimated from geometric considerations and estimates of the attractiveness of resources in the area. The saturated-zone transport problem uses the same saturated-zone calculational module developed for the geohydrology problem.

The gas-flow analysis uses travel-time distributions at various temperatures calculated by Disposal Safety Incorporated (DSI) to calculate surface releases from a source term similar to that used for the human intrusion. The source term is parameterized by the fraction of ^{14}C released from the waste. Retardation effects are included. The calculations estimate releases and a partitioning of occurrence based on failure rate of the waste packages.

The analysis of basaltic volcanism models radionuclide release due to the entrainment of waste in a dike reaching the surface. The probability that volcanism occurs within the potential repository is derived from LANL (Crowe's) work and incorporated into the CCDF. The actual entrainment and surface-release aspects are treated in a very simple manner. Chemical

interactions between volatiles and the waste, effect of the EBS, changes in water circulation, etc., are included in the formulation of this problem. The same source term used for human intrusion is used, but the range of outcomes depends on dike length, dike orientation, and the percentage of material estimated to be transported from the affected containers.

Probabilistic estimates of the releases are calculated for each of the individual components listed above. They are combined into a single estimate of probability of release as the overall product of the total-system analysis. In addition, calculations of doses at the accessible environment are done by PNL for both PNL and SNL total-system analyses.

Wingz, a commercial spreadsheet software package, has been adapted to provide graphics, data manipulation, and a front-end for a set of simple models that can be used to calculate CCDFs for a total-system performance assessment. This spreadsheet is available on PC, Macintosh, and UNIX workstation platforms. Wingz will provide a simple method for general control of data flow between the various computer programs used in assessments of total-system performance. Event models for nominal flow, human intrusion, volcanism, and tectonism have been coded. The progress to date on Wingz is reported in "Use of WINGZ Spreadsheet as an Interface to Total-System Performance Assessment" (Chambers et al.), an abstract submitted to the 1992 IHLRWM Conference in Las Vegas, Nevada, scheduled for April 12-16, 1992.

A milestone was completed with the submission of "A Simplified Radionuclide Source Term for Total System Performance Assessment" (Wilson, 1991) to YMPO. This report derives mathematical expressions for numerous features of the release of radionuclides from their original containment within a potential repository. It draws on other, more-detailed studies in an effort to include, in simplified form, the main release mechanisms. The equations it derives are useful in total-system assessments for which detailed calculations using complex computer codes are not practical.

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 progress report Section 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

Activity 1.3.1.1.1 - Synthesis and evaluation of hydrologic and environmental information needed to determine whether aquifers at the site meet the special source criteria. No progress during the reporting period; this is an out-year activity.

Activity 1.3.1.1.2 - Synthesis and evaluation of demographic and economic data needed to determine whether Class I or special sources of ground water exist. 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

Activity 1.3.2.1.1 - Synthesis and evaluation of releases of waste products to special sources 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. Factors internal and external to the program, which include delays in the processing of environmental permits, program funding levels, litigation, and study plan review, may continue to affect the program schedule.

This section presents the schedule baseline for the YMP as of March 11, 1991. More detailed schedules are maintained at the YMPO, in combination with work scopes and the dollars needed to accomplish this work.

Table 3.1 presents the summary milestones for the YMP. Figure 3.1 shows the relationship of the summary milestones to the major activities.

The schedule focuses on the early evaluation of site suitability of the Yucca Mountain site. With the delay in the start of Exploratory Studies Facility construction, DOE plans to take advantage of early surface-based tests.

Table 3.1. Summary Milestones[1].

Waste Package

Start Waste Package Advanced Conceptual Design	10/92
Start Waste Package License Application Design	6/96
Provide Engineering Barrier System Data To Waste Package License Application Design	7/98

Site

Start New Surface-Based Testing	1/92
Complete Deep Unsaturated Zone Hydrologic Hole Drilling	6/95

Repository

Complete Repository Program Plan	3/91
Start Repository Advanced Conceptual Design	10/92
Start Repository License Application Design	6/96

Regulatory

Provide Recommendation to the Director, OCRWM, on Alternative License Application Strategies for Review	8/91
Obtain Permits	12/91
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
Submit License Application to the NRC	10/01

ESF

Initiate Final ESF Title II Design	10/91
Start ESF Site Preparation	6/92
Start ESF Collar/Portal Construction	11/92
Complete ESF Shaft Connection	9/95
Start ESF In-Situ Test Phase	9/95
Complete ESF Geologic Drifting	11/97

[1] Table shows approved Program Schedule Baseline as of March 11, 1991.

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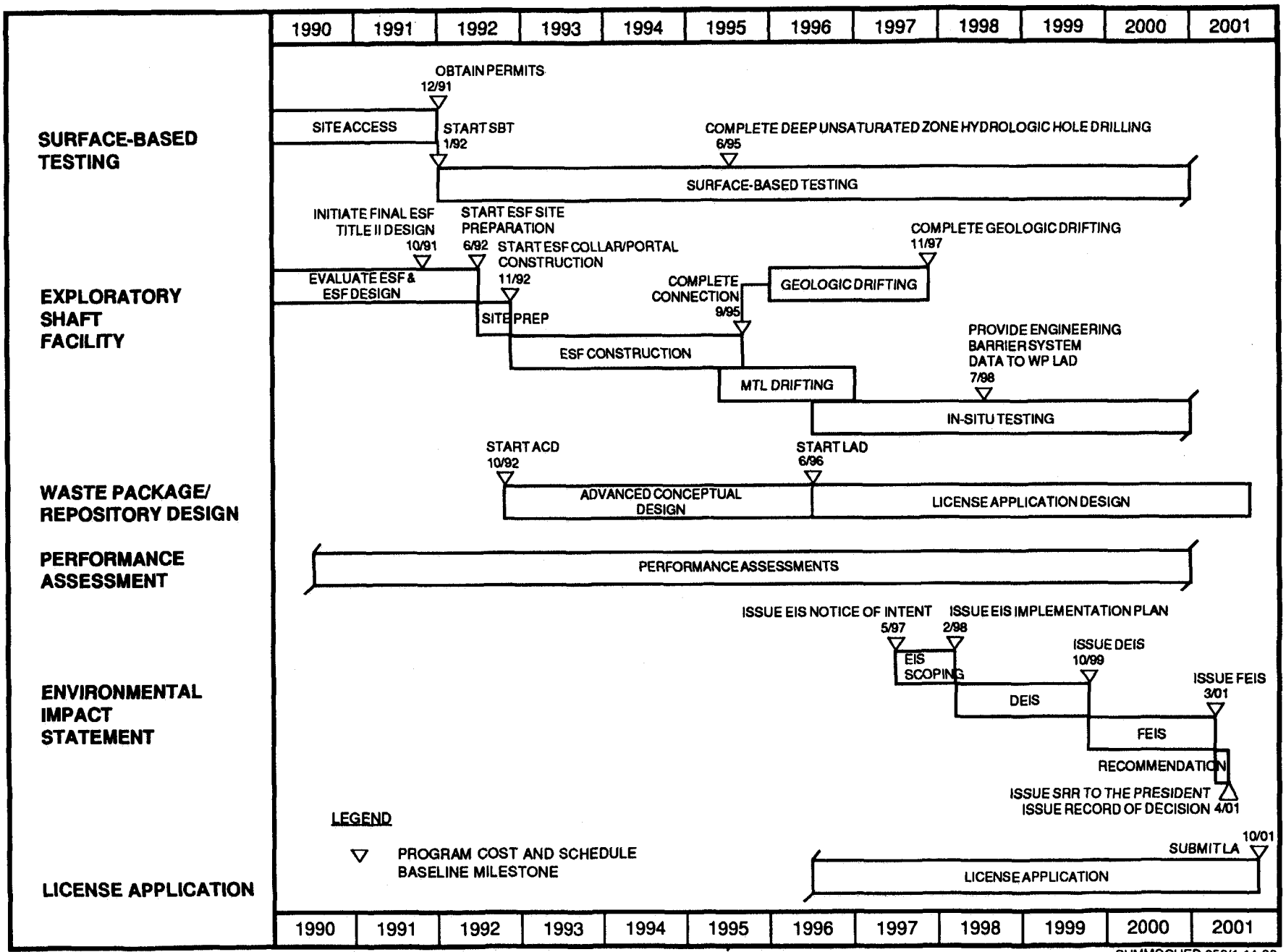

Figure 3.1. Site Characterization Summary Schedule.

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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

ACNW	Advisory Committee on Nuclear Waste
AECL	Atomic Energy of Canada Limited
AEM	Analytic Electron Microscopy
AGU	American Geophysical Union
ALTS	Apache Leap Test Site
ANL	Argonne National Laboratory
ANS	American Nuclear Society
APD	areal power density
ASTM	American Society for Testing and Materials
BLM	U.S. Bureau of Land Management
BWR	boiling water reactor
CCB	Change Control Board
CCDF	complementary cumulative distribution function
CDF	cumulative distribution function
CHRBA	Calico Hills Risk/Benefit Analysis
CSFM	commercial spent fuel
CTCN	Colloid Transport Code Nuclear
DFC	Denver Federal Center
DHLW	defense high-level waste
DIM	Design Investigation Memo
DIW	deionized water
DOE	U.S. Department of Energy
DOE/HQ	U.S. Department of Energy/Headquarters
DP	detailed technical procedure
DWPF	Defense Waste Processing Facility
EBS	engineered barrier system
ECM	Equivalent Continuum Model
EED	Equivalent Energy Density
EPPM	expected partial performance measure
EPRI	Electric Power Research Institute
EPTR	Equivalent Peak Temperature Rise
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
ET	evapotranspiration
FA	Floodplain Assessment
FSN	Fenix and Scisson of Nevada
FTIR	Fourier-Transform infrared spectroscopy
FY	fiscal year
GCP	Ground-Water Characterization Program
GOES	Geostationary Orbital Environmental Satellite
GSA	Geological Society of America
GSIS	Geoscientific Information System
GTM	gridded terrain models
GWC	gravimetric water content
GWSI	ground-water site inventory
GWTT	ground-water travel time
H&N	Holmes and Narver

HG&G	Hydrogeology and Geochemistry
HRF	Hydrologic Research Facility
IC	ion chromatograph
IDAS	Integrated Data Acquisition System
IHLRWM	International High Level Radioactive Waste Management
ILP	Implementing Line Procedures
INAA	Instrumental Neutron Activation Analysis
ISP	Individual Software Plan
LANL	Los Alamos National Laboratory
LAPD	Local Areal Power Density
LBL	Lawrence Berkeley Laboratory
LLNL	Lawrence Livermore National Laboratory
M&O	Management and Operating contractor
MPA	Mission Plan Amendment
MRS	Materials Research Society
MSIS	Management Systems Improvement Strategy
NAS	National Academy of Sciences
NCAR	National Center for Atmospheric Research
NEA	Nuclear Energy Agency
NER	New England Research, Inc.
NIST	National Institute of Standards and Technology
NMR	nuclear magnetic resonance
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NRC	U.S. Nuclear Regulatory Commission
NTS	Nevada Test Site
NWPA	Nuclear Waste Policy Act of 1982
NWPAA	Nuclear Waste Policy Amendments Act
NWTRB	Nuclear Waste Technical Review Board
OCRWM	Office of Civilian Radioactive Waste Management
OGD	Office of Geological Disposal
OIEA	Office of Institutional and External Affairs
OQA	Office of Quality Assurance
ORNL	Oak Ridge National Laboratory
OSTI	Office of Scientific Technical Information
PAC	potentially adverse condition
PACE	Performance Assessment Calculational Exercises
PDM	Problem Definition Memo
PI	Principal Investigator
PMF	probable maximum flood
PNL	Pacific Northwest Laboratory
PR	Site Characterization Progress Report
PWR	pressurized water reactor
QA	quality assurance
QAPD	Quality Assurance Program Description
QARD	Quality Assurance Requirements Document
REECo	Reynolds Electrical and Engineering Co.
RIB	Reference Information Base
RSF	relative sensitivity factors
RSN	Raytheon Services Nevada
SAIC	Science Applications International Corporation

SANL	DOE Operations Office/San Francisco
SCA	Site Characterization Analysis
SCP	Site Characterization Plan
SCPB	Site Characterization Program Baseline
SCP/CD	Site Characterization Plan/Consultation Draft
SDRD	Subsystem Design Requirements Document
SEM	scanning electron microscope
SEMP	Systems Engineering Management Plan
SGBSN	Southern Great Basin Seismic Network
SG&G	Structural Geology and Geoengineering
SMF	Sample Management Facility
SIP	Scientific Investigation Plan
SKB	Swedish Nuclear Fuel Supply Company
SNL	Sandia National Laboratories
SOC	Sample Overview Committee
SOF	Statement of Findings
SP	Socioeconomic Plan
SPANS	Spatial Analysis System
SPOC	submersible pressure outflow cell
SQAP	Software Quality Assurance Plan
SSSA	Soil Science Society of America
TBM	tunnel boring machine
TDR	time-domain reflectometry
TEM	transmission electron microscopy
TGA	thermogravimetric analysis
TL	thermoluminescence
T&MSS	Technical and Management Support Services
TPO	Technical Project Officer
T&S	Transportation and Systems
TSA	Total Systems Analyzer
TU	tritium units
TVA	Tennessee Valley Authority
UNE	underground nuclear explosion
UNLV	University of Nevada/Las Vegas
UNM	University of New Mexico
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
USNSN	U.S. National Seismic Network
UZ	unsaturated zone
VSP	vertical seismic profiling
WFCR	Waste Form Characteristics Report
WIPP	Waste Isolation Pilot Plant
WMSR	Waste Management System Requirements
WSNSO	Weather Service Nuclear Support Office
WVDP	West Valley Demonstration Project
XRD	x-ray diffraction
XRF	x-ray fluorescence
YMP	Yucca Mountain Site Characterization Project
YMPO	Yucca Mountain Site Characterization Project Office
YMQAD	Yucca Mountain Quality Assurance