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Site Characterization Progress Report: Yucca Mountain, Nevada

October 1, 1990 – March 31, 1991

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DISCLAIMER

FOREWORD

In accordance with the requirements of Section 113(b)(3) of the Nuclear Waste Policy Act of 1982 (NWPA), as amended, the U.S. Department of Energy (DOE) has prepared this report on the progress of site characterization activities at Yucca Mountain in southern Nevada from October 1, 1990, through March 31, 1991. This progress report is the fourth of a series of reports that are issued at intervals of approximately six months during the site characterization process.

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EXECUTIVE SUMMARY

In accordance with the requirements of Section 113(b)(3) of the Nuclear Waste Policy Act of 1982, as amended (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 October 1, 1990, through March 31, 1991. This report is the fourth in a series of reports that are issued at intervals of approximately six months during site characterization. The report covers a number of initiatives to improve the effectiveness of the site characterization program, and covers continued efforts related to preparatory activities, Study Plans, and performance assessment.

The Office of Civilian Radioactive Waste Management (OCRWM) realized substantive progress in many areas during the reporting period. What follows are brief synopses of some of the major efforts either begun, continued, or completed during this time.

The OCRWM successfully completed a qualification audit of its Quality Assurance (QA) program. This was an essential prerequisite to the conduct of new site characterization activities. Qualification of the DOE's QA program is a clear indication of its commitment to conduct the site characterization program according to sound technical principles in conjunction with appropriate QA procedures.

Approximately one-third of the study programs in DOE's Site Characterization Plan (SCP) for Yucca Mountain (34 studies out of 106) are ongoing. These ongoing non-surface-disturbing site characterization activities continued through the reporting period. These activities included meteorological monitoring, streamflow monitoring, monitoring of seismicity, and hydrologic monitoring in existing boreholes.

Performance assessment made significant progress in three high priority activities. In the first activity, calculations were completed for the performance assessment calculations exercises (PACE-90). Although the results of PACE-90 exercises cannot be considered reliable predictions for Yucca Mountain, the process yielded a number of insights that will be important for future data collection and analysis. With the conclusion of the PACE-90 calculations, the multiparticipant group turned to a new high-priority initiative, the early evaluation of site suitability. They defined calculations whose solutions will contribute to increased understanding of the site's ability to meet the DOE siting guidelines. In the third high-priority task, several detailed calculations were completed in support of the design of the Exploratory Studies Facility (ESF) (formerly the Exploratory Shaft Facility). In addition to these three efforts, performance assessment made significant progress in implementing the issue resolution strategies in the SCP. The resolution of the ground-water travel time issue was addressed through the development of a method for examining regulatory compliance on a rigorous probabilistic basis.

A readiness review was successfully completed in January for those surface-disturbing site characterization activities that will be initiated as soon as the necessary environmental permits are obtained. Also, the DOE was successful in litigation related to obtaining those permits, although Nevada's

processing of the permit applications had not been implemented by the end of the reporting period.

As a result of comments on the program and through the initiative of the Secretary of Energy (DOE, 1989), a major effort to develop and implement a methodology for early site suitability evaluation (ESSE) was initiated. Plans for the ESSE direct a core team to (1) develop a general approach to the evaluation of site suitability, and (2) make an early assessment of the suitability (or non-suitability) of the Yucca Mountain site for development as a repository. Related efforts of the Test Prioritization Task were completed and will provide input to the ESSE task.

The Calico Hills Risk/Benefit Assessment (CHRBA) was completed. The major recommendation of the CHRBA was that the ESF design should maintain the flexibility to accommodate extensive drifting in the Calico Hills nonwelded unit. The CHRBA results provided input to the ESF Alternatives Study (ESFAS). A report on the preliminary findings of the ESFAS was issued. On the basis of the documentation and the briefings provided to him, the OCRWM Director requested that the Yucca Mountain Site Characterization Project Office (YMPO) proceed with a design study focusing on the favorable features of the highest-ranked options identified in the ESFAS. This study will provide the information needed to support a final OCRWM decision on ESF configuration prior to start of Title II design, scheduled for October 1, 1991.

Implementation of the Management Systems Improvement Strategy (MSIS) continued with the implementation of a functional analysis of the program. The MSIS is expected to enhance the existing framework of the program, using the principles of systems engineering, to facilitate successful accomplishment of the program's mission.

A Management and Operations (M&O) contract was awarded to a team led by TRW Environmental Safety Systems, Inc. The M&O contractor will provide systems engineering, design, and management support and enhance integration across the OCRWM program.

Progress continued toward producing the 106 Study Plans needed for site characterization, especially those for ongoing activities. Study Plans describe the activities to be conducted in greater detail than the SCP provides. They are the link between the studies described in the SCP and the technical procedures that will be used in the field and laboratory. By the end of the reporting period, 21 Study Plans had been transmitted to the U.S. Nuclear Regulatory Commission (NRC) for review and several more were nearly completed. Well over half of all the Study Plans are in preparation or review.

Work continued on developing responses to comments on the SCP, Study Plans, and other aspects of the OCRWM program. The DOE is committed to responding to all comments received on the OCRWM program. The DOE released response packages for SCP comments submitted by the California Energy Commission, Lincoln County Commissioners, U.S. Environmental Protection Agency (EPA), Edison Electric Institute (EEI), U.S. Department of Interior, the State of Nevada (ESF comments), and the NRC. The DOE is continuing extensive efforts to complete responses to the State of Nevada's remaining comments on the SCP.

A peer review of plans for characterization of the unsaturated zone hydrology at Yucca Mountain using experts from outside the OCRWM program was nearing completion by the end of the reporting period. Another peer review using outside experts was directed at assessing the feasibility of seismic methods for site characterization. These peer reviews will provide valuable input for refining planned hydrological and geophysical site characterization activities.

The final report for the Alternatives to License Application Strategy (ATLAS) task was completed. This study focused on identifying alternative strategies which might shorten the schedule for the potential repository, while still fulfilling regulatory requirements for public health and safety. A series of workshops on strategic principles was completed. The outcome of these public meetings is being incorporated in preliminary drafts of a Mission Plan Amendment, which should be issued for comment later in 1991. Many of the potential alternatives identified by ATLAS are being considered in these strategic principles workshops.

Throughout the reporting period, numerous interactions were conducted with the NRC, Nuclear Waste Technical Review Board (NWTRB), Advisory Committee on Nuclear Waste (ACNW), Congress, State of Nevada, and other affected parties and oversight groups. These interactions covered virtually all aspects of the OCRWM program. Specific areas of interaction included briefings on the ESFAS, CHRBA, ESSE, and test prioritization activities; QA; seismic hazards; volcanic hazards; and radionuclide retardation.

The OCRWM is continuing to carry out an international program in cooperation with a number of countries and international organizations. These cooperative efforts cover a wide variety of activities ranging from technology development for site characterization and materials testing through public education concerning radioactive waste management.

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 October 1, 1990, through March 31, 1991. This report is the fourth in a series of reports that are issued at intervals of approximately six months during site characterization. The first, second, and third progress reports were issued in March 1990, November 1990, and April 1991, respectively.

The DOE's plans for site characterization are described in the SCP for the Yucca Mountain site (DOE, 1988a). The SCP has been reviewed by the NRC, State of Nevada, affected units of local government, other interested parties, and public. Responses to comments by these parties have either been issued or are in preparation. More detailed information on plans for site characterization is being presented in Study Plans for the various site characterization studies and their component activities. Further detail on responses to comments on the SCP and Study Plans is presented in Chapter 2 of this report.

The progress report presents short 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 receipt of performance-assessment results; and any changes that occur in response to external comments.

The progress report conveys information 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 controlled through DOE change-control procedures.

The progress report consists of two main sections: (1) an introductory section, and (2) a section on the status of site characterization activities, which generally follows the format of SCP Chapter 8. An appendix containing the current summary schedule for the repository program is included. The documents cited in the text are available for inspection at DOE public reading rooms in Washington, D.C., and the State of Nevada. They can also be obtained through the DOE Office of Scientific and Technical Information at Oak Ridge, Tennessee. A list of acronyms is also provided at the back of this report.

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 the only potential repository site to be characterized at this time. The DOE will conduct a program of detailed investigations and suitability evaluations at the Yucca Mountain site to determine whether it will be suitable for development of a repository. The plans, activities, and results of this program will be reviewed by the State of Nevada, NRC, NWTRB, and others external to the program.

If the site is found to be suitable, then the DOE will have to demonstrate to the NRC that the potential repository system, including the site, meets the applicable regulations governing licensing. If at any time scientific investigations support 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.

1.2.1 Site Characterization

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 potential repository; to acquire data necessary to develop more advanced designs for the potential repository and the waste package; to conduct the quantitative evaluations or performance assessments needed to evaluate site suitability; and to demonstrate to the NRC that a repository at the Yucca Mountain site will comply with their requirements for licensing. The activities planned for site characterization consist of surface-based studies, underground tests and studies conducted at the depth of the potential repository in an ESF, laboratory tests, and modeling. The performance assessments will determine (1) whether a 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; tests of, and experiments with, rock and water samples; geophysical surveys; seismic monitoring; and geologic mapping. If the necessary permits are obtained from the State of Nevada, new surface-based activities are scheduled to start in early 1992 and scientific investigations in the ESF are scheduled to begin in 1993. 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 in the year 2001. However, if the site is found to be suitable, selected surface-based and underground tests will

continue, and new testing and monitoring will be initiated as part of a performance confirmation program that is required to begin during site characterization. If a repository is developed at Yucca Mountain, the performance confirmation program will continue until such time as there is adequate assurance that the repository is performing as expected, and the NRC gives its approval to permanently close the repository.

Chapter 2 of this report describes in detail the accomplishments of the site characterization program during the reporting period.

1.2.2 Programmatic Developments

The OCRWM program realized substantive progress in several areas during the reporting period. A major accomplishment was the successful completion of the qualification audit for the OCRWM QA Program. The completion of the qualification audit is evidence of the DOE's commitment to conduct site characterization according to appropriate standards that will ensure the results of site characterization can be used in licensing proceedings, should the Yucca Mountain site be found suitable for repository development.

Efforts towards starting new surface-disturbing site characterization activities included the successful completion of a readiness review in January for two activities. These activities, known informally as Midway Valley trenching and calcite-silica trenching, are described in Study Plans 8.3.1.17.4.2, Location and Recency of Faulting Near Prospective Surface Facilities, and 8.3.1.5.2.1, Quaternary Regional Hydrology. The start of these activities is now prevented by Nevada's delays in processing environmental permit applications.

Progress was made during the reporting period towards obtaining environmental permits from the State of Nevada. The U.S. Supreme Court refused to hear Nevada's appeal of a U.S. Circuit Court decision that the Nevada legislature's actions (Nevada Assembly Bill 222, Assembly Joint Resolution 4, and Assembly Joint Resolution 6) did not constitute a valid notice of disapproval of the Yucca Mountain site under the NWPA. Resolution of this case allowed progress on the DOE's suit in the U.S. District Court to compel Nevada to consider three of DOE's permit applications. Nevada finally agreed to process DOE's permit applications within certain specified time limits as part of a negotiated settlement of the U.S. District Court case. The status of environmental permitting is covered in more detail in Chapter 2 of this report.

Although Nevada has tentatively agreed to process DOE's first set of permit applications, it is not clear that the State will not impede processing of subsequent permit applications. As a result of Nevada's continued opposition to site characterization, the DOE has sought a legislative solution to the permitting problem. This proposed legislation was originally included in the National Energy Strategy, released in late February.

Another major effort during the reporting period, in response to comments on the program and the Secretary of Energy (DOE, 1989), is the Early Site Suitability Evaluation (ESSE). Plans for the ESSE direct a core team to (1) develop a general approach to the evaluation of site suitability; and 2) make

an early assessment of the suitability or non-suitability of the Yucca Mountain site for development as a repository, using available data collected subsequent to the Environmental Assessment (DOE, 1986), in accordance with the DOE siting guidelines in 10 CFR Part 960. Presuming the site is not found unsuitable during this early evaluation, additional interim suitability determinations will be performed iteratively, at appropriate times, throughout the process of site characterization. The ESSE effort is described in more detail in Chapter 2 of this report.

DOE completed two workshops on strategic principles during the reporting period. These workshops, open to the public, were held in Salt Lake City, Utah, and Washington, D.C. A third workshop will be held in Denver, Colorado, on April 3-4, 1991. Their purposes were to elicit the views of interested and affected parties and provide a forum for discussion of the principles that will guide DOE's decisions and actions in managing the complex repository program.

The results of the strategic principles workshops have provided input to a preliminary draft Mission Plan Amendment (MPA) expected to be issued for comment later in 1991. In addition to describing OCRWM's strategic principles, the MPA describes the major technical and institutional changes to the program since the 1987 amendment of the NWPA. The MPA will also provide a more comprehensive discussion of initiatives resulting from the Secretary of Energy's reassessment of the program (DOE, 1989).

As requested by the Secretary of Energy, in February the DOE developed an initial response to the recommendations presented in "Rethinking High-Level Radioactive Waste Disposal," a position statement of the National Research Council's Board on Radioactive Waste Management (BRWM) on Geosciences, Environment, and Resources which was issued in July 1990. This initial response indicates that the DOE agrees with many of the recommendations in the BRWM report. In fact, the recent restructuring of the OCRWM program, prior to release of the BRWM report, has embodied initiatives that are in accord with the findings in the report.

Implementation of the MSIS continued through the reporting period. The primary activity in this area was a functional analysis of the physical and programmatic systems of the OCRWM program. This functional analysis traces the requirements placed on the program (e.g., federal and state codes and statutes, DOE Orders, internal constraints, etc.) through the structure of the OCRWM organization and the physical components of the conceptual repository design to ensure that all the functions of these systems are configured to address the requirements in an orderly and efficient manner.

Another accomplishment expected to improve the efficiency of the program was the award of a Management and Operations (M&O) contract to a team led by TRW Environmental Safety Systems, Inc. The M&O contractor will provide systems engineering, design, and management support to the DOE. The M&O contractor is expected to improve integration within and between the repository, monitored retrievable storage, and transportation programs.

The OCRWM is continuing to carry out an international program in cooperation with a number of countries and international organizations. These cooperative efforts cover a wide variety of activities ranging from technology

development for site characterization and materials testing through efforts in the area of public education regarding radioactive waste management. Selected activities related to site characterization are described below.

The Stripa project (Phase III) is concluding in 1991 and final project reports and technology transfer activities are being prepared. Discussions on the merit of conducting follow-on studies developed from the Stripa work are being held. The Pocos de Caldas Project (a natural analog study) in Brazil has also been completed and final summary reports are being prepared. The OCRWM program has joined the Alligator River natural analog project, an ongoing multinational study of a uranium deposit in Australia. Discussions have been held on the content of Phase II of the INTRAVAL project. This project involves the use of data from field, laboratory and natural analog studies for model validation exercises. A number of test cases for OCRWM participation are planned in Phase II.

The OCRWM has been negotiating the technical content and support level for two bilateral agreements involving cooperative field and laboratory testing. The project agreement with Switzerland is about to be signed and implemented for a five-year testing program involving underground testing and modeling of two-phase flow in fractured rocks, laboratory sorption testing, and development of improved techniques for seismic imaging and fluid logging. The second of these bilateral agreements is with Canada and involves field and laboratory tracer tests, calibration of an in situ hydrochemical tool, improvements to in situ stress measurement instrumentation, a natural analog study of a buried uranium deposit at Cigar Lake, development of a dissolution model for spent fuel, and a verification effort on the Canadian total system release code. The period for the bilateral testing agreement with Canada is also five years.

Since the issuance of the Section 175 Report (DOE, 1988b), the OCRWM has developed a Socioeconomic Plan (SP) 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. A consultation draft of the SP was issued in April 1990, and comments were received from affected parties. The OCRWM met with the commentors to resolve and clarify comments and issued a revised draft of the SP in April 1991. The April 1991 draft SP will be submitted to affected parties for review.

Two counties were granted affected party status, as provided in the NWPA, during the reporting period. These counties were Esmeralda County, Nevada, and Inyo County, California. Inyo County is the first county outside the State of Nevada to be granted affected party status. This action was taken in response to a decision of the U.S. Court of Appeals for the Ninth Circuit, reversing determinations by DOE denying affected party status to the two counties.

2.0 STATUS OF SITE CHARACTERIZATION

2.1 PREPARATORY ACTIVITIES

2.1.1 Quality Assurance Program

During the reporting period, the OCRWM QA Program was audited and qualified for initial scientific investigation activities. These activities include Midway Valley trenching and calcite-silica studies. Several recommended actions identified in the audit report are being incorporated into the QA program and will be implemented before the program is qualified for further site characterization work.

A qualification audit consists of verification that proper procedural controls are in place to fulfill the QA requirements of the NRC's regulations in 10 CFR 60 Subpart G. Qualification of the QA program for these two activities was based upon an audit performed at both the YMPO and OCRWM Headquarters during October 1990. The audit team was comprised of OCRWM personnel from Headquarters and the YMPO. The audit was observed by representatives from the NRC, Nye County, Clark County, the State of Nevada, and the EEI.

Additional audits conducted during the reporting period included the QA programs of Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL), the YMPO Technical and Management Support Services contractor (T&MSS), Reynolds Electrical and Engineering Company (REECo), and KOH Systems.

As a result of these and previous audits, and after a review of the QA Program Description documents, all YMPO contractor QA programs were accepted by the OCRWM and NRC with the exception of LANL and T&MSS. NRC letters of acceptance are pending on LANL and T&MSS. Full acceptance of YMPO contractor QA programs will require resolution of issues on procurement, software QA, and personnel qualification.

OCRWM Headquarters conducted surveillances of preparation of technical documents; the baseline change control process; indoctrination, training, and qualification of personnel; QA record control; and distribution of QA program documents. The YMPO conducted internal surveillances of training, technical baseline and surface-based testing and external surveillances of LANL, LLNL, Raytheon Services Nevada (RSN), T&MSS, Sandia National Laboratories (SNL), and the U.S. Geological Survey (USGS).

Revisions to the Quality Assurance Requirements Document (QARD) and the Quality Assurance Program Description (QAPD) were issued during the reporting period. The majority of the changes to the documents related to the reorganization of the OCRWM. These changes were conditionally accepted by the NRC. Final acceptance of the documents will require resolution of questions pertaining to the OCRWM's method of handling allegations, analyzing root cause of deficiencies, maintaining records, reviewing procurement documents, controlling software, and submitting QA programs to the NRC.

Further revisions to the QARD and QAPD have been initiated to resolve NRC questions, incorporate the new requirements of DOE System 80 as provided for in the U.S. Privacy Act (DOE, 1990a), and to merge both documents into a single QA program document.

Work was initiated to consolidate QA procedures used at the YMPO and OCRWM Headquarters into a single set of procedures. It is anticipated that the initial phase of this consolidation effort will take about six months to complete.

A need was recognized for providing assistance to YMP participants in understanding the application of the QA grading process and for entertaining suggestions to improve the development of the QA grading and software QA processes. As a result, a series of QA workshops were held during the reporting period to address issues relating to the application of software QA requirements and QA during scientific research. Workshop participants included senior scientists, DOE and YMPO contractor management, QA personnel, software developers and users, and technical specialists. Sessions were planned and structured to promote a better understanding of the issues involved, to foster more effective implementation of the QA program, and to propose solutions for improvements to the QA program.

Throughout the reporting period, the OCRWM actively engaged in consultations with the NRC to discuss QA items. To ensure that the NRC is kept informed of the status of the OCRWM's QA Program, ongoing bimonthly QA meetings are held. These meetings provide a forum for the NRC, DOE, EEI, 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. Two such meetings were held during the reporting period.

2.1.2 Exploratory Studies Facility Design and Construction

A preliminary report of the ESFAS was completed in December 1990. This report, entitled "Findings of the ESF Alternatives Study" (Stevens and Costin, 1991), provided an overall ranking of the 34 identified ESF configurations at the level of an executive summary. Based on several YMP recommendations, the highest-ranked configuration, two accesses by ramps and capability to access the Calico Hills unit (as recommended by the CHRBA) was enhanced by adding additional highly-ranked features such as an optional shaft, and relocation of the main test level area to the north end of the potential repository block. The new ESF configuration, while not final, is presently being referred to as the "Reference Design Concept" (RDC). A design study was initiated in February, using the RDC, which focuses on the favorable features of the highest-ranked ESF options, to ensure adequate design flexibility to support a final selection to be made prior to the start of Title II design.

Trade studies are presently underway for determining sizes for conveyers, ramps, shafts and fans, muck pile location and area sizing, portal siting, transportation, and ventilation. In addition, general arrangements and specifications are being prepared for the surface and sub-surface facilities. Revisions to the Design Summary Report are currently ongoing to incorporate the new ESF RDC.

In addition, a plan (DOE, 1991a) has been prepared and baselined in response to an OCRWM request to develop a phased approach to the ESF design development and implementation. This plan describes how the ESF design, construction, and testing activities will be conducted using a phased approach.

The new Architect/Engineer (A/E) organization, RSN, has completed its transition and is providing the technical support for the Design Study.

The Yucca Mountain Site Characterization Program Baseline (SCPB) was released in February. The Systems Engineering Management Plan (SEMP), YMP Site Characterization Project Design Plan (SCPDP), Yucca Mountain Mined Geological Disposal System Requirements, Yucca Mountain Mined Geological System Repository Design Requirements, Yucca Mountain Mined Geological Disposal System (MGDS) Description, Yucca Mountain MGDS ESF Design Requirements (ESFDR), and the ESF Plan are presently under Change Control Board (CCB) control. The A/E is revising the General Arrangements and the Title I Design Summary Report based on the current RDC configuration.

The Integrated Data System (IDS) Requirements Document was revised based on the technical review comments. The IDS designer began preparations for the restart of IDS design. A draft IDS Engineering Plan is now being prepared. The IDS design and implementation strategy is being developed in parallel with the Plan for a Phased Approach to ESF Design and Implementation.

2.1.2.1 ESF Alternatives Study

During the reporting period, work continued and a preliminary report on the ESFAS was completed as the expert panels continued to evaluate the 34 identified options. Scores and weighting factors were established and used in the decision-aiding methodology to rank each option. In December 1990, an overall ranking of options, based on the best estimate judgments of the various expert panels was presented to the YMP in a preliminary report (Stevens and Costin, 1991).

The report underwent a YMPO management review and was resubmitted for YMPO acceptance on January 10, 1991. The results of the ESFAS as identified in the findings report were presented to the OCRWM Director in a briefing on January 14, 1991. As a follow-up to this briefing, the findings report was officially transmitted to the OCRWM Director on January 23, 1991, together with several YMPO recommendations which might enhance the top-ranked options. On the basis of the documentation and the briefing provided to him, the OCRWM Director requested that the YMP proceed with a design study focusing on the favorable features of the highest-ranked options. This study will provide the information needed to support a final OCRWM decision on ESF configuration prior to start of Title II design. This design study is currently being conducted by RSN.

Important meetings with the NWTRB and the NRC with respect to ESFAS are discussed in Section 2.1.7.

2.1.3 OCRWM Initiatives and Surface-Based and Underground Testing Programs

2.1.3.1 Alternatives to License Application Strategy (ATLAS) Task

The final report for the ATLAS study was completed by the Office of Geologic Disposal/YMPO and delivered to DOE/HQ on October 18, 1990 (DOE, 1990b). The study was begun in February 1990 at the request of DOE/HQ in fulfillment of an initiative by the Secretary of Energy in a report to Congress (DOE, 1989) and focused on alternative licensing strategies which might shorten the schedule for the potential repository.

Alternatives examined by the ATLAS study were not limited to those meeting existing laws and regulations. Some of the ideas elicited suggested changes to existing laws and regulations applicable to the site characterization and licensing process that may reduce regulatory or technical uncertainties. The study focused on identifying and evaluating alternative strategies with the potential to shorten the repository schedule by more than one year, while still fulfilling regulatory requirements for public health and safety. The one-year criterion was chosen because it was both significant and within the accuracy of analytical resources available to the effort, given a short schedule for completion.

The evaluation process focused on delineation of beneficial ideas from those of uncertain benefit or feasibility. All recommendations assumed a suitable site. Two time-phased recommendations, each with various options, reflected (1) the current "pre-permit" period (Focus on Near-Term Evaluations, Licensing Organization, and Planning Strategies), and (2) the site characterization period (Evaluate Contingencies in Site Characterization and Construction). Table 1 of the ATLAS report (DOE, 1990b) summarizes the options under each recommendation.

The ideas and recommendations contained in the ATLAS report were used, along with many other resources, as part of an OCRWM effort to develop a set of programmatic strategic principles. Elicitation of ideas from sources external to the program are also part of this process. The strategic principles that result will be discussed in a new OCRWM Mission Plan Amendment currently in preparation.

2.1.3.2 Testing Prioritization Task (TPT)

The TPT issued its final report on March 1, 1991 (DOE, 1991b). The TPT accomplished its analysis and made recommendations on "tests" (e.g., at the SCP Study Plan and activity level, or multiples of these) that could be conducted early during site characterization and could have benefit in detecting any unsuitable site conditions. For this analysis, the TPT addressed only postclosure testing and measured the importance of tests in terms of reducing curies that potentially could be released to the accessible environment. Future analysis and consideration of the results and methods of the TPT will be considered under the ESSE task.

2.1.3.3 Risk/Benefit Analysis of Alternative Strategies for Characterizing the Calico Hills Unit at Yucca Mountain

The need for a risk/benefit analysis of alternative strategies for characterizing the Calico Hills nonwelded tuff hydrologic unit at Yucca Mountain resulted from NRC objection 2 to the SCP Consultation Draft (SCP/CD). The objection was lifted on the conditions that this risk/benefit analysis would be performed and that the NRC staff would be consulted before the results of the analysis were implemented. The DOE presented the status of the CHRBA in meetings with the NWTRB and the NRC on October 11 and 12, 1990, respectively.

In January 1991, a record memorandum was completed to document the results of the CHRBA (DOE, 1991, in preparation). The record memorandum includes a summary of the types of data that would be needed from the Calico Hills nonwelded unit, the applicable testing techniques, eight alternative testing strategies, and two decision-aiding methodologies that were developed to evaluate each testing strategy. The testing strategies are conceptual and were developed to encompass a range of approaches to characterizing the Calico Hills nonwelded unit.

The principal recommendation of the CHRBA, provided to the ESFAS, is to maintain the capability for extensive drifting to characterize the Calico Hills nonwelded unit within the potential repository block. This recommendation is based on the following conclusions of the CHRBA: (1) the potential impacts from characterization of the Calico Hills nonwelded unit on postclosure aqueous releases from the total system are expected to be low, and (2) testing strategies that include extensive underground exploration within or near the repository block provide a significant increase in scientific confidence in the performance of the Calico Hills nonwelded unit as a natural barrier to radionuclide transport. The report also recommends that planning for testing facilities in the Calico Hills nonwelded unit should focus on providing data as early as is practicable on those geologic features identified in the report. These features include fault zones within and bounding the potential repository block, the major stratigraphic facies of the Calico Hills nonwelded unit, unknown features (such as perched water), permeability contrasts, hydrochemistry, and similar rock characteristics outside the block where more aggressive testing could be conducted within the repository block.

A final commitment to full excavation in the Calico Hills nonwelded unit is not currently required because future understanding of data required for site characterization may indicate that the full amount of drifting is not necessary.

The results of the CHRBA were presented to the NRC on January 29-31, 1991. A similar summary of the results of the CHRBA was presented to the NWTRB on March 6, 1991.

2.1.3.4 Early Site Suitability Evaluation (ESSE)

An early focus on the evaluation of site suitability was advocated in comments on the program and proposed in the Secretary of Energy's Report to

Congress on Reassessment of the Civilian Radioactive Waste Management Program (DOE, 1989).

Consideration of the Secretary's proposal led to the conclusion that compliance with the NWPA and the General Guidelines (10 CFR Part 960) would require two levels of evaluation of site suitability: early evaluations that focus on conditions that would make the site unsuitable, and comprehensive evaluations of suitability that ultimately lead to a decision to recommend a site for development as a repository. The types of information or data needed for the latter comprehensive evaluation are those described in the SCP (DOE, 1988a).

The development and implementation of an approach to ESSE was initiated in October 1990. This approach was defined by the OCRWM Director in December 1990 (Bartlett memorandum, 1990), by direction to prepare and implement a plan covering the following actions:

1. Development of a general DOE approach to the evaluation of site suitability. This approach will 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 approach developed under item 1 above. This assessment should include an evaluation of potential disqualifying features and conditions at the site.

An activity plan (DOE, 1991c) and an implementation plan (T&MSS, 1991) were prepared and approved to cover this task.

The ESSE task was implemented by appointment of a core team composed of technical experts in a variety of disciplines. After their selection and qualification training, the core team began addressing the two aspects of the ESSE task.

Initial direction, pending the final development of the site suitability evaluation method, was to (1) address each of the system and technical guidelines of 10 CFR Part 960, both postclosure and preclosure; (2) compare the findings made for Qualifying and Disqualifying Conditions in the Yucca Mountain site Environmental Assessment (DOE, 1986) with the findings that might currently be made considering any additional information that has been developed in the interim; and (3) assess whether any positive findings have become negative or whether the level of any findings should be changed. Positive higher-level findings may indicate a sufficiency of information (suitability) for a particular condition. A negative higher-level finding may indicate that the site is unsuitable. If higher-level findings cannot be made, the core team was instructed to identify the additional data or information that is needed to make them.

The date for completion of a peer-reviewed report of the ESSE task was set by the implementation plan as early 1992.

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 also been completed.

2.1.4.2 Compliance with State Environmental Requirements

On December 26, 1989, the State of Nevada returned, without processing, the following permit applications to the YMPO:

Air Quality Permit for Surface Disturbance - required before disturbing more than 20 acres of land.

Underground Injection Control (UIC) Permit - required before injecting tracers into hydrologic test wells.

Water Appropriation Permit - required before withdrawal of groundwater.

The State contended that there was no need to process the applications because Assembly Bill No. 222 prohibited the storage of high-level radioactive waste in Nevada.

On January 5, 1990, the State of Nevada filed suit against DOE in the U.S. Court of Appeals for the Ninth Circuit, arguing that actions by the Nevada State Legislature had effectively vetoed the site under Section 116 of the NWPA, and raising constitutional challenges. On January 25, 1990, the DOE, thereafter, filed suit against the State of Nevada in the U.S. District Court at Las Vegas, Nevada, requesting an order that the State act on the DOE permits to remove obstacles to continuing site characterization activities, including the issuance of environmental permits. In September 1990, the U.S. Court of Appeals ruled on the Nevada suit in favor of the DOE. The State of Nevada subsequently petitioned the U.S. Supreme Court to review that decision. The DOE suit against the State of Nevada was stayed until a final decision was rendered by the Supreme Court. On March 4, 1991, the Supreme Court denied the State's certiorari petition. On March 20, 1991, in the case DOE against Nevada, the Federal District Court ordered that a stipulation be prepared in 30 days between both parties to establish the conditions under which the State would process the applications. The case was continued until July 17, 1991, to allow the State to expeditiously process the permit applications in accordance with State law.

On September 2, 1990, the DOE refiled the permit applications following the U.S. Court of Appeals decision. The State of Nevada returned the air quality and UIC permit applications pending the State's appeal to the Supreme Court. After the U.S. Supreme Court denied the State's petition, the State wrote a letter to the DOE on March 12, 1991, explaining that the applications would be processed. As a result of this letter and the District Court proceedings, in which the State said that the applications would be processed, the DOE refiled the air quality and UIC permit applications on March 20, 1991.

The State is expected to also begin processing the water appropriation permit application.

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.

If the request is for an area for which the YMP has previously received permission to operate, the permitting document is checked to ensure that the participant activity will comply with any terms or conditions stipulated by the document. If the activity will comply, permission for access is given; if not, action is started with the permitting agency to modify the agreement.

If the request is for an area for which the YMP has not previously received permission to operate, action is started with the agency controlling the land to obtain a permit, right-of-way, or other access document as required.

Nineteen participant requests to initiate new site characterization activities were processed during the period. Sixteen of these requests have been completed and access authorization granted. The remaining three have been partially completed. These requests have resulted in the following: 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; a special use permit from the U.S. Fish and Wildlife Service for three seismic stations in the Desert National Wildlife Refuge; a special use permit from the National Park Service (NPS) for a seismic station in the Lake Mead National Recreation Area; applications for three rights-of-way with the Ely District BLM office for seismic stations; applications for two rights-of-way with the Barstow Resource Area BLM office for seismic stations; a special use permit from the NPS for eight seismic stations in the Death Valley National Monument; and an access request to the USAF/DOE Liaison Office for seven seismic stations on the Nellis Air Force Base Range.

2.1.6 Public Outreach

The Office of Institutional and External Affairs (OIEA) had numerous accomplishments during the reporting period. These accomplishments included the following items.

OIEA coordinated the YMPO Public Update Meetings in Hawthorne, November 7; Amargosa Valley, November 8; and Henderson, November 20, 1990. These Project Update Meetings discussed general issues and, in part, the status of the scientific investigation program. About 300 people attended the three meetings in November. Staff began planning the next round of update meetings to be held in May 1991.

OIEA staff coordinated and handled logistics for an open house and tour of Yucca Mountain and Area 25 for the public on March 2, 1991, for approximately 400 people. The tour received wide media coverage. Staff began coordinating public tours of the site and Area 25 through June.

A tour program plan for the YMP was developed, and OIEA staff hosted approximately 32 tours of the Clark County Yucca Mountain Information Office in Las Vegas.

OIEA prepared briefing packages, handled logistics, and accompanied YMPO staff to approximately 60 YMP-related presentations, including 15 exhibit showings of the YMP table-top exhibit.

OIEA provided general back-up support, which includes preparing information letters, talks to universities requesting presentations, and summary papers for YMPO and T&MSS staff. Staff assisted YMPO staff in coordinating three press briefings and handling numerous media inquiries.

2.1.7 Interactions with NRC and Oversight Organizations

During the reporting period, the YMPO committed a significant level of effort in support of briefings, technical exchanges, meetings, and site visits with the NWTRB, NRC, and YMP oversight groups. The YMPO participated in eight meetings and three site visits with the NWTRB. The NWTRB was created by the NWPA, and its members are appointed by the President to advise Congress and the Executive Office on the conduct and technical progress of the DOE high-level waste program. The full board contains several panels composed of experts that interface with various aspects of the DOE program. The eight meetings held were: (1) a technical information exchange with the Structural Geology and Geoengineering panel on surface-based testing prioritization and progress on the Calico Hills study on October 11, 1990; (2) an Environment and Public Health Panel briefing on October 16, 1990; (3) a QA Panel briefing on November 1-2, 1990; (4) a technical information exchange with the Structural Geology and Geoengineering panel on ESF Scoring on November 19-20, 1990; (5) a presentation by the OCRWM Director at the Full Board Meeting on January 16-17, 1991; (6) a Structural Geology and Geoengineering Panel meeting on volcanic hazards on March 1, 1991; (7) a Structural Geology and Geoengineering Panel meeting on the CHRBA task, the ESFAS task, the ESSE task, and the TPT on March 6-7, 1991; and (8) a joint QA Panel/Structural Geology and Geoengineering Panel meeting on the QA of the ESF preliminary design and the DOE QA program on March 26-27, 1991. In addition to the technical briefings, the members of the NWTRB visited LANL, SNL, and the USGS to discuss QA concerns.

The YMPO also participated in several interactions with the NRC. Technical exchanges conducted over the reporting period included (1) an exchange on the surface-based TPT and the CHRBA on October 12, 1990; (2) an exchange on performance assessment on November 28-29, 1990; (3) an exchange on the NRC staff's draft technical position on seismic hazards on February 20, 1991; and (4) an exchange on radionuclide retardation and mineral stability on March 20-21, 1991. Two formal meetings with the NRC were held, one in December to schedule future interactions and one in January to discuss the status of the CHRBA and ESFAS tasks.

In addition, the YMPO has participated in ACNW working groups on Carbon-14, mixed waste, and the role of expert judgment. The YMPO also hosted Yucca Mountain site field trips for the National Academy of Sciences (NAS) Panel on Coupled Processes on October 18-20, 1990, and on January 29-30, 1991.

2.1.8 Hydrology Peer Review Task

On October 2, 1990, the Peer Review Record Memorandum was officially transmitted to YMP participants; the letter of transmittal included a request for responses to the conclusions and recommendations in the report. On February 6, 1991, the DOE's responses were transmitted to YMP participants. On February 22, Dr. Allan Freeze, the Chairman of the Hydrology Peer Review Team, was briefed by the YMPO on the DOE's responses and on action-items derived from the conclusions, recommendations, and responses. The DOE's responses and a list of action-items were officially transmitted to Dr. Freeze on March 12. On March 13, Dr. Freeze transmitted copies of this information to the other members of the Peer Review Team. Their evaluation of the responses, and hence the Hydrology Peer Review, should be completed in April 1991.

2.1.9 Comments on the Technical Program

The NWPA, Section 113(a), requires the DOE to obtain and fully consider comments on the SCP. Since release of the statutory SCP on December 28, 1988, the DOE has received a total of 2,771 comments in public hearings and in packages from various groups, government agencies, and organizations, some of which have oversight roles on the program. Letters received from citizens and groups during the SCP comment period and after (64 to date) have had responses returned. Additional letters are responded to as received.

In December 1990, the DOE released response packages for SCP comments submitted by (1) California Energy Commission (DOE, 1990c), (2) Lincoln County Commissioners, Nevada (DOE, 1990d), (3) EPA (DOE, 1990e), (4) EEI (DOE, 1990f), (5) U.S. Department of the Interior (DOE, 1990g), (6) the State of Nevada (ESF comments) (DOE, 1990h), and (7) the NRC (DOE, 1990i). The NWTRB provides comments on the SCP in recommendations made in their semiannual Reports to Congress (NWTRB, 1991). The DOE's responses to NWTRB recommendations are published in each succeeding report. The YMPO is tracking 122 commitments made in responses to these comments, and those carried over from responses to the SCP/CD, so they can be integrated into the technical program.

2.1.9.1 Comments on SCP Study Plans

The DOE and NRC follow protocol established in a signed agreement that resulted from a December 15, 1988, meeting on Study Plans. Upon receipt of DOE-approved Study Plans, the NRC will conduct a "start-work" (Phase I) review within three months, and inform DOE if there is any objection to starting work. The purpose of a start-work review is to identify concerns with SCP studies, activities, or specific tests or analyses that if begun could cause significant and irreparable adverse effects to the site, the site characterization program, or the eventual usability of the data in licensing.

If three months pass and the DOE is not informed of any objections, the DOE assumes that no objection exists.

Comments on DOE-approved Study Plans are forwarded to the responsible participant organization for an assessment of the comments' impact on the planned study or activity. Responses to these comments are provided by the DOE as enclosures in a letter to the commentor, or to the appropriate interfacing OCRWM office. Any actions to be taken as a result of comments are noted in responses and are tracked as commitments. Table 2-1 shows those Study Plans which have received comments.

The NRC has reserved the right to make detailed technical comments on selected Study Plans within six months of receipt. The State of Nevada receives Study Plans for its information at the same time distribution is made to the NRC. The State provides comments on Study Plans at its discretion. Responding to the NRC's detailed technical comments, or to comments from the State of Nevada, is not a prerequisite to starting site characterization work, but responses will identify how the comments were considered in planning, if appropriate.

TABLE 2-1 -- STUDY PLAN COMMENT STATUS

STUDY PLAN	COMMENTOR & NO.		STATUS
8.3.1.17.4.2 (Location and Recency of Faulting Near Prospective Surface Facilities)	NRC	16	Response 12/19/90
	NV	3	Response 10/15/90
8.3.1.5.2.1 (Quaternary Regional Hydrology)	NRC	9	Response 12/19/90
8.3.1.16.1.1 (Characterization of Flood Potential)	NV	9	In preparation
8.3.1.8.5.1 (Characterization of Volcanic Features)	NV	5	In preparation

2.1.10 Site Characterization Program Baseline (SCPB)

Revision 0 of the SCPB was prepared and issued as a controlled document by the Office of Geologic Disposal (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. Changing the SCPB involves 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.

SCPB change notifications and revisions to Study Plans through the YMPO document control system are the means by which the DOE will keep the NRC informed of changes to the technical program. SCP Study Plans are to be consistent with the SCPB. Study Plans are revised in response to SCPB changes through the YMPO review, approval, and revision procedure for Study Plans. Site Characterization Progress Reports (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 because Study Plans control levels of detail of program planning that can be below that contained in the SCPB.

The SCPB is being revised. The revision will be accomplished in preparation for the start of Title II design studies on the ESF. The revision of the SCPB will incorporate changes to program planning based upon the reference ESF design concept. Access to the ESF was previously planned to be via two vertical shafts that would be constructed by blasting. Although no final decision has been made, the current RDC plans call for a much larger ESF area with access via two inclined ramps drilled by tunnel boring machines.

2.1.11 Performance Assessment

Performance assessment made significant progress in three high priority activities. In the first activity, calculations were completed for the PACE-90. These exercises used a wide array of the YMP's capabilities for studying the long-term behavior of a repository system; modelers from several institutions worked with one another and with field-test personnel as well. After formulating in detail a set of problems for numerical solution, the participants used computer techniques to estimate releases of radionuclides from a repository whose site characteristics were similar to those of Yucca Mountain. The group obtained estimates for "nominal" conditions, similar to those now occurring at Yucca Mountain, and for certain disturbed conditions that could occur in the future. Although the results of PACE-90 exercises cannot be considered reliable predictions for Yucca Mountain, the process yielded a number of insights that will be important for future data collection and analysis. The exercises also demonstrated and enhanced the ability of the YMP staff to perform such calculations.

With the conclusion of the PACE-90 calculations, the multiparticipant group turned to a new high-priority initiative, the early evaluation of site suitability. They defined calculations whose solutions will contribute to increased understanding of the site's ability to meet the DOE siting guidelines. They also produced two sets of methods for use in the evaluation: a six-step process for carrying out detailed calculations and a general scheme for evaluating suitability.

In the third high-priority task, several detailed calculations were completed in support of the design of the ESF. These analyses were formulated to examine the ability of the ESF to meet certain requirements imposed on it;

they also helped to develop the requirements by deriving numerical criteria that interpret the nonquantitative requirements. The calculations were carried out under full quality-assurance procedures. They are valuable not only because they contribute quantitatively to the ESF design but also because they are prototypes for the extensive sets of design-support calculations that will take place in the future.

In addition to these three efforts, performance assessment made significant progress in implementing the issue resolution strategies contained in the SCP. The workers in total-system performance created, through meetings with YMP experts in numerous technical disciplines, a series of event trees that identify the features, events, and processes that may be important to the behavior of a potential repository at Yucca Mountain. The resolution of the ground-water travel time issue was addressed through the development of a method for examining regulatory compliance on a rigorous probabilistic basis. The method, along with numerical examples of its application, was presented in several forums to stimulate the wide-ranging discussion that will be necessary for the method to be accepted.

2.2 SITE PROGRAMS

The site characterization effort for the Yucca Mountain site consists of a number of component programs. These programs 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).

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

- Rock Characteristics - characterizes and models rock stratigraphic and structural features and distributions within the site area, and integrates geophysical and drilling activities to obtain subsurface stratigraphic and structural data (SCP Section 8.3.1.4).

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

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

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

- o 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).

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

- o 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).

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

- o 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).

- o 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).

- o Preclosure Tectonics - characterizes faults, seismicity and tectonic stress field, and evaluates the potential for faulting, ground motion, and volcanic ash fall in the site vicinity (SCP Section 8.3.1.17).

These programs are discussed in detail in Sections 2.2.1 through 2.2.13.

2.2.1 Geohydrology (SCP Section 8.3.1.2)

2.2.1.1 Study 8.3.1.2.1.1 - Characterization of the Meteorology for Regional Hydrology

Study Plan 8.3.1.2.1.1 was approved by the DOE on March 13, 1991.

Activity 8.3.1.2.1.1.1 - Precipitation and Meteorological Monitoring. Precipitation data were collected from the networks of plastic collection gages and tipping-bucket gages on and around Yucca Mountain. During this reporting period, there were 11 significant storm events. Two of these resulted in significant snowfall on Yucca Mountain and surrounding mountains. Snow samples were collected for geochemical analysis.

A preliminary report was prepared on the thunderstorm events of July 14-15, 1990. The Southwest Monsoon was active during the summer of 1990, with the subtropical jet stream providing considerable moisture in surges from the eastern Pacific, setting the stage for heavy rainfall in southern Nevada. Two storms produced significant precipitation over Yucca Mountain, in excess of

one inch at one rain gage in Midway Valley and about one and three-quarter inches at the Hydrologic Research Facility (HRF). Other locations received larger amounts. The information was provided to others studying surface runoff for their consideration and suggestions.

Lightning display equipment was tied into the Nevada Test Site (NTS) lightning detection system, which will permit personnel to monitor and record lightning activity affecting the Yucca Mountain region. This system is linked with the Weather Service Nuclear Support Office (WSNSO), which operates a network of cloud-to-ground lightning detectors on the NTS. The lightning data will be correlated with precipitation data from the dense rain-gage network of 100+ gages on and around Yucca Mountain, the NTS, and southern Nevada. The lightning data may be useful in filling in gaps in the precipitation network.

A satellite ground station for linking with geostationary and polar orbiting weather satellites was put into operation on February 1, 1991. Data were received from polar orbiting satellites, primarily National Oceanic and Atmospheric Administration 11, and from the geostationary satellite, GOES East. Data were archived upon receipt and will be integral in reconstructing and studying significant precipitation events at Yucca Mountain.

A preliminary analysis of the historical precipitation record was completed using data collected at two locations: NTS precipitation station 4JA on Jackass Flats and the National Weather Service station at Desert Rock Airport on the NTS. An analysis of strip-chart records for station 4JA was used to determine the frequency, duration, and intensity of heavy storms in July and August 1984. These results are being used to analyze the correlation between storm data and the timing of a runoff event in Pagany Wash that occurred on August 19, 1984. Daily precipitation accumulations at Desert Rock Airport were analyzed to determine the temporal distribution of storm events at this location for the period 1979-1989. It was determined that approximately 30 percent of the observed storm events resulted in precipitation accumulations that were less than the gage's resolution of measurement of 0.01 inch. This has resulted in the need to use precipitation gages with a higher resolution of measurement, such as 0.1 millimeter (0.004 inch), which have been installed at Yucca Mountain. The purposes of these higher resolution gages are to record trace amounts of precipitation at remote locations, and to obtain more accurate intensity and accumulation measurements of smaller precipitation events.

The calendar years 1983 and 1984 were determined to be anomalously wet years while the year 1989 was determined to be an anomalously dry year, relative to the ten-year record and to the average annual precipitation at Desert Rock. Although Desert Rock is located approximately 30 miles southeast of Yucca Mountain, annual and monthly accumulations of precipitation correlate well with measurements at Yucca Mountain. Desert Rock will be one of the surrounding stations used to estimate the historical precipitation record at Yucca Mountain for an analysis of current climatic conditions.

The vegetable oil used in the collection gage network to prevent evaporation was not satisfactory. It tended to evaporate and harden after about a two-month exposure to the harsh desert environment. Experiments were conducted on mineral oil and silicone oils to determine if they were more stable. These oils, including vegetable oil, were subjected to dry heat at

about 55°C between October 17 and January 24, 1991. Test results indicated that although vegetable oil contained moisture best, it was itself subject to deterioration. On the other hand, silicone oils allowed more moisture to escape over time at temperatures that simulate a desert environment. The oil that both contained moisture and retained its integrity best under hot, dry conditions was common mineral oil. This oil was selected for permanent use in the 93 plastic collection gages. All gages were replaced when the total catch reached more than one inch. This was because the scale resolution decreases at higher precipitation readings. The goal is to read the gages to the nearest .01 inch.

Arrangements were made with the WSNSO to obtain weather charts covering significant precipitation events affecting Yucca Mountain. These charts will be used in conducting case studies of these events.

The calibration of all heated tipping-bucket rain gages was completed. Calibration results for two gages were not satisfactory and possible problems in the design and workmanship of these gages are being investigated in the laboratory. The calibration of nonheated tipping-bucket gages continues. All successfully calibrated heated tipping-bucket gages were installed and maintained at various field sites for the 1990-1991 winter season.

Geostatistical analyses were conducted to analyze the spatial correlation of precipitation accumulation on a regional scale. Results for summer-time convective events indicated that spatial correlation is poor for distances of 10 miles or more and excellent at distances of less than 5 miles - the scale of Yucca Mountain. This information will be used to evaluate the efficiency of existing and future monitoring networks and to develop accurate mapping of precipitation events. Preliminary mapping of winter-time Pacific frontal storm events showed the precipitation pattern to be more spatially homogeneous than for convective events. Localized terrain effects have an influence on measured values. This information will be used to help develop a generalized stochastic model of winter-season precipitation at Yucca Mountain.

Historical precipitation data from the NTS, collected by the WSNSO, was provided to the USGS Surface Water Project (Activity 8.3.1.2.1.2.1). The data cover the water years 1983-1985. An open-file report covering this data will be published in the future. Drafts, and the final version, were reviewed and coordinated with the WSNSO to resolve inconsistencies. A meteorology working group was formed to provide direction, and efficiency, in implementing planned activities. The working group met on an as-needed basis. Because of its close proximity to Yucca Mountain, staff at the HRF were asked to collect precipitation samples for the unsaturated-zone hydrochemistry study at two locations on Yucca Mountain. The precipitation is collected in a stand pipe fitted with a plastic bag. Samples will be collected after each major storm event, if possible, and sent to Denver for geochemical analysis.

A presentation was given on the meteorology of Yucca Mountain and vicinity at the January 3 meeting of the Southern Nevada Chapter of the American Meteorological Society. Planned research topics and approaches to understanding the regional meteorology were also discussed.

Numerous tours were conducted during the period. Notable visitors were the Under Secretary of Energy, John C. Tuck; the Deputy Secretary of Energy,

W. Henson Moore; Congressman John J. Rhodes, III, of Arizona; the Director of the OCRWM, John W. Bartlett; and congressional staffers.

A technical review of Study Plan 8.3.1.12.2.1, "Meteorology Monitoring Plan for the Yucca Mountain Project," was completed with comment resolution and verification on February 25.

2.2.1.2 Study 8.3.1.2.1.2 - Characterization of Runoff and Streamflow

Study Plan 8.3.1.2.1.2 is in its final stages of review by the NRC. Responses to comments by the State of Nevada are also nearing completion.

Activity 8.3.1.2.1.2.1 - Surface-Water Runoff Monitoring. Ongoing monitoring activities included operation of five continuously-recording stream gages, ten peak-flow sites, and 21 storage-type precipitation gages. Final approval was received from DOE for the installation of three additional stream gages planned for Upper Fortymile Wash. The ALERT radio telemetry system was made operational after installation of receivers on Skull Mountain and Shoshone Mountain on the NTS. ALERT radio transmitters and sensors have been received and are planned for installation at all continuously recording network sites. When fully operational, the ALERT network will provide for real-time notification of runoff at all recording gages. Runoff events were documented during the reporting period at Topopah Wash along the southern area of Jackass Flats and at Amargosa River below Beatty. Estimates of peak discharge were computed at these crest-stage gage sites.

The final draft of the report "Streamflow and Selected Precipitation Data for Yucca Mountain and Vicinity, Water Years 1983-85" (Pabst et al.) was completed and is planned for distribution for colleague review. The initial draft was begun for the subsequent stream gage report covering water years 1986-1990. Compilation and QA checking of the 1986-91 surface-water records continued.

Activity 8.3.1.2.1.2.2 - Transport of Debris by Severe Runoff. Monitoring weather and potential flood conditions that could promote hazardous debris movement continued. Evidence of a debris flow was recently discovered near Hawthorne, Nevada. Deposits of this recent flow exhibit both classic and unusual hydraulic characteristics. The debris flow will be examined more thoroughly to determine whether knowledge can be gained that will enhance the understanding of potential debris hazards at Yucca Mountain. Debris movement by the summer storms of 1990 in southern Nevada may have been severe at some locations. Investigation of some of these sites is planned for the future.

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 approved by the YMPO on January 30, 1991, and subsequently sent to the NRC on February 15, 1991, for review.

Activity 8.3.1.2.1.3.1 - Assessment of Regional Hydrologic Data Needs in the Saturated Zone. An evaluation of this activity was made during the completion of Study Plan 8.3.1.2.1.3, in which a prioritization of data needs

was largely completed. It was determined that as new data becomes available, data needs may change based on previously unrecognized hydrologic conditions. The current data uncertainty was used to prioritize data collection needs, as documented in the Study Plan.

Activity 8.3.1.2.1.3.2 - Regional Potentiometric-Level Distribution and Hydrogeologic Framework Studies. Amargosa Valley and Crater Flat wells were plotted on quadrangle maps to verify locations and to cross-check site identifiers and locations with the Nevada USGS District computer files. A field trip was conducted to better determine actual locations of selected Amargosa Desert wells. YMP staff activated a digitizer to be used, in part, to enter digitized map coordinates for well locations.

All water-level data contained in ground-water site inventory (GWSI) for a polygon including Pahute Mesa, Timber Mountain, Oasis Valley, Yucca Mountain, and Crater Flat and data from mining-company water wells in Crater Flat and from Coffer's well in Beatty Wash were processed and plotted to show well locations, water-table altitude, and contours of the water-table altitude. Potentiometric contour lines for the Yucca Mountain area were produced from GWSI water-level data using automated contouring routines. The cause of an apparent potentiometric high at Rainier Mesa is being investigated to determine whether elevated water-level altitudes (1,700-1,800 meters) are caused by perched water.

Site location data for two wells in Crater Flat, and one well in Beatty Wash, were entered for use with the new Sample Management System which is now part of the USGS water-quality laboratory.

Orthophoto quadrangle maps from the USGS National Mapping Division were obtained as well as Coast and Geodetic Survey elevation control data within the Amargosa Desert. The USGS Water Resources Division/Sacramento owns some global positioning station equipment which may be borrowed for use on the project to help determine accurate field locations of these wells.

Three mining-company-drilled geologic exploration boreholes in the western Amargosa Valley, ranging in depth from 1,700 feet to 2,200 feet, were converted to deep piezometers, and will provide better three-dimensional definition of potentiometric and hydrogeologic data down-gradient from Yucca Mountain. Three additional deep drillholes are to be drilled in the Amargosa Desert by an oil company in the Spring of 1991 and may be available for selected testing.

YMP staff met with USGS Geologic Division personnel to discuss plans to characterize the stratigraphy of the Amargosa Desert and vicinity based in part on cuttings and geophysical logs available from mining company drill-holes. All available logs are being assembled and processed into a uniform format for analysis. Staff also attended a seminar entitled "FracMan: Data Analysis and Hydrologic Modeling of Fractured Rocks with Application to Yucca Mountain."

A technical review was performed on an abstract entitled "A Geologic Hypothesis for the Large Hydraulic Gradient Under Yucca Mountain, Nevada" (Fridrich et al.). The abstract was submitted for inclusion in an American Geophysical Union (AGU) Spring meeting special session entitled "The Potential

of Tectonism and Volcanism for Producing Significant Excursions of the Water Table."

Temperature log data obtained in 1986 from drillholes in the Amargosa Desert was assembled and provided to USGS-Flagstaff researchers for analysis.

Activity 8.3.1.2.1.3.3 - Fortymile Wash Recharge Study. An abstract entitled "Correlation Integral Analysis of South Twin River Streamflow, Central Nevada: Preliminary Application of Chaos Theory" (Savard, 1990) was accepted and published in EOS by the AGU for their Fall 1990 meeting. The abstract discusses the methodology and results of scoping work on applying chaos theory to characterizing streamflow. A poster in support of the abstract was presented at the Fall 1990 meeting in San Francisco.

This work includes a preliminary correlation integral computed for Steptoe Creek in east-central Nevada for comparison to the South Twin River correlation integral analysis. The results were similar with a stepping in the correlation integral at small radii and indication of a high (greater than 5) fractal dimension of a possible strange attractor.

A program to compute Lyapunov exponents from experimental time series data was converted to run on Hydrologic Investigations Program computers. The program was originally published in the physics literature. Lyapunov exponents measure the divergence or convergence of nearby orbits in phase space. A positive Lyapunov exponent indicates that the system is exhibiting chaotic behavior, which is necessary to determine if chaos theory is to be successfully applied to streamflow data for south-central Nevada and the Fortymile Wash surface water flow system.

Because chaotic behavior in stream flow may be dependent on initial conditions, an algorithm was developed to illustrate the concept of sensitivity to initial conditions in nonlinear systems. The algorithm uses the Lorenz system of equations, which models thermally-induced fluid convection. Model variables are plotted against time and in three variable space. The Lorenz strange attractor can also be displayed.

A Handar shaft encoder, data logger, and support software were evaluated for use in monitoring water level changes in tank water levels in ponding and infiltration testing. Unfortunately, the equipment was not compatible with currently used data loggers. Other equipment will be evaluated in the future. Estimates of the volume of water needed for planned infiltration tests in Fortymile Wash were computed based on the expected range of infiltration rates and the different sizes of infiltration tanks.

A field trip was held through the Fortymile Wash watershed to visit selected mapped springs along Fortymile Wash and to observe variations in plant type and density up the Fortymile Wash drainage and upland areas (Pahute Mesa, Timber Mountain, and Buckboard Mesa).

An abstract entitled "Correlation Integrals of Nevada Streamflow" (Savard) was written, reviewed, and submitted for inclusion in the AGU Spring 1991 meeting special session, "Chaos, Fractals, and Nonlinear Variability in Geophysics." The abstract will be published in EOS.

Activity 8.3.1.2.1.3.4 - Evapotranspiration Studies. Preparation began on a draft paper of the work presented in a poster entitled "Hydrochemical Stratification at Franklin Lake Playa, Inyo County, California" (Czarnecki et al.) that was presented at the AGU Fall 1989 meeting in San Francisco.

A report entitled "Geohydrology and Evapotranspiration at Franklin Lake Playa, Inyo County, California" was published (Czarnecki, 1990a) as an open-file report.

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 has been returned to the USGS for response to the comments from the DOE.

Activity 8.3.1.2.1.4.1 - Conceptualization of Regional Hydrologic Flow Models. A paper, "From Where and By What Flow Paths Does Ground Water Beneath Yucca Mountain, Nevada, Originate?" (Czarnecki et al., 1990), was presented at the AGU Fall 1990 Meeting and an abstract of the paper was published in the transactions of the meeting.

Conceptual models were developed for increased recharge under wetter climatic conditions and a localized increase in hydraulic conductivity in the vicinity of the large hydraulic gradient north and west of the potential repository area. An abstract 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) was prepared for publication in EOS and presentation at the AGU Spring 1991 meeting.

Activity 8.3.1.2.1.4.2 - Subregional Two-Dimensional Areal Hydrologic Modeling. Two presentations were made concerning the ground-water flow system under Yucca Mountain. A talk, "Possible Effects of a Wetter Climate on the Ground-Water Flow System of Yucca Mountain and Vicinity, Nevada-California" (Czarnecki), was given at the Geological Society of America (GSA) National Meeting in Dallas. A companion abstract was published in the proceedings of the meeting (Czarnecki, 1990b). A talk on the large hydraulic gradient at Yucca Mountain was given for the NAS Coupled Processes review panel concerned with the question, "Is the Water Table Likely to Rise into the Yucca Mountain Repository?" The meeting was held November 30, 1990, in Menlo Park, California.

A version of the USGS MODFE (Modular Finite Element) code was obtained and assembled to solve problems involving transient, vertical leakage. The code is being tested on problems related to abrupt increases in hydraulic conductivity in the vicinity of the large hydraulic gradient north of Yucca Mountain. Also, various approaches were tested for automatic time stepping control, using a nonlinear finite-element ground-water flow model which uses vertical leakage functions to accommodate evapotranspiration. Criteria for time-step control is based on maximum head change within each time step.

A follow-up meeting was held in Las Vegas with YMP participants on developing nominal-condition models of ground-water flow and transport for the flow system of Yucca Mountain and vicinity. YMP staff provided pertinent

input and output files for baseline 2-D finite-element simulations of the flow system for use by SNL.

YMP staff visited the Center for Advanced Decision Support for Water and Environmental Systems (CADSWES) to discuss their recent advances in object oriented software as applied toward Geographic Information System (GIS) and MODFLOW (USGS finite-difference ground-water flow model). YMP staff reviewed a software package called MICRODEM which was developed by the U.S. Navy and may have potential GIS applications within the YMP. A talk was prepared and delivered at the Southern Basin and Range Transect (SOBART) workshop in Phoenix, Arizona, on the hydrologic relation between Death Valley, California, and the Amargosa Desert.

YMP staff met with staff from the NPS, Ft. Collins, Colorado, to discuss modeling activities to date and their relation to NPS interests at Death Valley National Monument (DVNM). Also discussed was the possibility of hydrochemical sampling of major springs in DVNM.

A "call for papers" package was prepared and distributed soliciting abstracts for a special session to be held at the AGU Spring 1991 meeting in Baltimore entitled "The Potential of Tectonism and Volcanism for Producing Significant Excursions of the Water Table."

A meeting was held with the USGS staff from the Paleohydrology section regarding the need to characterize paludal sediments and their ages in an area in the central Amargosa Desert. A field trip is scheduled to be held following the International High Level Radioactive Waste Management (IHLRWM) conference in Las Vegas (April 28-May 3).

A paper entitled "Possible Validation of the Simulated Ground-Water Flow System Near Yucca Mountain with Paleohydrologic Evidence" (Czarnecki) was revised and forwarded for inclusion in a USGS Bulletin on scientific activities within the USGS Yucca Mountain Project.

Activity 8.3.1.2.1.4.3 - Subregional 2-D Cross Sectional Hydrologic Modeling. This is an out-year activity.

Activity 8.3.1.2.1.4.4 - Regional Three-Dimensional Hydrologic Modeling. The basic grid system for the development of the input data sets for the 3-D model have been generated. Model input data sets will make use of the GIS being developed by the YMP to allow rapid evaluation of various concepts. A draft manuscript on 3-D modeling of the Yucca Mountain area has been revised along with manuscripts on 3-D conceptual models of the regional ground-water flow system. An abstract for a paper discussing regional ground-water models was published by the GSA (Kolm et al., 1990).

2.2.1.5 Study 8.3.1.2.2.1 - Characterization of Unsaturated-Zone Infiltration

Study Plan 8.3.1.2.2.1 was transmitted to the NRC for acceptance on March 1, 1991.

Activity 8.3.1.2.2.1.1 - Characterization of Hydrologic Properties of Surficial Materials. Several surface mapping exercises were initiated as part

of prototype studies on sampling, testing, and mapping surficial materials. Several transects have been used to estimate the percent of exposed bedrock and fracture density. This activity has been combined with defining the subsurface distribution of some of the tuff units on Yucca Mountain to better understand the alluvium/tuff interactions. The movement of water percolating through the alluvium may be dependent on the properties of the underlying tuff units.

Rock outcrop samples were collected from a 2,000-foot transect along the Shardy Base of the Tiva Canyon unit and tested for bulk density, porosity, and saturated hydraulic conductivity. These samples and tests are being used for procedure development. Air permeabilities have been determined on several of the samples, but measurements are currently delayed while a new air permeameter is constructed. Imbibition tests will also be run on these samples. These data will be used to help determine the horizontal spatial variability of several important hydrologic properties and better define sample spacing for future boreholes and rock outcrop studies.

Cooperative agreements have been reached with EG&G to produce maps of surficial materials. The surficial mapping program will provide the raw data to be incorporated into the GIS data base. A series of additional existing GIS database overlays will be added to produce final maps for use by other YMP participants.

A cooperative effort with SNL was initiated to supply information required for performance assessment modeling. The efforts have required the estimation of representative surficial units, and distribution and quantity of recharge. These estimates are required for the preliminary performance assessment models being developed.

A cooperative effort with Lawrence Berkeley Laboratory (LBL) was initiated to develop a 3-D model of infiltration. The region to be described in the model covers a trapezoidal area from Yucca Wash in the north to well H-5 in the south, and from Solitario Canyon fault in the west to the Bow Ridge fault in the east. The infiltration program has provided preliminary inputs to the model by developing a generalized view of three surficial infiltration units within this area, ridge tops, side slopes and alluvium. A grid has been developed with these units and the major faults exemplified. An average annual precipitation overlay was developed based on 1,000-foot spacings and surface elevations that will be used for precipitation input to the model.

Activity 8.3.1.2.2.1.2 - Evaluation of Natural Infiltration. The ongoing program for monitoring natural infiltration in the shallow unsaturated zone continued through neutron moisture meter logging of 74 shallow, cased, boreholes. Each hole is logged to its total depth (or 50 feet in deeper holes) once each month. This data base has continuous records for over six years.

Preliminary work was initiated on the development of a conceptual model of natural infiltration with a detailed case study of Pagany Wash. Pagany Wash was chosen because it is well instrumented with neutron holes and has a history of runoff events, one of which was well-documented and allowed for the measurement of subsurface infiltration. A field trip with HRF personnel was conducted in order to help develop ideas concerning the relative significance

of channels and overland flow during infiltration events. A detailed outline for the case study has been written including a literature search and preliminary data collection and analysis.

Work continued on a computer program to aid with the interpretation of data from a Peltier-type thermocouple psychrometer. The thermocouple psychrometer is an instrument for measuring moisture potential in the unsaturated zone. The raw data from this instrument consist of a curve which must be manually interpreted by a very tedious process. When completed, this software should ease the burden by presenting the user with a graphical display of the data which can be interpreted on-screen and saved in a file.

A project to determine the feasibility of continuously monitoring the moisture in a shallow uncased borehole in unconsolidated alluvium continued in Topopah Wash west of Test Cell 'C'. The instrumentation includes temperature and pressure sensors, and Peltier-type thermocouple psychrometers.

Several activities continue in support of water budget studies. Prototype testing of equipment and methods for measuring evapotranspiration using the Bowen Ratio Energy Balance technique continued with the deployment of an instrument platform to a location at the mouth of Pagany Wash. Preliminary analysis of the data indicated that soil heat will be one of the most difficult components of the energy balance to measure.

Precision measurement of each component of the radiation balance equation continues at the Jackass Flats location. This work has lead to a better understanding of net radiometers and the measurement of net radiation. Monitoring continued at a Class A evaporation pan on Jackass Flats. The rates measured here will be compared with estimates of actual evapotranspiration close by to help further the understanding of these arid land processes. Data from other agencies operating similar pans in Southern Nevada were collected. Preliminary analysis of this data supports the hypothesis that very high advection in this environment may limit the use of evaporation pans to providing only the absolute upper limits of evapotranspiration.

Time-domain reflectometry (TDR) measurements are being collected in the field to test the feasibility of an automated system. Ten TDR probes are being monitored every two to three days to follow the wetting front from several rainfall events in March. This system uses TDR techniques to determine water content of soil by sensing the dielectric constant of the soil which increases with increasing water content. The automated TDR system will be used to sense water content changes in surface alluvium for evapotranspiration studies.

Heated snow gages on and around Yucca Mountain were monitored and serviced throughout the "snow season." Snow may be an important component of recharge at Yucca Mountain since evapotranspiration is typically low during these periods and the application of water to the surface via melting snow is slow (reduced run-off). Good data were collected during a snowstorm in the month of March.

Activity 8.3.1.2.2.1.3 - Evaluation of Artificial Infiltration. TDR will also be used in the simulated rainfall and ponding infiltration studies.

Measurements are currently being made in the field to test the feasibility of the automated system.

2.2.1.6 Study 8.3.1.2.2.2 - Water Movement Tracer Tests

Study Plan 8.3.1.2.2.2 was issued by DOE/HQ as a controlled document and was sent to the NRC and the State of Nevada on February 9, 1991.

Activity 8.3.1.2.2.2.1 - Chloride and Chlorine-36 Measurements. One problem that has limited the usefulness of chlorine-36 analyses for tracing meteoric water movement in the subsurface has been estimating the proportion of chlorine and chlorine-36 derived from the rock, which can significantly dilute the meteoric signal. HydroGeoChem, the contractor, began investigating the potential of stable chlorine isotope ratios for estimating the extent of dilution, assuming that meteoric and rock chlorine can be expected to have different characteristic 35/37 ratios. To test this hypothesis, samples from UZ-1 were selected that were considered to best represent end-members for meteoric and rock chloride; these samples were analyzed for their stable chlorine isotope ratios. Preliminary results indicate that the two end-members appear to have significantly different ratios and that this approach warrants more thorough investigation.

HydroGeoChem summarized the procedures it has been using for sample collection, preparation, and analysis. The principal investigator used this summary to identify procedures that needed improvement and to serve as the basis for several detailed technical procedures for inclusion in the LANL QA Program Plan. HydroGeoChem began working under the LANL QA program in September 1990. The contractor underwent an internal audit on November 13, 1990, and was found to be in compliance with the LANL QA Program. HydroGeoChem also completed an inventory of its holdings of Yucca Mountain samples.

On March 21, a talk entitled "Applicability of Natural Analog Research to Repository Transport Calculations" (Fabryka-Martin) was presented to the DOE/NRC Technical Exchange on Mineral Stability and Radionuclide Transport.

The Water Movement Tests Task was audited by the YMPO on March 28, 1991, and no deficiencies were found by the audit team.

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 resubmitted to the YMPO on March 5, 1991, for approval.

Activity 8.3.1.2.2.3.1 - Matrix Hydrologic Properties Testing. Laboratory analyses were performed on 131 samples of volcanic tuff core from the Apache Leap prototype drillhole in Arizona. The analyses included gravimetric water content, porosity, bulk density, grain density, and "as-received" water saturation. The effectiveness of sample handling procedures used at the prototype drilling site was evaluated with respect to the requirements of the matrix-hydrologic property activity. It was found

that standard soil moisture cans lost a measurable amount of water (several centigrams from a typical total water content of 10-20 grams) even though the cans were tightly sealed and the seams covered with black vinyl tape. An improved type of sample container is recommended for future water saturation sampling. An electrically-operated can-sealing machine was obtained for this purpose. Preliminary tests with distilled water sealed into #1-size steel soup cans indicate that less than a milligram of water was lost from a 150-gram sample in 10 days, which is a significant improvement.

Laboratory drying techniques and core saturation procedures were also evaluated on the Apache Leap samples. The standard saturation method of submerging samples in de-aerated water under vacuum appears to work quite well on these cores, as long as sufficient time is allowed for water to enter and fill the pore systems of the less permeable rocks. Standard soil-moisture drying methods (105°C in a conventional oven) were used on most of the Apache Leap core, although some samples were dried in controlled relative humidity ovens to experiment with a procedure for removing free pore water only from the rocks, leaving water-bearing minerals properly hydrated. The drying technique was not critical to gravimetric water saturation determination on the Apache Leap core, but could prove to be very important to the rocks at Yucca Mountain, which often contain hydrated smectite clays and zeolites. Two relative humidity ovens are being tested to investigate the stability of the chambers by collecting data on the wet bulb temperature, dry bulb temperature, cooling water temperature, and the weights of samples. It was determined that a constant-temperature bath may be required to chill or heat the cooling water before it enters the oven.

Core samples from Topopah Spring and Calico Hills tuffs were dried using two different methods and then observed under the scanning electron microscope (SEM) by Geologic Division staff. The vacuum-dried samples suffered significant damage to hydrated swelling clays, which were preserved in the humidity-dried rocks. Although the zeolite minerals appeared to undergo no structural changes after vacuum drying, they also were dehydrated and this caused measured porosity in these rocks to nearly double. The ideal drying would remove all free pore water while leaving the bound water intact..

A prototype gas/liquid permeameter was designed and constructed to determine saturated permeability of rock core. Further development is required and modifications will begin as soon as ordered items are received.

Development of a system to measure moisture retention on core samples using a submersible pressure outflow cell system (SPOC) continued. The system has been automated with the use of a load cell, connected to a data logger, to monitor weight change of the SPOC. Other modifications are currently in process to allow accurate outflow data with time to be collected so that unsaturated conductivity may be calculated along with moisture retention characteristics. A paper describing preliminary development and the accuracy of the data entitled "Use of a Submersible Pressure Outflow Cell for Determination of Moisture Characteristic Curves of Rock Core" (Flint and Flint) was presented at the Workshop V, "Flow and Transport through Unsaturated Fractured Rock," sponsored by the University of Arizona and the NRC in Tucson. A second paper entitled "Characterization of Rock Hydrologic Properties Using Model Verification" (Flint et al.) was also presented. Both papers are in review prior to publication in the workshop proceedings.

The evaluation of mathematical models from soil science literature describing relative water permeability and moisture retention characteristics from several measurement methods continued. Parameters from these equations are being used in the TOUGH code to simulate laboratory imbibition experiments. Imbibition is an easily measured unsaturated flow phenomena. This model verification technique has proven to be useful. Simulated imbibition was sensitive to different mathematical formulations describing the same property and to data from different measurement methods.

The data report entitled "Preliminary Permeability and Water Retention Data from Nonwelded and Bedded Tuff Samples, Yucca Mountain Area, Nye County, Nevada" (Flint and Flint) has been reclassified as an interpretive report and has received USGS approval. A paper entitled "The Influence of Scale on Sorptivity Values from Imbibition Experiments on Welded and Nonwelded Tuff" (Flint et al.) was presented at the Nuclear Energy Agency Workshop of Flow Heterogeneity and Site Evaluation in Paris, France. This paper is currently in review and will be published in proceedings of the workshop. Another paper was also presented entitled "Geostatistical Methods for Site Evaluation at Yucca Mountain" (Istok and Flint) at this same workshop.

At the annual INTRAVAL meeting in Cologne, Germany, in October, the Phase I report was finalized and planning began for Phase II. Input for the Phase I report concerned Test Case 12, which contains hydrologic data from G-Tunnel experiments. Final revisions were made to the report and it was submitted to the NRC.

Activity 8.3.1.2.2.3.2 - Site Vertical Borehole Studies. All planning activities for drilling and instrumenting three 40-feet-deep auger-holes to be located adjacent to the HRF were completed during the reporting period. A work package for this program was initiated by the YMP. YMPO approval for this work, however, is still pending. All downhole sensors (thermocouple psychrometers, thermistors, and pressure transducers) were delivered and calibration of these sensors was approximately 70 percent complete as of March 31, 1991. Ten downhole instrument station apparatus (DISA) units have been constructed. These first ten units will be used to instrument two of the HRF boreholes. Modified variants of the current DISA design will be used to instrument the third borehole. Exploratory discussions were held with personnel that are involved in the stemming of the boreholes used in the weapons testing program at the NTS. The purpose of these discussions was to develop a program to design, test, and evaluate grout mix designs and emplacement methodologies for stemming and instrumenting the deep unsaturated zone (UZ) boreholes.

Additional tests of the UZ borehole gas sampling system were conducted at the HRF calibration laboratory using a simulated instrument station to provide a continuous supply of vapor-saturated air at elevated temperatures (30° to 40°C). These tests confirmed results of earlier experiments and were used to evaluate alternative schemes for routing mixed gas (dry carrier gas and vapor saturated source gas) across the dew-point hygrometer sensor. These tests were conducted over tubing lengths of approximately 2,000 feet. A multi-station manifolded gas sampling apparatus that permits isolated gas streams to share a common hygrometer and precision mass flow meter has been designed. The assembly is configured to service up to 20 downhole instrument stations at

a time. Sharing of common components is done via remotely-actuated solenoid control valves. Additional support equipment is being evaluated in conjunction with development of the software specifications for this system. The first assembly should be completed by the end of August 1991. Current plans are to test the system and its software early in fiscal year 1992 (FY92) using the HRF boreholes to provide a multi-station (16) test bed facility.

Additional refinements to the sensor calibration procedures for sensors that will be used in the deep UZ borehole instrumentation and monitoring program were made during the reporting period. This work was conducted in conjunction with calibration of the HRF borehole sensors. A primary standards deadweight tester was incorporated into the pressure transducer calibration procedure. This is a 0.01 percent device that is used to maintain the accuracy of the precision pressure indicator that is used as the working transfer standard for calibrating pressure transducers. The pressure transducer calibration procedure was also modified to incorporate thermal hysteresis effects. Achievable accuracies for the pressure transducers are better than about 0.02 percent full scale (in the range 75 to 115 kPa) over a temperature range of 5° to 40°C. Modifications to the calibration chambers used in calibrating the thermocouple psychrometers were also made. These modifications have virtually eliminated the possibility of leakage. Repeatability tests of the psychrometers were also conducted. Results indicate less than a 1 percent variation in voltage output over the entire calibrated temperature and molality range. Additional tests of psychrometer measurements in the -1 bar range were also conducted. Results indicate ability to resolve water potential to within 1 percent at the wet end of the measurement. Data collected from the calibration of the HRF borehole sensors will be used to finalize selection of the calibration equation that will be used for the psychrometers. A market survey for a two-pressure humidity generator was conducted during the reporting period. This equipment will be used to maintain calibration of the dew point hygrometers that will be used in the gas sampling program. Delivery of the equipment in January 1992 is anticipated.

Vertical seismic profiling (VSP) software, formerly resident on the Colorado School of Mines' Gould mainframe and Colorado State University's Cyber computers has been successfully transported to Florida State University's Cray computer and Colorado School of Mines' IBM RS/6000 work stations. Major improvements to the wave mode separation program and an improved version of the P-S converted wave imaging procedure were made during the reporting period. Improvements in the wave mode separation program yield a much sharper image of the shear wave mode data set. The effects of destructive interference caused by algebraic sign reversals for certain reflected P-S events has been greatly reduced with the new version of the reverse time migration imaging program. Data (multiple component, multi-mode) acquisition from a simplified physical VSP fault model is nearing completion. These data are being analyzed using the improved versions of the wave mode separation and reverse time migration imaging programs. A 3-D, three-component data set has been obtained from a new 3-D physical model (6' x 6' x 2' concrete monolith block) and has also been analyzed with the revised software packages. Work continued on the Yucca Mountain VSP computer model and on the simplified 2-D physical model of Yucca Mountain. A total of 28 computer-calculated synthetic VSPs and 5 VSPs from the physical model have been obtained. These are being imaged to test all revisions to the imaging

software and especially to check the ability of the software to image variable velocity media.

The final design and component specifications for Integrated Data Acquisition System (IDAS) field site instrument shelters is nearing completion. Research into replacements for the GEMLink microwave transmitters indicate that these devices are not available as a single off-the-shelf unit. Upgrading of the IDAS' multi-drop microwave data network will require integration of wide-band microwave transmitters and receivers with full-function conventional modems. Three sources of suitable microwave equipment and two manufacturers of suitable modems have been identified. Work continued on reviews and revisions of technical procedures, and on writing new technical procedures for the integrated data acquisition system program.

The 8-inch diameter straddle packer assembly for air-permeability testing is 80 percent complete and is scheduled to be finished in June 1991. The support trailer used to operate the packer assembly has been rescheduled for completion in September 1991. The trailer is behind schedule because of boom and winch modifications required to expand its capacity for use with 12.25-inch packer assemblies.

Prototype air-permeability testing was conducted in an 8-inch diameter hole at the Apache Leap Test Site near Superior, Arizona, during March 1991. The tests involved placing pressure transducers in the UZ hydrochemistry gas-sampling packer assembly and monitoring test interval pressures during gas sampling. The method worked well, and three drawdown and four recovery tests were conducted on three test intervals. The tests have been analyzed using pressure-squared and pseudo-pressure methods developed for the Site Vertical Boreholes. Test results are within an order of magnitude of results from the University of Arizona and previous USGS testing of the same volcanic tuff.

A report discussing the drilling and geohydrologic data for Test Hole USW UZ-1 was published (Whitfield et al., 1990).

Prototype drilling program activities centered around designing, purchasing, and inspecting the YMP's new dry coring/drilling rig. The LM-300, manufactured by Lang Drilling Company of Salt Lake City, Utah, was completed in February 1991. The semi-automatic pipe handling system will be completed and added to the rig in time for field trials scheduled for July 1991. These trials will take place in the Mercur district southwest of Salt Lake City. This location is near the Lang manufacturing facility where in-trial modifications may be effected if required. During field trials, Field Operations Geologist (FOG) teams from the Sample Management Facility (SMF) will process samples and core, exercising field procedures upgraded as a result of the Apache Leap operations in 1990. This represents positive changes in SMF procedures as a result of lessons learned during prototype activities at Apache Leap.

Participant organizations drafted scripts to be used in staging and preparing videotapes for training. Once videotapes of rig testing activities are edited and processed, master films will be available for YMP use in training personnel and for the public outreach program. Topics will include rig mobilization and demobilization, safety, drilling, coring, reaming, pipe

handling, core and sample handling and processing, depth control, and records keeping.

Through a contract with the Earth Mechanics Institute (EMI) of the Colorado School of Mines, the YMP started conducting extensive tests on several coring and reaming bits. The YMP supplied samples of moderately welded Apache Leap tuff from Arizona and densely welded Topopah Springs tuff from the Yucca Mountain area for the tests. The EMI routinely uses prepared samples of Indiana Limestone as a baseline for comparisons. The three rock types were cast with cement into individual drilling blocks measuring 6′ x 4′ x 3′. Carbonado diamond bits and two different reaming bits were tested on the three blocks of representative rock types. Through analyses of the tests, the YMPO will be able to evaluate the cutting structure and design of the bits in terms of the efficiency and capability for drilling boreholes during site characterization. Details of the tests can be found in an RSN report entitled "Colorado School of Mines Bit Testing."

Participants of the Prototype Drilling team established positive means and drafted procedures for depth control for use during field drilling activities. This will ensure accurate depth values to within +/- 1.0 foot for any sample or core processed from a YMP borehole.

Reclamation of the Apache Leap, Arizona, prototype drill site at Oak Flat Campground was completed with the sealing of boreholes, and disposal of drill cuttings and oil stained topsoil near the boreholes. The deeper of the two prototype boreholes was made available to the U.S. Forest Service for use as a source of water for the campground.

Activity 8.3.1.2.2.3.3 - Solitario Canyon Horizontal Borehole Study. 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

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. A large Mariotte reservoir system was designed for controlling hydraulic pressure and flow rates. Included in the system was an electrode for monitoring dissolved oxygen (O_2).

Development of the Moire projection method for fracture profile characterization continued. Significant modifications were made in the digitizing hardware and software designs. A Fast-Fourier Analysis approach is being considered for use in the analysis and reduction of topographical data from fracture surfaces. During this prototype phase, a variety of optical techniques for mapping fracture surfaces have been considered. The possibility of using stereoscopic methods for viewing the Moire fringes was also evaluated. Efforts focused on calibration and benchmarking methods for the Moire projection equipment. An accuracy in the tens of microns is being sought for asperity measurements in fracture planes. Preparation of a journal article on this subject was begun.

As part of the prototype testing of small laboratory block samples, mineralogic analyses have been performed on a fractured block of moderately welded tuff. The analyses provided separate determinations for fracture coatings and rock matrix. Results from X-ray diffraction (XRD) were comparable to those obtained from similar tuff samples by LANL. Of particular interest was the presence of smectite (montmorillonite) clays as fracture coatings, a feature that may contribute to low fracture conductivities under moderately saturated conditions.

A series of prototype air-permeability tests were performed on a large block sample. The purpose of the test was to provide information on the performance of various packer designs and to discern the location of conducting fractures in the block sample. Additional prototype investigations were performed on a grout core block in preparation for subsequent unconfined permeability tests on fractured core samples. The grout core will also be used as a source for small cores of the matrix material. These will serve as readily accessible samples for use in designing various permeability and porosity tests. A standard operating procedure is being prepared for porosity determination, based on the preliminary experiments. As more laboratory results are obtained, the methodology will be incorporated into a technical procedure.

An open-file report describing the proposed fracture-sampling methods test was started. A paper entitled "Assessment of Fracture Sampling Techniques for Laboratory Tests on Core" (Severson and Boernge) was submitted to the American Nuclear Society (ANS) for presentation at the IHLRWM Conference scheduled to be held from April 28 to May 3, 1991, in Las Vegas.

Activity 8.3.1.2.2.4.2 - Percolation Tests in the Exploratory Studies Facility. Work continued on a variety of prototype testing activities pertaining to the laboratory measurement of imbibition and relative permeability testing in a fractured rock mass. Imbibition experiments were performed on a core of welded tuff containing a single, axially-oriented fracture. These transient tests were performed in two ways. In the first experiment, imbibition into the matrix occurred through the fracture. The second experiment involved the separation of the two halves of the core sample so that imbibition occurred directly into the core matrix, excluding the contribution of a fracture. Following these preliminary tests, fracture porosity and total porosity were measured on the fractured core sample. Subsequently, the core was fitted with porous plates to measure the water transmitting capacity of the fracture at various water tensions. During the course of these tests, the fracture surface was examined for the presence of clays and calcite deposits. Air permeability measurements were also conducted on the sample and the response of the fracture during both drying and wetting phases was determined. The data were processed and analyzed for inclusion in a paper entitled "Numerical and Laboratory Investigations of Transient and Steady-State Flow in a Fractured Core" (Kwicklis et al.), presented at the January 9 workshop co-sponsored by the University of Arizona and the NRC in Tucson, Arizona.

Miniature packer assemblies were set up with mass flow meters and a prototype data acquisition system to perform cross-hole air-injection tests in a large block sample of fractured tuff (54.3 cm long x 29.7 cm wide x 80.6 cm high). Actual measurements began in December. Air permeability data were

collected during transient and steady-state tests. The data were then used to estimate hydraulic conductivities. The results of the experiments have indicated the location of discrete fracture pathways through the block. Identification of these conduits is important for subsequent water-phase testing. Preparation for water percolation testing also was initiated.

A report entitled "Alternative Method to Mariotte Reservoirs for Maintaining Constant Hydraulic Pressure " (Thamir) was submitted to the ANS in October for presentation at the IHLRWM Conference in April 1991 in Las Vegas. The article describes the Mariotte reservoir system and alternative designs.

Development of the following technical procedures began during this reporting period: (1) fracture location within welded tuff samples, (2) preparation of core samples for imbibition and infiltration tests, (3) saturating rock samples under a vacuum, (4) porosity measurement of welded and nonwelded tuff core samples, and (5) calibration of pressure transducers. The procedure for fracture location has been submitted for technical review.

Activity 8.3.1.2.2.4.3 - Bulk-Permeability Test in the Exploratory Studies Facility. Investigations continued on the analytical and interpretive approaches for the proposed bulk-permeability test. Stochastic methods have been reviewed.

The Edgar Mine, a testing facility owned by the Colorado School of Mines near Idaho Springs, Colorado, was removed from consideration as a viable analog site for prototype testing purposes.

Activity 8.3.1.2.2.4.4 - Radial-Borehole Tests in the Exploratory Studies Facility. Prototype gas-injection testing was conducted at the Apache Leap test site near Superior, Arizona, during December 1990.

Data analysis of Apache Leap testing in May, June, and December 1990, continues. Several pressure, pressure-squared, and pseudo-pressure analysis methods have been investigated and used. Preliminary results show the pressure-squared and pseudo-pressure give identical results and both methods are applicable for compressible fluids.

Testing has shown that locating connecting fractures for cross-hole testing is much more difficult than originally believed. Only a few of the numerous cross-hole tests had sufficient connections to show a response.

Single-hole injection testing produced the same calculated permeabilities for the volcanic tuff matrix at Apache Leap for variable flow rates and pressures. Injection tests using nitrogen versus air show the same calculated permeabilities. Thermistors showed no temperature changes. These results are important because they show that the calculated permeabilities are not dependent on the gas, injection rate, or pressures at which the tests are conducted. The results also suggest that forcing water away from the test area and thereby increasing the effective permeability is not a problem. The test results compare favorably with those of the University of Arizona and the surface-based borehole testing by the USGS.

Additional testing has been scheduled for May and September 1991 at Apache Leap. The testing goal is to conduct cross-hole tests at variable flow

rates and pressures to determine if the calculated fracture permeabilities are dependent on flow rate or pressure.

Activity 8.3.1.2.2.4.5 - Excavations Effects Tests in the Exploratory Studies Facility. No progress was made in this activity due to lack of funding.

Activity 8.3.1.2.2.4.6 - Calico Hills Tests in the Exploratory Studies Facility. This is in out-year activity.

Activity 8.3.1.2.2.4.7 - Perched Water Test in the Exploratory Studies Facility. No progress was made in this activity due to lack of funding.

Activity 8.3.1.2.2.4.8 - Hydrochemistry Tests in the Exploratory Studies Facility. This is an out-year activity.

Activity 8.3.1.2.2.4.9 - Multipurpose Borehole Testing Near the Exploratory Studies Facility. No progress was made in this activity due to lack of funding.

Activity 8.3.1.2.2.4.10 - Hydrologic Properties of Major Faults encountered in the Main Test Level of the Exploratory Studies Facility. This is an out-year activity.

2.2.1.9 Study 8.3.1.2.2.5 - Diffusion Tests in the Exploratory Studies Facility

Study Plan 8.3.1.2.2.5 is being revised to incorporate YMPO and DOE/HQ comments.

Activity 8.3.1.2.2.5.1 - Diffusion Tests in the Exploratory Studies Facility. A test planning package was drafted for this study describing the requirements for the prototype testing and the diffusion tests planned for the ESF. The test planning package requests two prototype test locations that provide access to representative Yucca Mountain welded and nonwelded tuff. Test locations for the diffusion tests in the ESF are requested within the Topopah Spring Member and the Calico Hills unit, and two test locations are desired within the Calico Hills formation (one in the vitric zone and another in the zeolitic zone of the Calico Hills unit). The test planning package was submitted to the YMPO for approval.

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 resubmitted to the YMPO in October 1990 and is in the final stage of DOE verification audit review.

Activity 8.3.1.2.2.6.1 - Gaseous-Phase Circulation Study. Gas samples were collected from eight zones in borehole USW UZ-6, nine zones in USW UZ-6s, and one zone in each of three neutron boreholes located on the USW UZ-6 pad. Laboratory gas chromatograph analyses for approximately 500 gas samples were completed. The characteristics of the airflow from an open borehole at Yucca

Mountain were published in a paper presented at the Topical Meeting on Nuclear Waste Isolation in the Unsaturated Zone, Focus '89 (Thorstenson et al., 1990).

Gas flow measurements in USW UZ-6s were initiated and pressure measurements were started for the three neutron boreholes located on the USW UZ-6 drill pad. Techniques were also developed to improve gas chromatograph accuracy.

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 approved by the YMPO in September 1990 and forwarded to DOE/HQ for transmittal to the NRC.

Activity 8.3.1.2.2.7.1 - Gaseous-Phase Chemical Investigations. The annual USW UZ-1 gas sampling was conducted in late January to early February 1991. Besides the routine collection of ^{14}C-gas and water-vapor samples, 15 ^{13}C samples of gas in 2-L aluminum cylinders, 15 ^{13}C samples in Tedlar bags of mixed 3-L and 10-L sizes, and 15 gas samples in 500-mL flow-through glass containers were collected using high-volume pumps, about 50 L per minute, for comparison studies of carbon-isotope fractionation. Comparable data were obtained by all three methods except in a few cases where differences were greater than the statistical errors. The differences probably were caused by small concentrations of CO_2 in the soil gas (less than 0.02 percent by volume). Oxygen-isotope ratios in the CO_2 gas samples were more variable, probably due to CO_2-gas exchange with oxygen atoms of water molecules during up-flow through the small-sampling tubes (water vapor likely condensed inside the tubes due to flow resistance).

Analyses of gas samples obtained during July through August of 1990 at Apache Leap, Arizona, showed that CO_2 concentration in the soil gas of the top zone (top 40 feet) was about atmospheric concentration, while all other deeper zones (down to 220 feet) are typical of the higher soil-zone CO_2 concentration. Results of Carbon-14 and Carbon$^{13}/_{12}$ analyses indicated that zone 2 was the youngest and was probably influenced by atmospheric penetration. This is because zone 2 is the most fractured zone, as evidenced from camera logs of borehole, and is probably connected to the open borehole (UZP-4) located 8 feet west of UZP-5. Gas-sampling at the UZP-5 prototype borehole at Apache Leap, Arizona, was again conducted in March 1991. The March 1991 trip was to collect additional CO_2 concentration, Carbon-14 and Carbon$^{13}/_{12}$ samples to check for the reproducibility of the data, and also to check the fracture zone (zone 2) by using Freon-12, 13 tracers. This was accomplished by injecting concentrated Freon tracer into the UZP-4 hole and pumping from four zones of UZP-5 to determine the first appearance of the injected tracer. Also, pressure transducers were installed into zones of UZP-4 and UZP-5 to monitor the responses of in situ pressure changes against the external pressure changes. Several core-gas samples squeezed from Apache Leap cores were analyzed for tracer gas, SF_6, which was added to the drilling-gas stream during drilling. To date, no detectable SF_6 was present in the core-gas; that is, drilled cores were not contaminated by drilling air.

Activity 8.3.1.2.2.7.2 - Aqueous-Phase Chemical Investigation. The investigation for improving liquid scintillation counting efficiency using

newly designed pure-quartz-glass vials instead of the existing copper-teflon vials provided by the manufacturer continued. The oxalic acid standard procured from the National Institute of Standards and Technology (NIST) for conversion to benzene as a ^{14}C counting standard arrived and will be synthesized to benzene and put into a quartz vial for a counting-efficiency study. For tritium counting, it was found that Picofluor-LLT scintillation cocktail to be mixed with the tritium-water sample for counting was far better than the Instagel previously used. Therefore, several gallons of this cocktail were ordered from the factory. The detection level of tritium in the new counter with 8 ml water and 12 ml of cocktail is about 3 Tritium Units (TU) for a 1000-minute count.

Portions of the UE-25 UZ#4, UE-25 UZ#5, and USW UZ#6s cores stored at the Sample Management Facility at the NTS were shipped to Denver on January 17, 1991. Several cores were used to distill pore-water for a tritium concentration check. This precautionary measure was taken because there is a chance that these core samples may have been contaminated with tritium from G-Tunnel samples. The pore water of G-Tunnel samples had a tritium concentration of one to two million picocuries per liter or .31 to .621 million TU.

Results of Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) analyses conducted by Pacific Northwest Laboratory (PNL) of Richland, Washington, on two UE-25 UZ#4 pore-water samples from the unsaturated zone indicated that measurable concentrations of heavy rare-earth elements (Tb, Dy, Ho, Er, Tm, Yb, Lu) were detected, while these elements were not detected in J-12 and J-13 ground water. For further confirmation, two additional pore-water samples were sent to PNL for analysis.

Various core-sealing methods to preserve moisture were tested. These were (1) beeswax seal--cores were wrapped in aluminum foil, covered with cheese cloth, and dipped into melted wax; (2) Lexan liner--cores were placed inside 2.5-inch Lexan tube with caps on both ends, then the cap edge was taped with duct tape; (3) Protecore seal--cores were placed inside the Protecore wrapper and heat-sealed at the edge; (4) Protecore over-pressurized--cores were placed inside the Protecore wrapper, which was then inflated and heat-sealed; (5) Protecore under vacuum--cores were placed inside the Protecore wrapper, which was then evacuated and heat-sealed; (6) wax and Protecore seal--cores were wrapped in aluminum foil, covered with cheese cloth, and dipped into melted wax, then the cores were placed inside the Protecore wrapper and heat-sealed at the edge; (7) Lexan and Protecore seal--cores were placed inside 2.5-inch Lexan tube with caps on both ends, the cap edges were taped with duct tape, then the cores were placed inside the Protecore wrapper and heat-sealed at the edge. All sealed packages were weighed every month to monitor the moisture-weight loss. Percent-moisture loss will be calculated when cores are taken out, dried, and weighed to determine the total moisture content. Preliminary results indicate differential moisture loss from cores sealed by different methods.

The aqueous-phase tracer contract work to the New Mexico Institute of Mining and Technology was completed in mid-January 1991. The conservative tracers that can be used at Yucca Mountain include bromide, iodide, and borate. Organic tracers, although conservative, may decompose to CO_2 by biological activity and be of concern for gaseous-phase hydrochemical studies.

Pore water was squeezed from ten G-Tunnel nonwelded samples, and eight partially welded core samples from Apache Leap, Arizona. Core-moisture content of the partially welded tuffs ranged from 4.49-6.12 percent, and averaged yields of pore water were 5.28 ml water and 22.94 ml gas. Nitrogen injection was needed in most instances to extract the pore water.

A paper entitled "Pore-Water Extraction from Unsaturated Tuffs using One-Dimensional Compression" (Mower et al.) has been approved and accepted for presentation at the 1991 IHLRWM Conference. The paper will be published in the Proceedings of the Meeting. A paper comparing pore-water extraction methods was published by the American Institute of Hydrology (Yang et al., 1990).

The construction of the high-pressure cell (up to 120,000 psi axial pressure) for welded-tuff squeezing is 95 percent complete. The ordering of steel sheeting to wrap the cell for safety operation, and the building of a model to test the effects of compression on the lubricant which aids in removal of the sampling sleeve, is in process.

2.2.1.12 Study 8.3.1.2.2.8 - Fluid Flow in Unsaturated, Fractured Rock

Study Plan 8.3.1.2.2.8 was submitted to the YMPO in September 1990 and is undergoing technical review by the DOE.

Activity 8.3.1.2.2.8.1 - Development of Conceptual and Numerical Models of Fluid Flow in Unsaturated, Fractured Rock. A variety of computer simulations were performed during the reporting period in support of the development of conceptual and numerical models. A number of simulations using a modified version of the VS2DT code were run to examine the effects of fractures on the recovery of gaseous tracers. Code modifications have enabled the simulator to express tracer concentration as a mass fraction in order to account for fluid compressibility.

A computer code designed to explicitly account for roughness properties continued to be modified and refined. The simulator generates two-phase relative permeability, saturation, and matric potential relationships for a variable aperture fracture. Some of these simulations used data obtained from prototype experiments on fractured, welded tuff core samples (Activity 8.3.1.2.2.4.2). The resulting curves for relative permeability, saturation, and matric potential relations were incorporated into the TOUGH code to depict transient imbibition into fractured welded core. The influence of assumed variance in the natural logarithm of aperture on both saturated hydraulic aperture and on the relative permeability, saturation, and matric potential relations was then examined.

Results from recent laboratory imbibition experiments (Activity 8.3.1.2.2.4.2) were analyzed using new solutions proposed by investigators at LBL.

A paper entitled "Regional Ground-Water Characteristics Determined from Geochemistry and Isotopes at the Nevada Test Site" (Boughton) was presented at the Committee for the Advancement of Science in Yucca Mountain Project (CASY)

Symposium on Isotope Geology, Hydrochemistry, and Geochemistry in Characterization Studies of Yucca Mountain on October 10, 1990. YMP members contributed to a paper entitled "Adsorption of Water into Porous Blocks of Various Shapes and Sizes" (Zimmerman et al., 1990) in the November issue of Water Resources Research. The results of transient imbibition simulations were described in a paper entitled "Numerical and Laboratory Investigations of Transient and Steady-State Flow in a Fractured Core" (Kwicklis et al.). This paper was presented at Workshop V on Flow and Transport in Unsaturated, Fractured Rock held in Tucson, Arizona, January 7-10, 1991.

Activity 8.3.1.2.2.8.2 - Validation of Conceptual and Numerical Models of Fluid Flow through UZ Fractured Rocks. This is an out-year activity.

2.2.1.13 Study 8.3.1.2.2.9 - Site Unsaturated Zone Modeling and Syntheses

Study Plan 8.3.1.2.2.9 was completed and submitted to DOE/HQ in January 1991 for approval.

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 is continuing in conjunction with developing a coarse, 3-D model.

Activity 8.3.1.2.2.9.2 - Selection, Development, and Testing of Hydrologic-Modeling Computer Codes. The design of a coarse, 3-D model of Yucca Mountain was started with the development of a preliminary areal grid, based on the locations of existing and proposed boreholes, tectonic features, geologic outcrops, and infiltration topography. Work was started on the evaluation of the composite fracture/matrix model for site-scale modeling studies.

USGS and LBL investigators met at the NTS and in Denver prior to the start of development of the site-scale model. A magnetic tape providing stratigraphic data and a map of infiltration areas (crests, slopes and alluvium) for Yucca Mountain were obtained from unsaturated-zone investigators. A request was sent to SNL requesting data from its Site and Engineering Properties Data Base.

An analytical criterion was developed to assess the range of validity of the effective continuum approximation for fractured/porous media. Computer simulations to validate this criterion were started.

Activity 8.3.1.2.2.9.3 - Simulation of the Natural Hydrogeologic System (UZ). This is an out-year activity.

Activity 8.3.1.2.2.9.4 - Stochastic Modeling and Uncertainty Analysis (UZ). This is an out-year activity.

Activity 8.3.1.2.2.9.5 - Site Unsaturated Zone Integration and Synthesis. This is an out-year activity.

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

Study Plan 8.3.1.2.3.1.1-6 was approved by the DOE on February 13, 1991, and was transmitted to the NRC on March 7.

Activity 8.3.1.2.3.1.1 - Solitario Canyon Fault Study in the Saturated Zone. 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 16 wells and quarterly measurements were made in 3 wells in the periodic network. Hourly water-level data were collected from 19 zones in 13 wells in the continuous water-level network. Approximately 50 transducer calibrations were performed on the continuous network and approximately 20 transducers were replaced. A new type of transducer that appears to be less prone to excursions was installed in eight zones. Three additional satellite data-collection platforms were installed to supplement the two already in service. Two zones of one well were equipped with strip charts that give continuous data on water levels. Water levels remained stable during the October 1990-March 1991 period; the rate of instrument failure was reduced from previous periods.

Determining if apparent "water-level excursions" are real or instrument malfunction was a major priority during this period. The excursions, which have occurred in different wells at approximately the same time, last from a few hours up to several days. Five such excursions occurred during this six-month period. The excursions occurred during periods of unsettled weather with low barometric pressure, rain, and lightning. Satellite data-collection platforms that send data directly to a Prime computer in Denver every four hours were used to monitor the apparent excursions. Manual water-level measurements made in one well during one excursion conclusively showed that the excursion was not a real water-level change, but rather some type of electrical interference. Manual measurements also seemed to show this in two other cases, but these data were not as conclusive.

In December 1990, a packer was removed from well USW H-3 to remove a transducer blocking access to the lower zone of the well. When the packer was inspected, a plug was found in the access tube at the packer. This means that the access tube was never in communication with the well and all previously collected water-level data from the lower zone of well USW H-3 are invalid. The packer was reset in the well, but not at the same depth level, due to hole conditions. The well was placed on the periodic network until the water level stabilizes; the well will then be returned to the continuous network.

Additional access tubing was added to well UE-25 WT #18 to reach within a few meters of the bottom of the well. Water was found near the bottom of the well, but it is unknown if this water surface represents the water table.

Activity 8.3.1.2.3.1.3 - Analysis of Single- and Multiple-Well Hydraulic-Stress Tests. The C-hole complex hydrogeology report has been revised based on review comments and updated fracture information. The report has been submitted for supervisor and management review. The C-hole intra-borehole flow and hydraulic stress test report is about 30 percent

complete. Downhole television and caliper logs were run on the C-holes after the removal of the packers and tubing in November 1990. Because of discrepancies in fracture orientations obtained from various TV logs, the logs of UE-25c#3 and c#1 were re-analyzed to ensure the original data was correct.

Five shallow neutron holes and one UZ hole are being monitored for changes in borehole gas pressure as a result of changes in barometric pressure. These data are being used to develop a method for determining pneumatic diffusivity.

Hydraulic pressure and water level data collected at UE-25c#1 during 1990 was analyzed for barometric and earth tide responses. UE-25b#1 has been equipped with a continuously recording strip chart to monitor the hydraulic effects of underground nuclear explosions (UNEs) and earthquakes. The UNE event of November 14, 1990, was successfully monitored in all four zones of USW H-1. A technical presentation dealing with strain-related water level fluctuations was given at the March 22, 1991, Technical Project Officer meeting in Las Vegas.

Activity 8.3.1.2.3.1.4 - Multiple-Well Interference Testing. The multiple-zone hydraulic and tracer testing packer system has been continually refined. An agreement was reached on a joint project between the USGS, LBL, LANL, and Atomic Energy of Canada, Ltd. (AECL) to test methods that will be used at the C-hole complex and at the Underground Research Laboratory in Canada. This project calls for an analog site to be set up within the U.S. that resembles the hydrologic and geologic conditions at the C-hole complex. This site will then be tested using the methods that are planned for Yucca Mountain.

Preliminary simulations of C-hole hydrology have been attempted using various models (i.e., FracMan, Trinet) based on estimates of fracture distribution and connectivity. This activity is ongoing as new hypotheses and information are obtained. The overall quality of these simulations will be greatly enhanced by planned cross-hole seismic tomography at the C-holes.

Activity 8.3.1.2.3.1.5 - Testing of the C-Hole Sites with Conservative Tracers. A proposal for an additional cored test hole (possibly an angle hole) at the C-hole complex is being evaluated by YMP participants to determine exact location, depth, drilling angle, and mode of drilling. The hole is needed to provide core for geochemical analyses in connection with reactive tracer testing and to provide detailed information on the sub-vertical fractures that make up the fracture network in the saturated zone at the C-holes.

Work continued to select codes for preliminary simulation of conservative tracer tests. General hydraulic parameters and preliminary fracture distributions have been determined for use in these simulations. Several different methods for tracer-test analysis have been assessed and will be tested using hypothetical data sets.

Activity 8.3.1.2.3.1.6 - Well Testing with Conservative Tracers Throughout the Site. This is an out-year activity.

Activity 8.3.1.2.3.1.7 - Testing of the C-Hole Sites with Reactive Tracers. Detailed plans for the laboratory batch sorption experiments for lithium were developed. First, experiments designed to determine the sorption isotherm (surface concentration versus fluid concentration at equilibrium) will be carried out. Then, a series of experiments designed to elucidate the mechanism of sorption of lithium on Yucca Mountain tuff is planned. This part of the study will help evaluate applicability of the isotherm values by providing detailed information on the mechanism. Then, sorption experiments covering the range of rock and fluid compositions likely to be encountered at the C-wells will be carried out to evaluate the inherent uncertainty in the sorption parameters to be used in the models.

With the lifting of the stop work order on software development, work progressed on model development and documentation. The computer code SORBEQ, a one-dimensional simulator of transport with equilibrium sorption, is being developed under the LANL Software QA Plan (SQAP). The code development, documentation, and testing are approximately 90 percent complete. The three-dimensional FEHMN model is being documented in accordance with the provisions in the SQAP for qualification of existing development software. This effort is approximately 75 percent complete. Other development efforts were documentation of the existing code FRACNET, a two-dimensional simulator of flow and transport in fractured media (10 percent complete), and development and testing of input/output software tools and a plotting program.

Work continued on writing or revising the detailed technical procedures (DP) necessary for the laboratory experiments of this study. The DP "Calibration and Use of Analytical and Top-Loading Balances" was completed.

Activity 8.3.1.2.3.1.8 - Well Testing with Reactive Tracers throughout the Site. No progress during the reporting period; this is an out-year activity.

2.2.1.15 Study 8.3.1.2.3.2 - Characterization of the Saturated-Zone Hydrochemistry

Study Plan 8.3.1.2.3.2 was reviewed by the YMPO and DOE/HQ. Comments were reviewed and formal responses prepared. Tables of all comments and attendant responses will be sent to each reviewer in early April for consideration prior to the formal comment-resolution meeting (scheduled for late April).

Activity 8.3.1.2.3.2.1 - Assessment of Saturated-Zone Hydrochemical Data Availability and Needs. Investigators from the Water Resources Center, Desert Research Institute (DRI), University of Nevada System and the USGS support staff to the DOE Weapons Program observed a test application at the NTS of a wireline tool for pumping tests and for in situ hydrochemical sample and data collection. The tool performance was discussed with the investigator in charge of the DRI's participation in the DOE Environmental Restoration and Technology Development Branch Ground-Water Characterization Program (GCP). He reported that the tool, as tested, was unsatisfactory for hydrochemical data collection.

Activity 8.3.1.2.3.2.2 - Hydrochemical Characterization of Water in the Upper Part of the Saturated Zone. USGS YMP staff at the NTS collected

ground-water samples from two mining company boreholes in the west-central vicinity of Crater Flat. The holes were drilled in an attempt to obtain sufficient water for mining operations. Analytical data from the samples will provide preliminary estimates of water chemistry for the area in the vicinity of Bare Mountain. The planned collection of samples from planned GCP did not take place, as drilling has not yet begun.

Investigators and staff were identified and contacted at the EPA Environmental Monitoring Systems Laboratory in Las Vegas, at EG&G and DOE offices at the Idaho National Engineering Laboratory, at Battelle PNL, and at Oak Ridge National Laboratory (ORNL) to provide input on the feasibility of using 85Kr as a means of identifying the presence of drilling fluid in gaseous and aqueous samples to be collected in the course of Study 8.3.1.2.3.2. Contacts were also intended to identify laboratories that could provide requisite analytical services, and to identify satisfactory methods for collection and handling of gaseous samples.

The imminent finalization of proposals for cooperative work between the DOE and AECL required coordination of budget and plans for equipment tests at the AECL Whiteshell Nuclear Research Establishment Borehole Instrumentation Test Facility and at the Lac du Bonnet site area. Coordination with the Svensk Kärnbränslehantering AB (SKB) on the adaptation of the SKB downhole hydrochemical tool, by the manufacturer in Oskarshamn, to the sampling-pump to be used in Study 8.3.1.2.3.2 will begin immediately after final agreement has been reached.

Activity 8.3.1.2.3.2.3 - Regional Hydrochemical Characterization. Samples were collected from a stock-watering well site northwest of Yucca Mountain, at the southwest edge of the Timber Mountain caldera, to provide a preliminary estimate of water chemistry to be expected in that general area. This information will be used to further evaluate sites proposed for additional water-table boreholes.

Hydrochemical data along selected ground-water flow paths were compiled and examined to support presentation of a paper at the Fall 1990 meeting of the AGU. A preliminary agreement with USGS Weapons Program support staff was also established regarding the entry of historic data into data bases. Final agreement should be reached in April for this work to be done this fiscal year.

Activity 8.3.1.2.3.2.4 - Synthesis of Saturated-Zone Hydrochemistry. 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 transmitted to the YMPO on September 4, 1990, and is still in review.

Activity 8.3.1.2.3.3.1 - Conceptualization of Saturated-Zone Flow Models Within the Boundaries of the Accessible Environment. YMP staff assembled 1988 average water-level data for Yucca Mountain and began working with the data in preparation for a revised potentiometric-surface map. This map will reflect

the gains made in water-level data accuracy (more accurate data on well measuring points, inclusion of borehole deviation information, and start up of the water-level monitoring network) since Robison's report (1984). The potentiometric map is planned to be distributed in USGS Open-File format as a map, scale 1:24000. Work on the Regional Hydrology of Yucca Mountain and Vicinity three-day field trip for the GSA's October 1991 meeting continued. Field trip stops were selected, finalized, and discussions written. In addition, a geologic road log from the vicinity of Las Vegas to Death Valley, including the NTS, was made. Coordination and direction of GIS activities for the Saturated-Zone and Quaternary Regional Hydrology projects were discussed. Initial data for a 3-D geologic model was assembled for 21 wells at Yucca Mountain. A paper entitled "Evaluation of Geoscientific Information Systems for Three-Dimensional Ground-Water Modeling" (Turner et al.), was accepted by the ANS for IHLRWM presentation at its April 1991 Quaternary Regional Hydrology meeting.

Activity 8.3.1.2.3.3.2 - Development of Fracture-Network Model. The LBL 3-D flow and transport code, TRINET, was de-bugged and underwent verification runs of the transport option and installation of a conjugant gradient solver. Computer runs for the verification of the hydrologic inversion technique were conducted by LBL. For a simple case, it was verified that the technique yields the correct transmissivity and storativity values. A hypothetical design study of the C-hole hydraulic and tracer experiments was conducted. Percolation characteristics of hierarchically-structured fracture networks are being investigated for analyzing the planned hydraulic tests in the C-hole complex. Staff conducted a reconnaissance of outcrops of the Crater Flat Tuff near Yucca Mountain to determine if the outcrops are suitable for fracture mapping. Three areas were identified as suitable. Data from fracture mapping will be used as input to the LBL fracture-network generator. A paper entitled "Method Development and Strategy for the Characterization of Complexly-Faulted and Fractured Rhyolitic Tuffs, Yucca Mountain, Nevada, USA" (Karasaki) was presented to the Organization for the Economic Cooperation and Development, Nuclear Energy Agency in Paris. The paper, "Prematurely Terminated Slug Tests" (Karasaki et al.), was forwarded to the American Society of Civil Engineers for the 1991 International Symposium on Ground Water.

Activity 8.3.1.2.3.3.3 - Calculation of Flowpaths, Fluxes, and Velocities within the Saturated Zone to the Accessible Environment. 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

Study Plan 8.3.1.3.1.1 was revised, reviewed, and transmitted to the YMPO on March 15, 1991.

Activity 8.3.1.3.1.1.1 - Ground-Water Chemistry Conceptual Model. Staff began examining efforts and personnel requirements to bring the LLNL EQ3/6 code package and data base into compliance with LANL SQAP. LANL efforts could be significant, depending on LLNL plans for developing the program package and data base in FY92 and beyond. Discontinued or disrupted code package and data base development by LLNL will delay both activities in this study.

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

Study Plan 8.3.1.3.2.1 was accepted by the NRC for review on September 4, 1990.

Activity 8.3.1.3.2.1.1 - Petrologic Stratigraphy of the Topopah Spring Member. Staff provided some early trial applications of the developmental LANL-YMP-SQAP, R0. The SQAP was approved and became effective on January 25, 1991; affected personnel working on this activity were trained in December 1990. Statistical analysis of mineralogic and chemical data for the Topopah Spring Member (samples from Solitario Canyon) was delayed.

Activity 8.3.1.3.2.1.2 - Mineral Distributions between the Host Rock and the Accessible Environment. This activity was delayed pending approval of the SQAP because much of the activity's progress depends on the software used to obtain quantitative mineralogic information from XRD data. Investigators were trained to LANL-YMP-SQAP, R0, and have begun qualifying the software they use.

The trace-mineral studies were completed and will be detailed in a future report. XRD work on oxide-mineral separates is being completed.

"Detection of Trace Erionite Using X-Ray Powder Diffraction: The Distribution of Erionite in Yucca Mountain, Nevada, Tuff" (Bish and Chipera), a paper on the uses of XRD for the detection of trace amounts of the fibrous mineral erionite, was submitted to the journal Clays and Clay Minerals.

Activity 8.3.1.3.2.1.3 - Fracture Mineralogy. The principal investigator was trained to LANL-YMP-SQAP, R0, in January 1991. Commercial software accepted for interim use was used for SEM analysis, and samples recently released by the YMP Sample Management Facility greatly expanded the amount of fracture material available for study. A paper and presentation on fracture mineralogy was prepared for the IHLRWM Conference.

2.2.2.3 Study 8.3.1.3.2.2 - History of Mineralogic and Geochemical Alteration at Yucca Mountain

Study Plan 8.3.1.3.2.2 was revised and submitted to the DOE on October 17, 1990, for verification audit.

Use of the electron microprobe and other analytical capabilities is delayed, pending QA approval of the operating system and data-reduction software. Steam-atmosphere experiments are being delayed until a YMP-approved vendor is designated for thermal calibration of ovens.

Activity 8.3.1.3.2.2.1 - History of Mineralogic and Geochemical Alteration at Yucca Mountain. K/Ar studies of zeolite samples from Yucca Mountain continued. Studies of calcite-silica in bedrock breccias along fault

zones, plant influences on silica deposition in soils, and near-surface vein fillings continued. An abstract on the interpretation of paleohydrologic and paleothermal conditions in the Yucca Mountain pyroclastic sequence, using mineralogical and K/Ar illite/smectite dating information, was presented at the GSA annual meeting (Bish et al.). Petrographic and SEM studies of Topopah Spring vitrophyre glass alteration continued. An evaluation of mineralogic data as paleohydrologic indicators of static water-level change was begun.

A paper and presentation on the alteration history of Yucca Mountain for the High-Level Waste Conference were prepared.

Activity 8.3.1.3.2.2.2 - Smectite, Zeolite, Manganese Minerals, Glass Dehydration and Transformation. Long-term heating studies of zeolite and clay samples continued, with periodic X-ray diffraction monitoring of crystal lattice structural changes. Long-term vitrophyre dehydration studies reached a point at which the only observed changes were in response to seasonal changes in ambient humidity. The rehydration stage of the experiment, under conditions of controlled humidity, was begun.

LANL staff gave presentations on glass dehydration/rehydration and short- and long-term heating experiments and the results of illite/smectite studies at a technical exchange with the NRC on the radionuclide transport program.

To assess the long-term thermal stability of clinoptilolite under the thermal conditions imposed by the potential repository, a series of experiments was conducted at temperatures of 100° and 200°C for up to five years. Results indicate that significant volume changes might occur in heated zeolitic tuffs underlying the potential repository.

2.2.2.4 Study 8.3.1.3.3.1 - Natural Analog of Hydrothermal Systems in Tuff

This study is inactive.

2.2.2.5 Study 8.3.1.3.3.2 - Kinetics and Thermodynamics of Mineral Evolution

This study is inactive.

2.2.2.6 Study 8.3.1.3.3.3 - Conceptual Model of Mineral Evolution

This study is inactive.

2.2.2.7 Study 8.3.1.3.4.1 - Batch Sorption Studies

Study Plan 8.3.1.3.4.1 is being revised to incorporate DOE/HQ review comments and to incorporate the sorption strategy that resulted from the Sorption Workshop.

Sorption studies were divided between laboratory studies and concept-development activities. The laboratory studies concentrated on the sorption behavior of Tc and Np on pure mineral phases representative of

minerals identified in Yucca Mountain. Concept development activities centered around the development of a strategy for the integration of the sorption barrier into transport modeling codes used in performance assessment activities.

Activity 8.3.1.3.4.1.1 - Batch Sorption Measurements as a Function of Solid Phase Composition. Laboratory studies of Tc adsorption behavior were designed to test whether Tc was sorbed by any of the mineral phases tested (J-13 water) at pH=7.0.

Laboratory studies of Np sorption on minerals identified in Yucca Mountain were divided into two aspects. One aspect was designed to identify minerals that had significant sorption affinity for Np in Yucca Mountain ground waters. The second aspect concerned the investigation of detailed sorption behavior of Np on the iron oxide, hematite. A draft report on Np sorption on hematite is in preparation.

Activity 8.3.1.3.4.1.2 - Sorption as a Function of Sorbing Element Concentrations (Isotherms). See previous activity.

Activity 8.3.1.3.4.1.3 - Sorption as a Function of Ground-Water Composition. See previous activity.

Activity 8.3.1.3.4.1.4 - Sorption on Particulates and Colloids. This activity was inactive during the reporting period.

Activity 8.3.1.3.4.1.5 - Statistical Analysis of Sorption Data. No progress during the reporting period; this is an out-year activity.

2.2.2.8 Study 8.3.1.3.4.2 - Biological Sorption and Transport

Study Plan 8.3.1.3.4.2 review comments were incorporated, and the revised Study Plan was submitted to the YMPO.

Experiments were conducted to investigate the chelation of 239Pu(IV) by citrate, EDTA, desferal (a commercially available siderophore), and a naturally occurring siderophore isolated from Yucca Mountain. Using a scanning spectrophotometer, the absorption spectra of the ligand/Pu complexes indicated that EDTA, desferal, and siderophore all form strong complexes with Pu. A draft paper is in preparation.

2.2.2.9 Study 8.3.1.3.4.3 - Development of Sorption Models

The concept development activities centered on the formulation of the "minimum K_d strategy" for the inclusion of the sorption barrier in transport calculations. This strategy recognizes that many of the important elements in nuclear waste have very high affinities for many of the mineral surfaces available in Yucca Mountain. These values are highly relative to the species of nonradioactive elements in Yucca Mountain ground waters. A minimum K_d strategy has been formulated in which the K_d values used for each radionuclide in performance assessment calculations are single values for either all of Yucca Mountain or for each of the major hydrologic units. These single-value

K_d's are designed to reflect the worst-case scenario in terms of the sorption potential of mineral surfaces, the ability of ground waters to dissolve radionuclides, and the concentration of radionuclides in solution. For the key radionuclides of Carbon, iodine, and technetium, no sorption credit is assigned (that is, K_d=0). For the key radionuclides of uranium and neptunium, more complicated models are required. The results of this concept development effort will be evaluated through discussion with the modelers responsible for the performance assessment calculations.

Completed reports include "Yucca Mountain Project Far-Field Sorption Studies and Data Needs" (Meijer, 1990), "Sorption of Americium in Tuff and Pure Minerals Using Synthetic and Natural Groundwaters" (Triay et al., 1991a), and a response to the NWTRB regarding comments on the September 1990 Sorption Workshop held at LANL. The Triay et al. report contained the results of isotope dilution analyses of americium at ultra-low concentrations to ensure the absence of precipitation effects on the sorption experiment involved. The NWTRB comment response was essentially a summary of important issues raised at the September workshop and YMP plans for addressing these issues in future work. The DOE compiled the responses and submitted them to the NWTRB.

2.2.2.10 Study 8.3.1.3.5.1 - Dissolved Species Concentration Limits

Study Plan 8.3.1.3.5.1 was submitted to the DOE on August 17, 1990, and is undergoing YMPO review.

Activity 8.3.1.3.5.1.1 - Solubility Measurements. Solubility experiments using neptunium, plutonium, and americium in UE25p#1 well water from oversaturation at pH 6, 7, and 8.5 at 25°C continued. Solubility experiments with J-13 water will be completed in June.

Activity 8.3.1.3.5.1.2 - Speciation Measurements. Efforts have been underway, in collaboration with the Biological Sorption and Transport Task (8.3.1.3.4.2), to investigate the complexation of plutonium by microbially produced siderophores and related ligands (e.g., citrate, EDTA, and commercial siderophores).

Photoacoustic Spectroscopy (PAS) System Development and Application: A new passive, analog-filtering circuit based on the published design of the Argonne group, was constructed and successfully tested. Additionally, more thorough UV-vis absorption studies of the hydrolysis of U(IV) in THF were completed and analyzed. Four important species in the early (ligand metathesis) stage of the hydrolysis are in contrast to suggestions from earlier work in which only two species were thought to be present.

The comparative analysis of the three waveform acquisition and processing schemes was completed. In order of increasing sensitivity, the three approaches rank as follows: simple boxcar integration and averaging with a narrow (approximately 2-3 ms) gate is less than RMS rectification, boxcar integration and averaging with a broad (approximately 130 ms) gate is less than digital oscilloscope averaging and computer rectification, and integration with an effective gate width of either 100 or 200 ms. Preliminary assessment suggests that the sensitivity increase is on the order of 1:2:4 (same order as above).

A new ganged filter/amplifier configuration has been incorporated into the PAS system with a concomitant increase of ~4 in sensitivity. Current single-cell (i.e., without background correction) detection limits are estimated at ~50 nanomolar for Pu^{4+} in carbonate.

Spectral acquisition and comparison continues with the U(IV) model complexes. Room temperature and 77K spectral data for approximately 10 different complexes have been collected. Spectral variations as a function of changes in speciation are apparent and are being correlated with symmetry and ligand field strengths.

Other spectroscopy efforts included using nuclear magnetic resonance (NMR) spectroscopy (^{1}H, ^{13}C, and ^{18}O) as a very powerful speciation tool. About 250 milligrams of americium-243 were obtained for planned experiments studying americium carbonate complexation via NMR.

Progress has been made in four areas of model complex speciation studies. (1) The acquisition and assembly of the inert atmosphere facilities for the synthesis of these model complexes continued. The major components are now onsite and awaiting installation. (2) The syntheses of a multitude of Th(IV) model complexes were successfully carried out; many of these complexes have been characterized by XRD. Th(IV) is studied because it is quite analogous to U(IV), and extension of the model complex approach to PU(IV) may be valid and experimentally attainable. (3) Spectroscopic characterization of a number of U(IV) and Th(IV) model complexes using UV-Visible-Near Infrared electronic absorption, emission, and Raman vibrational spectroscopies continued. (4) New experimental approaches to controlling and understanding actinide hydrolysis continued, and data were collected for the controlled hydrolysis of U(IV) as UCl4 in tetrahydrofuran.

LANL staff travelled to Sweden on October 15-19 to participate in the second phase of the SKB/DOE Technical Exchange on Transport Processes.

Staff presented a poster titled "Spectroscopic and Electrochemical Studies of EDTA and Siderophore Complexes of Plutonium" (Hobart) at the "50th Anniversary of the Discovery and First Chemical Identification of Plutonium," held in Berkeley, California, on February 22-23, 1991. Staff also served on the Expert Panel on the Radionuclide Source Term for the WIPP Site on March 7-8 in Albuquerque, New Mexico, sponsored by SNL.

Staff attended the MRS Symposium on the "Scientific Basis of Nuclear Waste Management XIV" in Boston, Massachusetts, on November 26-29 and presented a talk entitled "Basic Research for Assessment of Geologic Nuclear Waste Repositories: What Solubility and Speciation Studies of Transuranium Elements Can Tell Us" (Nitsche).

Activity 8.3.1.3.5.1.3 - Solubility Modeling. This activity was inactive during the reporting period.

2.2.2.11 Study 8.3.1.3.5.2 - Colloid Behavior

The Study Plan is combined with Study Plan 8.3.1.3.5.1.

Activity 8.3.1.3.5.2.1 - Colloid Formation Characterization and Stability. Correlations of colloid size and method of preparation continued, using autocorrelation spectroscopy in collaboration with the Dynamic Transport Task (8.3.1.3.6.1). Sample preparation was completed, and cell design and construction are on hold for planned X-ray absorption spectroscopy studies. These experiments should provide the definitive molecular structural information for Pu(IV) colloid.

Activity 8.3.1.3.5.2.2 - Colloid Modeling. This activity was inactive for the reporting period.

2.2.2.12 Study 8.3.1.3.6.1 - Dynamic Transport Column Experiments

Study Plan 8.3.1.3.6.1 is being revised to incorporate YMPO and DOE/HQ comments.

Activity 8.3.1.3.6.1.1 - Crushed Tuff Column Experiments. Staff completed collecting preliminary data describing the transport behavior of strontium, cesium, barium, neptunium, and plutonium (in solutions prepared with water from 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. A paper and presentation for the IHLRWM Conference were prepared.

Activity 8.3.1.3.6.1.2 - Mass Transfer Kinetics. A paper was published on "Observation of Time Dependent Dispersion in Laboratory Scale Experiments with Intact Tuff" (Rundberg et al., 1991). The paper describes migration behavior of radionuclides Sr, Cs, and Ba through intact tuff. Time-dependent dispersion was investigated.

Activity 8.3.1.3.6.1.3 - Unsaturated Tuff Columns. Staff worked on establishing a collaborative agreement between Dr. James Conca and LANL. Dr. Conca is expected to assess 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.

Activity 8.3.1.3.6.1.4 - Fractured Tuff Column Studies. No progress during the reporting period due to insufficient funding.

Activity 8.3.1.3.6.1.5 - Filtration. The assessment of the capabilities of the autocorrelation photon spectrometer (APS), located at LANL, for the size determinations of colloidal particles of known sizes was the subject of "Size Determinations of Pu Colloids Using Autocorrelation Photon Spectroscopy" (Triay et al., 1991b) published in Radiochimica Acta. In this paper, the size distributions of Pu(IV) colloidal suspensions, synthesized by dilution, peptization, and auto-oxidation of Pu(III), were reported.

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.

Activity 8.3.1.3.6.2.1 - Uptake of Radionuclides on Rock Beakers in a Saturated System. No progress during the reporting period; this is a long-term experiment in progress.

Activity 8.3.1.3.6.2.2 - Diffusion through a Saturated Tuff Slab. The study of the uptake of radionuclides by intact tuff from solutions prepared with water from well J-13 was completed. The radionuclides studied were technetium, strontium, cesium, barium, neptunium, and americium. The data collected is under analysis using the code TRACRN.

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

Study Plan 8.3.1.3.7.1 revision based on DOE/HQ comments was completed and will be submitted to the YMPO in April in preparation for a comment resolution meeting.

Activity 8.3.1.3.7.1.1 - Analysis of Physical/Chemical Processes. The NAS/National Research Council panel met in November on coupled process analyses at Yucca Mountain. Staff were invited to attend this meeting to represent LANL's simulation efforts. The meeting focused on YMP efforts in coupling the effects of basin and range tectonics and heat flow processes on the regional water table near Yucca Mountain. The panel desires that scoping calculations include any credible mechanism for raising the water table. Individuals on the panel plan to be involved with some calculations themselves, but favor more YMP involvement in attempts to bound the problem.

Staff began work to obtain a Yucca Mountain 3-D grid and velocity profile for a far-field flow calculation. They should be able to simulate colloid transport for this 3-D system using Colloid Transport Code Nuclear (CTCN). Upgrading of the internal CTCN documentation to meet QA requirements is also in progress.

Activity 8.3.1.3.7.1.2 - Geomechanical/Geophysical Model of Yucca Mountain and Integrated Geochemical Transport Calculations. Work concentrated on discrete sensitivity analyses to bound the unsaturated zone transport problem and the initial efforts on model validation. Sensitivity analyses included examination of the effects of simulation dimensionality and geologically variable sorption on radionuclide transport. Calculations were completed for isotopes of cesium, technetium, and iodine--radionuclides that span the mobility of expected materials leached from emplaced waste. Calculations indicate that mobile radionuclides such as iodine and technetium, as opposed to cesium, appear to require more detailed analysis to predict migration. 3-D realizations of K_d, based on geostatistical mineralogic data, do not show significantly different migration plumes. However, 3-D analysis of transport indicates the potential for formation of fast paths to the water table that may not be seen in 2-D calculations. On the other hand, cesium

sorption is sufficiently strong that a lower level of detail in both K_d and dimension of analysis seems appropriate to predict migration. These analyses support the prioritization of sorption work by radionuclide; however, analyses of radionuclides of intermediate sorption are necessary. Further, hydrologic assumptions are likely to have the most profound effect on transport; therefore, we need to examine the sensitivity of results not only to permutations of the existing conceptual model but to fracture-dominated models as well.

With regard to validation, data were received from the Las Cruces Trench experiment, and staff are reviewing the data for Experiments 1, 2, and 2b--initially for simulation with TRACR3D and eventually with TRACRN. All these experiments appear to be well-documented and should provide a challenging test of LANL's ability to model transport. Staff began to review the Las Cruces Trench data to test our UZ zone-modeling methods.

Staff also began studies associated with boundary conditions for flow/transport calculations at Yucca Mountain. They will study the effects of washes and evapotranspiration on the distribution of infiltration at depth, using the code FEHMN, which will handle complex geometries, nonisothermal conditions, and evapotranspiration. This work involves close interaction with the USGS hydrology researchers, as well as with SNL, PNL, and LBL. Staff have set up an initial mesh.

Activity 8.3.1.3.7.1.3 - Transport Models and Related Support. The FEHMN users manual (also see 8.3.1.2.3.1.7) was completed; modifications to FEHMN dealt with improved boundary condition implementation, improved phase change numerics for superheated vapor to two-phase conditions, fixing some bugs in the stress module, and coding the double porosity tracer module.

Prompted by the need in the PACE work for 3-D graphics, a graphics capability was added to GENMSH, the preprocessor for FEHMN.

A Software Change Request, to bring TRACRN into compliance with the LANL SQAP, was submitted, and it was decided that a reverse engineering approach (LANL-YMP-SQAP, R0, Section 5.2.5.1) for pre-existing software should be used. The in-process review of the requirements phase for TRACRN was completed, and the Software Design Document and the Models and Methods Summary Document for TRACRN were written. These documents are being reviewed internally. NetCDF input interface-tables have been added to TRACRN, and work on the NetCDF output interface-tables is continuing. Memory management has been added to TRACRN, so that the code does not have to be recompiled for each problem setup, and it will tell the user how much memory will be required to run a problem. TRACRN was placed in a local configuration control system on a Sun network system, so that all codes changes can be tracked and users can interface more with SQAP requirements. Staff are trained in using this new system.

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.

2.2.2.16 Study 8.3.1.3.8.1 - Gaseous Radionuclide Transport Calculations and Measurements

This study was inactive.

2.2.3 Rock Characteristics (SCP Section 8.3.1.4)

2.2.3.1 Activity 8.3.4.1.1 - 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

YMPO and OCRWM comments on the draft Study Plan were reviewed and preliminary resolution of comments prepared.

Activity 8.3.1.4.2.1.1 - Surface and Subsurface Stratigraphic Studies of the Host Rock and Surrounding Units. A paper entitled "Assessing the Natural Performance of Felsic Tuffs Using the Rb-Sr and Sm-Nd Systems--A Study of Altered Zone in the Topopah Spring Member, Paintbrush Tuff, Yucca Mountain, Nevada" (Peterman et al.), was presented at the Materials Research Symposium meeting in Boston. Core samples of the Topopah Spring Member of the Paintbrush Tuff from drillhole UE-25a#1 were analyzed for Sr and Nd isotopes and selected minor and trace elements to constrain the origin of a zeolitized zone associated with the lower vitrophyre. The Sm-Nd radiogenic isotope system is unperturbed by the alteration. The Rb-Sr system shows open-system behavior due primarily to the addition of Sr to the altered zones. The thick densely-welded high silica rhyolite is remarkably uniform in composition and shows only a slight decrease in initial 87Sr/86Sr ratios with depth (0.7129-0.7125). Quartz latite in the upper Topopah Spring has significantly lower initial Sr isotope ratios (0.7095-0.7114). Locally in the altered zone in and near the lower vitrophyre, Sr and Ca were gained in substantial amounts, and K, Rb, and Y were depleted. Ti, Zr, Nb, Ba, La, Ce, Sm, and Nd were relatively immobile during the alteration. Sr added to the altered zone had an isotopic composition of 0.7119 +/-0.0002 and was probably derived from dissolution of glass in the bulk Topopah (high silica rhyolite + quartz latite) and transported downward by infiltration.

Ongoing activities centered on calibration of the energy dispersive X-ray fluorescence (EDXRF) system using USGS standard rock samples, validation of parts of the trace element data base for drill core samples, EDXRF analyses for the calcite/silica activity, laboratory maintenance, and calibration of the #2 mass spectrometer by multiple analyses of standard EN-1 with data

collected from ultra-stable signals at different intensities (check for nonlinearity in the measuring circuits). The data bases for minor and trace element data obtained by EDXRF continue to be checked for accuracy of data entry. In addition, verification continued of 6- to 8-year-old television fracture data from water-table boreholes.

YMP personnel prepared and analyzed 45 bulk-rock samples of drill core from USW H-1 and UE-25b#1 for energy dispersive XRF analyses (K, Ca, Tl, Rb, Sr, Y, Zr, Nb, Ba, La, and Ce), and developed a sample preparation protocol for outcrop samples of volcanic rocks.

Samples of carbonate vein fillings were obtained for strontium isotope analyses from a collection of drill core obtained from LANL. Drill core with additional carbonate vein fillings arrived from the Sample Management Facility and the "Yucca Mountain Room" was reorganized to accommodate these new samples.

Reports entitled "Paleomagnetic Constraints on the Geometry and Timing of Deformation of Yucca Mountain, Nevada" (Rosenbaum et al., 1991) and "Geologic Map of the Surficial Deposits of the Skull Mountain Quadrangle, Nye County, Nevada" (Swadley and Huckins, 1990) received YMPO approval.

A preliminary draft was prepared for technical procedure, GP-18, R1" Laboratory Analysis for Volcanic Stratigraphic Studies." In addition, a revision to technical procedure, GPP-11, "Magnetic Methods," was prepared.

Activity 8.3.1.4.2.1.3 - Borehole Geophysical Surveys. Work continued on summarizing the density, electrical, sonic, and permeability measurements on cores from USW G-3, USW G-4, and UE-25a#1.

Reports entitled "Geophysical Borehole Logging in the Unsaturated Zone, Yucca Mountain, Nevada" (Schimshal and Nelson) and "Major Results of Gravity and Magnetic Studies at Yucca Mountain, Nevada" (DOE, 1990j) were approved for presentation at the IHLRWM Conference to be held in Las Vegas, Nevada, on April 28 through May 2, 1991.

The transfer of televiewer and television data from the HP 9845 to the VAX computer was initiated so the fracture data can be merged with other log data.

During the first three weeks of January 1991, a diverse geophysical logging program was conducted in borehole USW G-2 at Yucca Mountain, Nevada. The purpose of the prototype operation was to collect the following:

1. A variety of density log data in support of a USGS calibration study.

2. Geochemical logging data to support a YMP evaluation of the new geochemical logging device for possible use during site characterization studies.

Three different logging service companies provided various services, allowing certain comparisons between generic logging tools of different vendors.

T&MSS filed an Operations Report and a "Logger's Log," a chronology of well site activities. The Operations Report will be used by the YMPO to guide its borehole geophysical logging program during site characterization of Yucca Mountain. Information from both reports will enable the YMP to establish its draft policy paper for geophysical logging during the site characterization phase. The T&MSS contractor has been tasked to provide a draft policy paper, which will be forthcoming after preliminary evaluation of the recently collected USW G-2 data.

The Operations Report contains recommendations on contracts, training, readiness, and field data collection techniques. The report, the precursor to a policy paper for geophysical logging, indicated that the existing contracts and procedures in place for geophysical logging on the NTS, including those specific to the YMP, will not adequately serve YMP needs during site characterization. The report included recommendations for the following actions for YMPO consideration:

Develop YMP-specific criteria for geophysical logging matters, including, but not limited to, contracts, data collection, and data management.

Separate geophysical logging for Weapons-related and non-Weapons-related work on the NTS and YMP.

Restructure the existing logging subcontract; specifically, that pertaining to Maintenance of Capability.

Provide a more commercially competitive atmosphere for procuring small-hole logging services on the NTS and YMP.

A subsequent report on data results, due in the last quarter of FY91, will be used to aid the YMPO in determining the generic types of logs to use for various site characterization purposes.

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

Review comments for Study Plan 8.3.1.4.2.2, Activities 8.3.1.4.2.2.3 and 8.3.1.4.2.2.5, were reviewed and comment responses have been incorporated. Marked-up text and comment resolution forms were submitted to the DOE in November. Comment resolution for this Study Plan is pending DOE scheduling.

Activity 8.3.1.4.2.2.1 - Geologic Mapping of Zonal Features in the Paintbrush Tuff. YMP personnel measured volcanic sections and collected samples of relatively-unaltered outcrops to be used in the development of "reference chemostratigraphic" sections. These reference sections will be helpful for the restart of geologic mapping and will be compared with future measurements at Yucca Mountain. Volcanic units included Topopah Spring, Calico Hills, and Crater Flat Tuffs.

A report entitled "Distribution of Rubidium, Strontium, and Zirconium in Tuffs from Two Deep Coreholes at Yucca Mountain, Nevada" (Spengler and

Peterman) was approved for presentation at the IHLRWM Conference to be held in Las Vegas, Nevada, on April 28 through May 2, 1991.

Staff participated in the field trip to Crater Flat and Death Valley organized for the NAS panel investigating tectonic and hydrologic coupled processes at Yucca Mountain. In addition, a presentation entitled "Status of Trace-Element Studies--Assessing the Natural Performance of the Rock Mass" (Spengler) was made as part of the CASY seminar "Isotope Geology, Hydrochemistry, and Geochemistry in Characterization Studies of Yucca Mountain."

YMP personnel conducted reconnaissance fieldwork in the northeastern part of the YMP study area. This trip was designed (1) to establish criteria for distinguishing between rhyolite flows of the Paintbrush Formation; (2) to define the structural fabric between Fortymile Canyon and Yucca Wash; and (3) to test the sample handling procedures of the Sample Management Facility. For the first objective, rhyolite flows near Yucca Wash and Paintbrush Canyon were studied in the field and 20 samples were collected for more detailed study; for the second objective, faults mapped by Christiansen and Lipman (1965) and Scott and Bonk (1984) were examined in the field; and for the third objective, core from the Apache Leap prototype borehole was examined in the SMF, and selected samples were marked for removal. Reconnaissance fieldwork was conducted at the north end of the Yucca Mountain study area to study Miocene-age rhyolitic lava flows between Fortymile Canyon and Yucca Wash. Particular attention was paid to basal vitrophyres that are situated above early pyroclastic deposits (surge flow, and fallout), and below thick devitrified zones. The vitrophyres should allow the original compositions of the rhyolite flows to be established, and estimates of the degree of post-emplacement alteration to be determined.

A spreadsheet application was developed for modeling combined crystal fractionation and assimilation of igneous systems. The application may be used to study magmatic processes that operated in the Timber Mountain magma chamber. Staff also began preparation of a report on the geology of rhyolite lava flows in the northeastern part of the Yucca Mountain site area. These rocks were originally mapped by R. Christiansen and P. Lipman in the 1960s. A question has arisen concerning vent areas for flows, and the impact of dikes and feeders for the flows, on the hydraulic regime at the north end of Yucca Mountain. One aspect of future field investigations will focus on the possibility that the steep hydraulic gradient is controlled in large part by these features. In addition, update of the geochemical data base continued with input of data from drillholes UE-25a#1 and UE-25b#1. Personnel also studied petrographic and geochemical data of the Fortymile Canyon rhyolites. The data provide detailed descriptions of Fortymile Canyon rhyolites, but will have limited usefulness for correlating rhyolites for the YMP.

Staff participated in a performance assessment meeting to explain current thoughts on models of tectonics, basaltic volcanism, and saturated zone processes for the development of "event trees" and refinement of calculational approaches to performance assessment. YMP members also participated in a two-day meeting to continue to refine the phase one approach to the prioritization of testing at Yucca Mountain. This meeting was one of a series of meetings focused specifically on evaluating combinations of tests and their

accuracies related to three top-ranked potential concerns of complex geology related to aqueous and gas flow, and basaltic volcanism.

Activity 8.3.1.4.2.2.2 - Surface Fracture Network Studies. Fieldwork continued on fracture outcrop studies including localities in the caprock unit of the Topopah Spring Member and in the upper lithophysal unit of the Tiva Canyon Member. As many as five individual fracture sets were identified at each locality, and cooling joint sets were recognized and characterized at each locality. Criteria are being developed to distinguish cooling joints from tectonic sets in each unit studied. Several computer software programs were compared for use for the outcrop fracture data base. In addition, staff attended a meeting with personnel from the Hydrologic Investigations Program to discuss an integrated approach to data collection for planned surface fracture studies in the Crater Flat Tuff. Technical procedure GP-12, "Mapping Fractures on Pavements, Outcrops and Along Traverses," was in revision.

Activity 8.3.1.4.2.2.4 - Geologic Mapping of the Exploratory Shaft and Drifts. Work continued on training and operation of the Kern DSR-11 analytical stereoplotter, and GEOPROGRAM data acquisition software for trench mapping. Development continued on data translators for rotation and projection of trench data as required prior to editing in KORKKDMS digital mapping system. Staff also reviewed the specifications for the test pit excavation.

Activity 8.3.1.4.2.2.5 - Seismic Tomography/Vertical Seismic Profiling. As a follow-up to work with the multicomponent, multisource VSP at the NTS, amplitude studies were carried out to determine relative attenuation of the P- and S-waves. The "Q" of the S-waves was 30 percent higher than that of the P-waves in the partially saturated section in the tuff. This has important implications for any VSP work at Yucca Mountain; it is further evidence that multicomponent data will be successful in imaging the structure at Yucca Mountain. ANRAY90 was improved to optimize the two-point ray tracer and to verify the cubic spline fitting routine. Modeling was conducted of the USW G-4 well log data using ANI90 (formerly ANRAY90). Modeling parameters have been implemented in 3-D to determine sensitivity to fracture content, saturation, fracture orientation, and density. Previous results using "conventional codes," i.e., codes that implement a bulk parameters approach, indicated that the results were sensitive to crack density and orientation. The latest results confirm this with the added result that 3-D polarization analysis may reduce the ambiguity between crack density and matrix anisotrophy. This program will be used to model well log information from USW G-4 and the C-hole complex (UE-25c#1, UE-25c#2, and UE-25c#3). In addition, preliminary drafts were prepared for technical procedures SP-13, "VSP and Crosshole Tomographic Surveys," and SP-17T, "VSP-Crosshole Seismic Imaging."

2.2.3.5 Study 8.3.1.4.2.3 - Three-Dimensional Geologic Model

No progress was made in the development of this Study Plan 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

Activity 8.3.1.4.3.1.1 - Systematic Drilling Program. The Study Plan for the Systematic Drilling Program has been prepared, reviewed by the YMPO and DOE/HQ, and returned for revision and resolution of comments. The text has been revised to incorporate comments, and comment resolution forms are being prepared.

It has been observed that many of the more significant comments received on the Study Plan concern the interaction of the Systematic Drilling Program with other SCP studies. Many studies are wholly or partially dependent upon this study for sample material or other information. In addition, it is intended that information regarding stratigraphic contacts, large-scale lithologic descriptions, and numerous hydrologic rock properties to be obtained by several other drilling programs be closely integrated with that obtained by the Systematic Drilling Program. These other studies include primarily Study 8.3.1.2.2.3, but also Studies 8.3.1.2.3.1, 8.3.1.2.2.4.9, and 8.3.4.4.2.5. The intended integration of site work has developed significantly beyond the plans which existed when the SCP was written, when most studies were relatively self-contained entities. It is not entirely clear how a single Study Plan can specify interactions with numerous other studies, and by extension, how these comments can be resolved in isolation. Some integration, particularly as it relates to physical sample material, can be afforded by the YMP Sample Overview Committee. Discussions of these problems and alternatives for their resolution via YMP-level committees, administrative procedures, and other means are continuing.

A scoping study has been developed that will expand upon previous efforts to refine spatial continuity patterns for various rock properties in tuff. This information is required to help defend current (SCP and Study Plan) plans for drillhole spacing and down-hole sample patterns. The work is in cooperation with the USGS (Study 8.3.1.2.2.3), and is also cast in the framework of helping to resolve modeling issues associated with site suitability analyses. The work includes outcrop sampling (both at Yucca Mountain and in similar tuffs elsewhere at NTS) and testing for material properties, followed by evaluation of spatial structure.

Changes in drillhole spacing may result from the scoping work being conducted both by this study and by the USGS (Study 8.3.1.2.2.3). Additionally, changes may result in proposed down-hole sampling patterns by other studies.

During the period, the report "Estimates of Spatial Correlation in Volcanic Tuff, Yucca Mountain, Nevada" (Rautman, 1991a) was completed. This report describes the results of some preliminary outcrop sampling and material properties data for porosity and air permeability for specimens of Calico Hills tuff. Some existing drillhole values of porosity, saturated hydraulic conductivity, and bulk density are also included. Geostatistical evaluation indicates that the range of correlation for porosity may be approximately 3,000 feet (1,000 meters) horizontally and about 200 feet (60 meters) vertically (stratigraphic coordinates). For the permeability properties, the range of correlation is no greater than about 300-500 feet (100-150 meters). Bulk density resembles porosity in the vertical dimension.

2.2.3.7 Study 8.3.1.4.3.2 - Three-Dimensional Rock Characteristics Models

Activity 8.3.1.4.3.2.1 - Development of Three-Dimensional Models of Rock Characteristics at the Repository Site. The major portion of the modeling work to be conducted by this study is considered out-year activity, and is dependent upon data to be obtained by site characterization. No Study Plan has been prepared, and how the requirements for (site) Study Plans will be applied to this analysis activity has not yet been determined.

Significant scoping activities to develop and practice intended modeling techniques have been conducted and the results reported in various forums. These techniques focused on geostatistical simulation algorithms and their implementation.

The following reports describe the application of geostatistical simulation methodology to unsaturated permeability data from the Yucca Mountain site, and the results of conducting unsaturated flow calculations on the resulting geologic models: "Characterization Uncertainty and Its Effects on Models and Performance" (Rautman and Treadway, 1990); "Geologic Uncertainty in a Regulatory Environment: An Example from the Proposed Yucca Mountain Nuclear Waste Repository Site" (Rautman and Treadway, 1991); and "Geostatistical Techniques for Describing and Modeling Heterogeneities in Rock Properties" (Rautman, 1991b), which describes how uncertainty in the resulting ground-water travel times is shown to be a function of the uncertainty in the description of the site.

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 in this study 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 was completed and submitted to the YMPO for review on October 25, 1990.

2.2.4.3 Study 8.3.1.5.1.3 - Climatic Implications of Terrestrial Paleoecology

Study Plan 8.3.1.5.1.3 was submitted to the YMPO for review on February 11, 1991.

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

Comments were returned from the DOE review of Study Plan 8.3.1.5.1.4 and comment resolution was completed January 9, 1991.

Activity 8.3.1.5.1.4.1 - Modeling of Soil Properties in the Yucca Mountain Region. A manuscript on Kyle Canyon soils was completed and submitted to the DOE for approval. Staff participated in a field trip to Yucca Mountain for the NWTRB and the NRC Technical Exchange in June, and also discussed work plans as described in Study Plan 8.3.1.17.4.6, Quaternary Faulting within the Site Area, at that exchange.

2.2.4.5 Study 8.3.1.5.1.5 - Paleoclimate-Paleoenvironmental Synthesis

No progress was made in the development of this Study Plan during the reporting period due to inadequate funding.

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

The work plan for WBS element 1.2.3.6.2.1.6 has been issued as a controlled document (no SCP activity). The National Center for Atmospheric Research (NCAR) has passed the QA mandatory hold point and the contract between SNL and the NCAR has been finalized for FY91. The draft Study Plan has been completed and is currently undergoing the SNL internal review.

Activity 8.3.1.5.1.6.1 - Global Climate Modeling. The final testing of the global climate model GENESIS has been completed. GENESIS is ready to be delivered to the global climate modeling group.

Activity 8.3.1.5.1.6.2 - Regional Climate Modeling. As part of 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 is expected to be completed by May 1991.

Activity 8.3.1.5.1.6.3 - Linked Global-Regional Climate Modeling. This is an out-year activity.

2.2.4.7 Study 8.3.1.5.2.1 - Characterization of the Quaternary Regional Hydrology

Study Plan 8.3.1.5.2.1 (Activity 1) was submitted for review by the YMPO in late September 1990.

Activity 8.3.1.5.2.1.1 - Regional Paleoflood Evaluations. Literature reviews of paleoflood knowledge and techniques used in paleoflood investigations are continuing until actual work at the site is approved. Field activities associated with ongoing monitoring of streamflow and flooding are continuing to provide spinoff information regarding candidate sites and situations amenable to future investigations of paleoflooding.

Activity 8.3.1.5.2.1.2 - Quaternary Unsaturated Zone Hydrochemical Analysis. The YMPO currently plans to transfer this activity to another Study Plan. The USGS is preparing a change request to alter the SCPB accordingly.

Activity 8.3.1.5.2.1.3 - Evaluation of Past Discharge Areas. A draft USGS open-file manuscript on ostracode time series data from the San Francisco area was submitted to the YMPO for concurrence. A semi-quantitative estimate of chrysophyte cyst abundance for samples from Ruby Marsh sites and surrounding areas was created. The information was then plotted on graphs showing all pair-wise combinations of available chemical data.

Surficial samples were collected from 31 dry playas from three states: 6 in New Mexico, 6 in Nevada, and 19 in California. Data will be used to calibrate ostracode response to playas supported by ground water versus those supported only by over-land runoff.

Water samples to be analyzed for strontium ion ratios and uranium age determination were collected from three pumping wells in NTS Area 25 and Crater Flat. Water samples were also collected for similar analyses from eight water table and hydrologic test-wells near Yucca Mountain.

A sampling trip with USGS Geologic Division staff of Activity 8.3.1.5.1.2.1 to the Amargosa Desert spring line and Death Valley collected samples from eight spring-sites for water quality and isotope data, and flora and fauna. These data are indicative of the present environment. The data also indicate the processes controlling 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. Therefore, information about paleoclimate can be gleaned from proxy data.

Data on depth of basement, soils, surface elevation, fracture systems, faults, and lineations were entered into the GIS Spatial Analysis System (SPANS) for the Amargosa Desert and part of the NTS.

Activity 8.3.1.5.2.1.4 - Analog Recharge Studies. Two field trips were conducted to the study sites. The area was experiencing below normal snow pack as of the January field trip. This may have been relieved with recent winter storms. There has been no discharge at one of the basins for more than one year.

A report entitled "Chemical Analysis of Water from Selected Wells and Springs in the Yucca Mountain Area, Nevada and Southern California" (McKinley et al.) was forwarded to the publisher in March.

The USGS automated data-processing system (ADAPS) was updated with preliminary data from both analog sites. Work is underway to put data into final format. This involves development of an understanding of the relationship of weather stations in central and south-central Nevada to the analog study areas so that data can be confirmed. The first draft was completed of a report describing the vegetation investigations at the analog sites.

Bulk precipitation samples were collected in January from the vicinity of the National Atmospheric Deposition Project sites in southern Arizona. In October, a 33-meter meteorological tower was installed at the study site in Organ Pipe Cactus National Monument in southern Arizona. Instrumentation will be installed as soon as calibration is completed. Scientists from the USGS,

National Research Program, and the Agricultural Research Service visited the vicinity of the tower site to investigate the relation between climate and vegetation distribution in stream channels. The New Mexico Institute of Mining and Technology initiated field work on soils dating and soil zone solute transport modeling. Several chlorine-36 dates have already been measured. Personnel at the University of New Mexico have essentially completed soils mapping and characterization; a copy of the finished work should be available within a month.

Activity 8.3.1.5.2.1.5 - Studies of Calcite and Opaline-Silica Vein Deposits. Reports entitled "Strontium Isotopes in Carbonate Deposits at Crater Flat, Nevada" (Marshall et al.) and "Isotopic Discontinuities in Ground Water Beneath Yucca Mountain, Nevada" (Stuckless et al.) were approved for presentation at the 1991 IHLRWM Conference.

The following technical procedures were in a state of revision: GCP-05, R2, "Radium-Equivalent Uranium, Thorium, and Potassium Analysis by Gamma Ray Spectrometry"; GCP-15, R3, "Oxygen Isotope Analysis of Opaline Silica, Chalcedony and Quartz"; GCP-17, R3, "Determination of the Isotopic Ratio of H/D in H2O"; and GCP-24, RO, "Modifications to U-Th-Pb Isotope Geochemistry Procedure." In addition, a preliminary draft was prepared for GCP-07, R2, "Mineral Separation for Geochemistry and Isotopic Analysis."

A search was completed for microfossils on residues from opaline-calcite veins. Staff also continued analyzing carbon and oxygen standards. It now appears that the mass spectrometer is back in calibration, but that the extraction lines have become contaminated. The problem will have to be corrected prior to restarting analysis of YMP samples.

Staff participated in a three-day field trip in the Yucca Mountain region for the NAS Panel on Coupled Processes.

A report entitled "Unpublished Letter from U.S. Geological Survey Scientists to the Editor of the New York Times Magazine Regarding William J. Broads's November 18, 1990, Article on Yucca Mountain" (Dudley et al., 1991) was published during the reporting period.

All necessary technical procedures for work in Trench 14 after planned deepening have been completed. Training to those procedures has also been completed. Environmental training and safety training have been completed by all those who expect to work in the field.

Preliminary analyses of drill core samples obtained from LANL through a recently-executed internal memorandum of understanding have been completed. Because the core is not qualified, the work is scoping in nature. Results do not duplicate the tight linear trends for isotopic composition with depth noted by Szabo and Kyser (1990), but do show a general tendency of increasing $\delta 180$ with depth. δD values do not show a good trend with depth, but rather show a more bimodal distribution. Analysis continued of carbonate samples from the Crater Flat area and of water and carbonate samples from the Ruby Mountains, which may be an analog to the deposits in the Las Vegas Valley. Staff also continued U-series work on mineral separations of calcite from the Crater Flat localities as well as on microsamples from blocks from Trench 14 that have been studied petrographically by LANL.

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

Study Plan 8.3.1.5.2.2 was submitted to the YMPO for review in January 1991.

Activity 8.3.1.5.2.2.1 - Analysis of Future Surface Hydrology Due to Climate Changes. No progress during reporting period due to lack of funding.

Activity 8.3.1.5.2.2.2 - Analysis of Future Unsaturated Zone Hydrology Due to Climatic Changes. A technical change request was submitted to YMPO by the USGS proposing the elimination of this activity because the scope of work will be performed in Activity 8.3.1.2.2.9.5, "Site Unsaturated-Zone Integration and Synthesis."

Activity 8.3.1.5.2.2.3 - Synthesis of Effects of Future Climate Change on the Hydrologic System. Development work on the isotope model SNODIF2 was completed and the preliminary version tested and compared with data sets from Snowshoe Mountain, Colorado. The model code is now being modified to include more parameters or parameter ranges found in the field. SNODIF2 was developed to aid the analysis of isotope data from water samples taken in the YMP area to determine the origin of the water. Intensive technical planning was conducted on approaches to store the various graphic data sets being generated by the YMP and the use of geoscientific information systems (GSIS) to aid the use of 3-D models. An abstract discussing the potential applications of 3-D GSISs to ground-water models was printed by the AGU (Turner, 1990).

2.2.5 Erosion (SCP Section 8.3.1.6.1)

No work will be carried out on erosion in FY91 due to lack of funding.

2.2.6 Postclosure Tectonics (SCP Section 8.3.1.8)

2.2.6.1 Study 8.3.1.8.1.1 - Probability of a Volcanic Eruption Penetrating the Repository

The Study Plan was transmitted to the NRC on June 19, 1990.

Activity 8.3.1.8.1.1.1 - Location and Timing of Volcanic Events. No progress during the reporting period due to a lack of permits.

Activity 8.3.1.8.1.1.2 - Evaluation of the Structural Controls of Basaltic Volcanic Activity. Staff examined the probability of disruption of a hypothetical repository located in the zone of active volcanism in the Lunar and Cima volcanic fields; 82 Quaternary centers that form 28 clusters have been identified in the Lunar Crater volcanic field. The field erupted >60 km^3 of magma. The probability of magmatic disruption of a hypothetical repository located in the active area of volcanism of the Lunar Crater volcanic field ranges from 1×10^{-6} yr^{-1} (vent count model) to 5×10^{-7} yr^{-1} (cluster model). A two order of magnitude decrease in the disruption probability (1 percent probability of disruption) is gained by locating the hypothetical repository 5 kilometers from the center of the active zone of volcanism.

Twenty-nine volcanic vents in 22 clusters have been identified in the Cima volcanic field. Greater than 20 km^3 of magma have been erupted in the field during the Quaternary. The probability of disruption of a hypothetical repository located in the zone of Quaternary basaltic volcanism in the Cima volcanic field is 3 x 10^{-7} yr^{-1} (vent count model) to 2 x 10^{-7} (cluster model). A two order of magnitude decrease in the disruption probability (1 percent probability of disruption) is acquired by locating the hypothetical repository 11 kilometers from the center of the volcanic field.

These calculations show that there is a regular and predictable geometry to the distribution of centers in volcanic fields. The degree of geographic dispersion of vents from the center of fields to the flanks is 10 kilometers. These considerations can be used to bound models of the structural controls of disruption of the potential repository. There are seven Quaternary volcanic centers in three clusters in the Yucca Mountain region. About 0.5 km^3 of magma were erupted in the region during the Quaternary. The distribution of volcanic centers defines a north-northwest trending zone. The closest approach of the zone to the structural block of Yucca Mountain is 12 kilometers.

The above data were presented to the NWTRB on March 1, 1991, and are in the official record of the meeting. The data were also presented to the GSA in March 1990.

Activity 8.3.1.8.1.1.3 - Presence of Magma Bodies in the Vicinity of the Site. Staff participated on the steering committee for SOBART (Southern Basin and Range Transect), a combined NSF-OBES-USGS project to plan and conduct field and drilling studies across Death Valley and extending into the Yucca Mountain region. As part of the duties, staff selected speakers and set up a schedule for a volcanism/magmatism section of the SOBART meeting in Phoenix.

Staff attended the four-day SOBART meeting in Phoenix. LANL personnel coordinated the second day of the meeting, which covered volcanism and magmatic processes, and presented talks on the basaltic volcanic history of the Yucca Mountain region and geochemical cycles of Crater Flat. A lengthy discussion took place on geophysical evidence of a possible magma chamber beneath southern Crater Flat and the Amargosa Valley. Letters discussing the possible existence of subsurface magma in the Amargosa Valley were exchanged with SOBART participants from the USGS and Stanford University.

Activity 8.3.1.8.1.1.4 - Probability Calculations and Assessment. The laser theodolite surveying system was successfully tested at the A Cone in the Cima volcanic field, and over 300 points were surveyed on the north flank of the cone in one day. The results were used as a trial data set and contoured using surface-display software. The approach of developing 3-D contour maps of volcanic centers using the theodolite surveying system appears feasible. These contour maps will be used for volume calculations.

The first draft of coding of a computer program that simulates random distribution of volcanic centers in a volcanic field was completed. The code will be debugged and qualified for the LANL SQAP. Runs of the computer code show that polycyclic activity may be expected in long-lived volcanic fields that do not show spatial migration of volcanism. The probability of

polycyclic events increases in direct proportion to increase in the area occupied by vent cones as a field develops. Rates of volcanic activity have been examined for the Cima and Lunar volcanic fields. Rate data from these fields show that the rate of volcanic activity in the Yucca Mountain region is bounded by 10^{-5} to 10^{-6} events per year. These results were presented to the NWTRB and the GSA in March 1991.

2.2.6.2 Study 8.3.1.8.1.2 - Effects of a Volcanic Eruption Penetrating the Repository

The Study Plan is in preparation.

Activity 8.3.1.8.1.2.1 - Effects on Strombolian Eruptions. A planning meeting was held to develop work plans for evaluating the effects of magmatic disruption of the potential repository.

A memorandum was written and submitted to the performance assessment staff, outlining boundary parameters for volcanic processes that should be used for calculations of the effects of magmatic disruption of the potential repository.

Activity 8.3.1.8.1.2.2 - Effects of Hydrovolcanic Eruptions. No progress during the reporting period; this is an out-year activity.

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 following receipt of review comments.

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 in this study 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 in this study 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

The Study Plan was accepted by the NRC for review on September 4, 1990. Review comments were received from the NRC and the State of Nevada, and responses were completed and submitted to the DOE.

A LANL QA surveillance was completed for consultants and research staff at the University of New Mexico. Four deficiency reports were noted, two of which were resolved during the surveillance. The participants in the volcanism study at the Las Vegas office were audited by LANL QA personnel. No deficiency reports were reported.

Activity 8.3.1.8.5.1.1 - Volcanism Drill Holes. No progress during the reporting period due to a lack of permits.

Activity 8.3.1.8.5.1.2 - Geochronology Studies. Four participants from the volcanism program attended and presented talks on surface exposure dating methods at the Penrose Conference, sponsored by the GSA.

Field sampling of soils to test the thermoluminescence (TL) dating method was completed for sites in the Snake River Plains. TL age estimates were obtained that are in close agreement with ^{14}C and K-Ar age determinations and soil correlations for deposits that range from 2 to 100 ka.

Convergent geochronology results were obtained for the A Cone lava flow in the Cima volcanic field for all methods except the $^{39}Ar/^{40}Ar$ method. Staff obtained TL ages of 7 to 10 ka. Independent researchers outside the YMP have obtained generally consistent results, including 14-20 ka (radiocarbon age on varnish), 10-30 ka (^{36}Cl), and about 12 ka (cosmogenic ^{3}He). The $^{39}Ar/^{40}Ar$ method yielded an age of about 138 ka. Staff obtained an age of about 25 ka for a baked soil beneath the Q13 lava at the Lathrop Wells center, which is consistent with soils and geomorphic data but inconsistent with K-Ar results (130 ka). A surface exposure age of about 15 ka, based on the $^{3}He/^{4}He$ method, was obtained for the middle scoria sequence of the A Cone at the Cima volcanic field. These results were presented to the NWTRB on March 1, 1991.

Activity 8.3.1.8.5.1.3 - Field Geologic Studies. A backhoe system was installed on a dual-wheel 4x4 truck that will be used to dig soil pits for soils studies and for sampling for TL studies. Participants from the volcanism task were trained in the safe operation of the truck. Locations in the Cima volcanic field that may be chosen for construction of soil pits were surveyed by DOE participants in the environmental program.

Participants from the volcanism program attended and made presentations during the field trip for the NAS subcommittee on coupled processes. Presentations were made at the Lathrop Wells center, Steve's Pass, Greenwater Mountains, and southern Death Valley.

Samples were collected from the Cima volcanic field from the A and I Cones for exposure age dating. Samples were collected from a lava flow unit of the Cima volcanic field that may provide data to evaluate the time variability of an Av zone using the TL method.

Sampling was completed of lava unit Ql6 at the Lathrop Wells volcanic center for U-Th disequilibrium studies for the geochronology activity. Sampling of two sites in the Lunar Crater volcanic field was also completed for U-Th disequilibrium studies and surface exposure dating by the ^{3}H method.

Analyses of the $^{3}He/^{4}He$ ratios of surface samples of volcanic units of the Lathrop Wells volcanic center were completed, which are part of an experiment to test for two sets of information. First, is the volcanic center polycyclic; and second, what are the ages of volcanic units at the center? Three sites were sampled, and data were obtained for two sites. A surface sample of the Ql4 lava yielded replicate age estimates of 49±6 and 39±8 ka. Bombs collected from the summit of the Lathrop Wells cone yielded age estimates of 26±5 ka and 22±6 ka. The production term of ^{3}He is not well constrained and could have a calibration uncertainty of 20 percent to 25 percent. The results are significantly younger than K-Ar and U-Th age estimates by slightly less than a factor of 3 for the lava and about a factor of 5 for the cone. The results support a recognizable difference in age between the Qs1 (cone) and the Ql4 lavas. These results were presented to the NWTRB on March 1, 1991.

Activity 8.3.1.8.5.1.4 - Geochemistry of Scoria Sequences. Instrumental neutron activation analysis (INAA) data were received from Washington University for basalt samples from the Lathrop Wells volcanic center. The data were evaluated using acceptance/rejection criteria. All data were judged acceptable except for chromium, nickel, and uranium.

Samples from Black Cone and Little Black Peak Cone were crushed, following sample-processing procedures, in preparation for geochemical analysis.

Activity 8.3.1.8.5.1.5 - Geochemical Cycles of Basaltic Volcanic Fields. A database reference system was developed for basaltic volcanic fields in the southwest United States; the system will be used to determine which basalt fields meet the selection criteria for studies of the evolutionary cycles of volcanic fields.

2.2.6.9 Study 8.3.1.8.5.2 - Characterization of Igneous Intrusive Features

Scoping work to support preparation of Study Plan 8.3.1.8.5.2 continued and an annotated outline was prepared.

Responses were prepared relative to igneous features in response to State of Nevada comments on the SCP.

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 in this study 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

YMPO and OCRWM comments on Study Plan 8.3.1.9.2.1 were reviewed and preliminary resolution of comments prepared during the reporting period.

2.2.7.2 Study 8.3.1.9.2.2 - Water Resource Assessment of Yucca Mountain

The Study Plan is currently in revision following receipt of comments from the YMPO, YMP participants, and DOE/HQ.

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 2, completed the review cycle and has been approved.

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, Revision 2.

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

The revised Meteorological Monitoring Plan was submitted for review as a Study Plan on September 28, 1990.

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, Revision 2.

2.2.9 Offsite Installations and Operations (SCP Section 8.3.1.13)

No work will be carried out on Offsite Installations and Operations in FY91 due to lack of funding.

2.2.10 Surface Characteristics (SCP Section 8.3.1.14)

A Study Plan incorporating Studies 8.3.1.14.2.1, .2, and .3 was prepared and reviewed by the YMPO.

2.2.10.1 Study 8.3.1.14.2.1 - Exploration Program

Activity 8.3.1.14.2.1.1 - Site Reconnaissance. No progress during the reporting period. Funding was not available to support this activity.

Activity 8.3.1.14.2.1.2 - Preliminary Exploration. No progress during the reporting period. Funding was not available to support this activity.

Activity 8.3.1.14.2.1.3 - Detailed Exploration. No progress during the reporting period. Funding was not available to support this activity.

2.2.10.2 Study 8.3.1.14.2.2 - Laboratory Tests and Material Property Measurements

No progress during the reporting period. Funding was not available to support this study.

Activity 8.3.1.14.2.2.1 - Physical Property and Index Laboratory Tests. No progress during the reporting period due to lack of funding.

Activity 8.3.1.14.2.2.2 - Mechanical and Dynamic Laboratory Property Tests. No progress during the reporting period due to lack of funding.

2.2.10.3 Study 8.3.1.14.2.3 - Field Tests and Characterization Measurements

No progress during the reporting period. Funding was not available to support this study.

Activity 8.3.1.14.2.3.1 - Physical Property Field Tests and Characterization. No progress during the reporting period due to lack of funding.

Activity 8.3.1.14.2.3.2 - Mechanical Property Field Tests. No progress during the reporting period due to lack of funding.

Activity 8.3.1.14.2.3.3 - Geophysical Field Measurements. No progress during the reporting period due to lack of funding.

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

Activity 8.3.1.15.1.1.1 - Density and Porosity Characterization. No progress during this reporting period due to lack of funding.

Activity 8.3.1.15.1.1.2 - Volumetric Heat Capacity Characterization. Draft procedures to govern calibration and testing requirements are in various stages of review. One technical procedure (for calibration of mechanical and electrical measuring equipment used in thermal properties testing) was approved and issued. Some scoping tests were performed to evaluate the accuracy and precision of the test technique (adiabatic pulse calorimetry). Funding constraints halted work in this activity in January 1991.

Activity 8.3.1.15.1.1.3 - Thermal Conductivity Characterization. The same procedural progress as reported for Activity 8.3.1.15.1.1.2 also applies to this activity. Some scoping tests were performed to evaluate the accuracy and precision of the test technique (guarded heat-flow-meter and thermal comparator).

2.2.11.2 Study 8.3.1.15.1.2 - Laboratory Thermal Expansion Testing

Activity 8.3.1.15.1.2.1 - Thermal Expansion Characterization. Draft procedures which govern calibration requirements for this activity are in various stages of review. One technical procedure (calibration of mechanical and electrical measuring equipment used in thermal expansion testing) was approved and issued. A procedure to govern thermal expansion testing is being written. Several scoping tests will be conducted to evaluate the accuracy and precision of the test technique (pushrod dilatometry).

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

Technical review of Study Plan 8.3.1.15.1.3 was completed. It will be submitted to the NRC for review in the near future.

Delays in the schedule of these activities have occurred as a result of delays in surface-based drilling and construction of the ESF. General site characterization testing will not proceed until a large volume of appropriate, site-specific samples are collected.

Activity 8.3.1.15.1.3.1 - Compressive Mechanical Properties of Intact Rock at Baseline Experiment Conditions. The technical procedures for baseline-condition testing are being written in anticipation of the start of drilling activities in the near future. Baseline conditions are defined as saturated samples tested at room temperature, atmospheric pressure, and an axial strain rate of $10^{-5}s^{-1}$.

Activity 8.3.1.15.1.3.2 - Effects of Variable Environmental Conditions on Mechanical Properties. The technical procedures for a series of low-strain-rate and constant-stress (creep) experiments have been completed and approved. In addition, two experiments at a nominal axial strain rate of $10^{-9}s^{-1}$ have been completed and the data are being reduced and analyzed. This series of experiments will provide data concerning the time dependent deformation of the Topopah Spring welded tuff.

A paper entitled "Mechanical Anisotropy of the Yucca Mountain Tuffs" (Price et al.) has been approved for presentation and publication at the 1991 IHLRWM Conference.

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 management review and the submittal to the YMPO is anticipated in April.

Delays in the schedule of these activities have occurred as a result of delays in surface-based drilling and construction of the ESF. General site characterization testing will not proceed until a large volume of appropriate, site-specific samples are collected.

Activity 8.3.1.15.1.4.1 - Mechanical Properties of Fractures at Baseline Experiment Conditions. A laser profilometer has been developed and is being tested. This tool will aid in the characterization of naturally-occurring and artificially-produced fracture surfaces. These data will be analyzed and used in an attempt to predict in situ behavior from laboratory mechanical test results.

Activity 8.3.15.1.4.2 - Effects of Variable Environmental Conditions on Mechanical Properties of Fractures. Some scoping experiments are being run to compare results from rotary and triaxial friction techniques and to begin an investigation of the time dependent behavior of fractures.

2.2.11.5 Study 8.3.1.15.1.5 - Excavation Investigations

The preparedness review for Work Plan 1.2.4.2.1.1.1 has been completed. The work encompassed by this plan cannot be conducted until the ESF is completed. The work in the ESF will be controlled by Study Plan 8.3.1.15.1.5.

Prototype testing activities were canceled for activities under this study due to closure of G-Tunnel.

Activity 8.3.1.15.1.5.1 - Shaft Convergence. No progress during the reporting period due to lack of funding.

Activity 8.3.1.15.1.5.2 - Demonstration Breakout Rooms. No progress during the reporting period due to lack of funding.

Activity 8.3.1.15.1.5.3 - Sequential Drift Mining. No progress during the reporting period due to lack of funding.

2.2.11.6 Study 8.3.1.15.1.6 - In Situ Thermomechanical Properties

Work plans and associated preparedness review notebooks for these WBS elements were completed. Information on costs and activities for long-range planning were entered into the Planning and Cost Scheduling (PACS) system.

Two meetings of the Exploratory Studies Test Committee were held in Las Vegas during this reporting period. Principal Investigators engaged in site characterization testing discussed their respective status. In general, little activity has been supported in the testing area. A brief review of the design requirements for testing (Exploratory Studies Facility Design Requirements Document) (ESFDR) was provided by YMP participants.

A review of the thermomechanical and mechanical experiments planned for the ESF was completed by the Yucca Mountain Rock Mechanics Review Panel during the month of September 1990. In response to input from the panel, these experiments are being scrutinized. Decisions will be made regarding the viability of each test from several different perspectives: (1) rock mechanics feasibility, (2) model validation, (3) risk/benefit, (4) issues resolution, and (5) potential to deploy successfully without prototype experiments. (SCP Activities 8.3.1.15.1.6 and 8.3.1.15.1.7)

As of March 22, 1991, these WBS elements and other supporting fielding of geomechanical tests in the ESF (namely, 1.2.4.2.1.1.1, 1.2.4.2.1.1.2, 1.2.4.2.1.1.3, and 1.2.4.2.1.1.4) have been reduced to zero budget. The principal impacts of this budget shift will be that Study Plans 8.3.1.15.1.6 and 8.3.1.15.1.7 will be delayed indefinitely, and SNL will be able to provide only very limited support to the Test Manager's Office for test related activities other than those in direct support of the ESF design effort. The SNL PACS system will be modified to reflect these changes.

Activity 8.3.1.15.1.6.1 - Heater Experiment in Unit TSw1. No progress during the reporting period due to lack of funding.

Activity 8.3.1.15.1.6.2 - Canister-Scale Heater Experiment. No progress during the reporting period due to lack of funding.

Activity 8.3.1.15.1.6.3 - Yucca Mountain Heated Block. No progress during the reporting period due to lack of funding.

Activity 8.3.1.15.1.6.4 - Thermal Stress Measurement. No progress during the reporting period due to lack of funding.

Activity 8.3.1.15.1.6.5 - Heated Room Experiment. No progress during the reporting period due to lack of funding.

2.2.11.7 Study 8.3.1.15.1.7 - In Situ Mechanical Properties

Work Plan 1.2.4.2.1.1.3, "In Situ Mechanical Properties," was completed and issued as a controlled document. The plan includes the rock mass response experiments and the plate loading tests to be conducted in the ESF and certain accesses. The preparedness review was completed. The work in this plan cannot start until the underground excavations are well-advanced. The feasibility of deployment of the plate loading test outside the ESF depends upon the proposed repository/ESF configuration. This work will be controlled by Study Plan 8.3.1.15.1.7.

Activity 8.3.1.15.1.7.1 - Plate Loading Tests. Given under Study 8.3.1.15.1.7.

Activity 8.3.1.15.1.7.2 - Rock-Mass Strength Experiment. Given under Study 8.3.1.15.1.7.

2.2.11.8 Study 8.3.1.15.1.8 - In Situ Design Verification

Study Plan 8.3.1.15.1.8, "In Situ Design Verification," was submitted to the YMPO for review.

Work Plan 1.2.4.2.1.1.4, "In Situ Design Verification," was completed and issued as a controlled document. The preparedness review has been completed. The work in this plan cannot start until the underground excavations are well-advanced. This work will be controlled by Study Plan 8.3.1.15.1.8.

The prototype testing activities listed below have been canceled due to the closure of G-Tunnel.

Activity 8.3.1.15.1.8.1 - Evaluation of Mining Methods. No progress during the reporting period due to lack of funding.

Activity 8.3.1.15.1.8.2 - Monitoring of Ground-Support Systems. No progress during the reporting period due to lack of funding.

Activity 8.3.1.15.1.8.3 - Monitoring Drift Stability. No progress during the reporting period due to lack of funding.

Activity 8.3.1.15.1.8.4 - Air Quality and Ventilation Experiments. No progress during the reporting period due to lack of funding.

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.

Activity 8.3.1.15.2.1.1 - Anelastic Strain Recovery Experiments in Core Holes. 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

An outline for Study Plan 8.3.1.15.2.2 was prepared.

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 submitted to the NRC for acceptance in October 1990. The Study Plan is in its final stages of review by the NRC. Resolution of review comments made by the State of Nevada is also nearing completion.

Activity 8.3.1.16.1.1.1 - Site Flood and Debris Hazards Studies. The intense convective storms that ranged throughout southern Nevada during the summer of 1990 resulted in only minor effects in the drainages directly associated with Yucca Mountain. As a result, local runoff did not occur at or near the site. A few small storms during the winter of 1990-91 have restored some moisture to soils mantling the land surface at and surrounding Yucca Mountain, but none of the precipitation events were adequate to promote surface runoff or flooding.

A recent visit to the Yucca Mountain area resulted in important information regarding historic flooding. An encounter with an NTS employee revealed that he had been an eyewitness to flooding that was caused by the severe and widespread storm of late February 1969. The eyewitness observed intensive runoff in Fortymile Wash from a vantage point on the high, east-valley wall of the wash near water well J-12. His observations and recollections provide long-sought information on the magnitude and characteristics of Fortymile Wash runoff during this historic episode of major regional flooding.

Ongoing monitoring is continuing of weather conditions and situations conducive to flooding.

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

2.2.13 Preclosure Tectonics (SCP Section 8.3.1.17)

2.2.13.1 Study 8.3.1.17.1.1 - Potential for Ashfall at the Site

This study was inactive during the reporting period.

2.2.13.2 Study 8.3.1.17.2.1 - Faulting Potential at the Repository

No progress during the reporting period. Funding was not available to support this study.

Activity 8.3.1.17.2.1.1 - Assess the Potential for Surface Faulting at Prospective Sites of Surface Facilities Important to Safety. Inactive during the reporting period, as funding was not available to support this activity.

Activity 8.3.1.17.2.1.2 - Assess the Potential for Displacement on Faults That Intersect Underground Facilities. Unnamed SAND Report in preparation.

2.2.13.3 Study 8.3.1.17.3.1 - Relevant Earthquake Sources

YMPO and OCRWM comments on the draft Study Plan were reviewed, and preliminary comment resolutions were prepared.

2.2.13.4 Study 8.3.1.17.3.2 - Underground Nuclear Explosion Sources

This is an out-year activity.

Activity 8.3.1.17.3.2.1 - Determine the Range of UNE Sources. This is an out-year activity.

Activity 8.3.1.17.3.2.2 - Determine Maximum Underground Nuclear Explosion Sources. 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)

Activity 8.3.1.17.3.3.2 - Select or Develop Empirical Models for Ground Motion From Underground Nuclear Explosions. Activities during this reporting period emphasized submittal of data acquired during 13 UNEs to the Local Records Center. Data submittal (raw data, digitized data, and data evaluations) was delayed pending approval and implementation of a software program that would facilitate translation of raw data into physical values.

Retrieval of downhole instrumentation from USW G-2, USW GU-3, and UE-25RF4 was completed. Instrumentation in USW G-1 was not removed because of cost constraints; the presence of this instrumentation should not adversely affect installation of new equipment in the hole or other YMP objectives. (No SCP Activity.)

SAND91-2507C, "Weapons Test Seismic Investigations at Yucca Mountain" (Phillips et al.), has received YMPO approval for presentation at the IHLRWM Conference to be held April 28 through May 2, 1991, in Las Vegas, Nevada.

2.2.13.6 Study 8.3.1.17.3.4 - Effects of Local Site Geology on Surface and Subsurface Motions

YMPO and OCRWM comments for Study Plan 8.3.1.17.3.4 were reviewed, and preliminary comment resolutions were prepared.

2.2.13.7 Study 8.3.1.17.3.5 - Ground Motion at the Site from Controlling Seismic Events

Study Plan 8.3.1.17.3.5 was completed and submitted to DOE on October 4, 1990.

Activity 8.3.1.17.3.5.1 - Identify Controlling Seismic Events. This is an out-year activity.

Activity 8.3.1.17.3.5.2 - Characterize Ground Motion From the Controlling Seismic Events. This is an out-year activity.

2.2.13.8 Study 8.3.1.17.3.6 - Probabilistic Seismic Hazards Analyses

This is an out-year activity.

Activity 8.3.1.17.3.6.1 - Evaluate Earthquake Sources. This is an out-year activity.

Activity 8.3.1.17.3.6.2 - Evaluate Ground Motion Probabilities. This is an out-year activity.

2.2.13.9 Study 8.3.1.17.4.1 - Historical and Current Seismicity

Study Plan 8.3.1.17.4.1 was transmitted to the NRC on October 22, 1990.

Activity 8.3.1.17.4.1.2 - Monitor Current Seismicity. Seismometer testing benchmarks were established and sites were surveyed for deployment of the portable seismometers in Midway Valley. Testing of 16 portable seismometers was conducted in the field by deploying them across and around Yucca Mountain and recording broadband ground motion.

Several portable seismographs were modified and the evaluation of data acquisition and telemetry system proposals for the network upgrade were completed. Software development for the upgrade continued. Portable seismograph tests, installation, and operation procedures were in the process of being developed. Technical procedure SP-15, RO, "Compilation and Analysis of Non-Instrumental Historical Earthquake Intensities Data," was approved.

A presentation was made at the Rocky Mountain AGU meeting on hazard assessment in intra-plate regions (the southern Great Basin was used as an example). A poster was presented at the 1990 AGU in San Francisco entitled, "Seismicity Detection/Location Threshold and Strain in the Southern Great Basin" (Gomberg). A second poster was presented at the USGS annual "Expose Yourself to Science" exhibition; the poster was entitled "The Effect of S-Wave Arrival Times on the Accuracy of Hypocenter Estimation" (Gomberg).

2.2.13.10 Study 8.3.1.17.4.2 - Location and Recency of Faulting Near Prospective Surface Facilities

Progress continued on previously authorized, non-surface-disturbing work within Midway Valley. Non-surface-disturbing work is that which does not require excavation, drilling, or off-road access by vehicles. The majority of the effort for WBS element 1.2.3.2.8.4.2 requires environmental permits for surface-disturbing work; these permits have not been issued. Until these permits are issued, only a limited portion of the overall objectives of SCP Study 8.3.1.17.4.2, "Study Plan for Evaluating the Location and Recency of Faulting Near Prospective Surface Facilities," can be completed.

A compilation and evaluation of existing geological and geophysical data was completed. Fieldwork continued on defining and mapping surficial geologic units. A lineament analysis of available imagery was performed with limited field inspection of photolineaments.

Two SAND reports were prepared for this WBS element and submitted to the YMPO for policy review: (1) SAND90-2491, "Summary and Evaluation of Existing Geological and Geophysical Data Near Prospective Surface Facilities in Midway Valley" (Gibson et al., 1990); and (2) SAND91-0607, "Preliminary Mapping of Surficial Geology of Midway Valley, Yucca Mountain Project, Nye County, Nevada" (Wesling et al., 1991). SAND90-2491 summarizes all existing geological work done within Midway Valley and forms the basis for additional research. SAND91-0607 presents surficial geologic and photolineament maps at 1:6000 and a description of these mapping units.

Job Package 90-01 was prepared by the DOE, SNL, and other participants for initial surface-disturbing work in the form of excavations to the north of Exile Hill along the Bow Ridge Fault near the western margin of Midway Valley. A Readiness Review found that all prerequisites were satisfied except acquiring the necessary environmental permits.

Further work on the Midway Valley Study is postponed until environmental permits are obtained.

Activity 8.3.1.17.4.2.1 - Identify Appropriate Trench Locations in Midway Valley. See above information for Study 8.3.1.17.4.2.

Activity 8.3.1.17.4.2.2 - Conduct Exploratory Trenching in Midway Valley. See above information for Study 8.3.1.17.4.2.

2.2.13.11 Study 8.3.1.17.4.3 - Quaternary Faulting within 100 Km of Yucca Mountain, including the Walker Lane

A preliminary draft of Study Plan 8.3.1.17.4.3 is nearly complete.

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 major product to date for this activity is completion of the report "Status of Data, Major Results, and Plans for Geophysical Activities, Yucca Mountain Project," (DOE, 1990j). NRC concern with the adequacy and overall integration of geophysical activities in the SCP/CD was the impetus for DOE to prepare this white paper report. The report was distributed during the reporting period.

An initial resistivity depth analysis was conducted of 35 deep-penetrating electrical soundings acquired using the magnetotelluric (MT) method in 1986. Sections were contoured to show the main features of resistivity structure along several contiguous sections totaling 170 kilometers in length, and penetrating up to 25 kilometers in depth. The sections are produced by a method that directly reduces observed data (frequency-impedance) to depth-resistivity. The method, which was developed by F. Bostick, University of Texas, Austin, graphically displays the uncertainties, resolution, depth of penetration, and probable true resistivities with a minimum of subjective judgments such as required in forward modeling. The sections are to be part of the data report for the 1986 MT survey.

A videotape was reviewed that presented the recommendations of the panel members of the Seismic Reflection/Refraction Peer Panel, held September 11-13, 1990, in Las Vegas, Nevada. Staff also consulted with LANL and others on possible deep drilling to investigate postulated continuing volcanism at Crater Flat.

Compilation and evaluation was started on 25 dipole-dipole sections in the vicinity of Yucca Mountain. The dipole-dipole work is significant because of the density of data across the northern part of Yucca Mountain. It also includes data in Crater Flat, Yucca Wash, and Jackass Flats. Work continued to complete plates showing unpublished dipole-dipole data on Yucca Mountain.

This work is aimed toward presenting an integrated picture of data acquired on Yucca Mountain up to about 1982. The extent of the data is indicated in Chapter 2 of the "White Paper" report (DOE, 1990j). In addition to the data reported in YMP/90-38, there are 34 additional dipole-dipole lines which have not been released but may have value. Work in the first quarter of FY91 was largely focused on putting this data into presentable form for analysis.

Efforts were also directed toward continuing the draft work on the electrical traverses in the Yucca Mountain area. The draft versions of maps showing all USGS electrical data have been completed and now cross-sections for unpublished lines on DC-electric surveys are being worked on using the dipole-dipole method.

A paper entitled "Is Yucca Mountain, Nevada, a Safe Place to Store High-Level Nuclear Waste?--Major Issues, Results to Date, and Comparisons with European Plans" (Oliver) was presented to the Peninsula Geological Society at Stanford University on November 15, 1990.

A report entitled "Feasibility Study of the Seismic Reflection Method in the Amargosa Desert, Nye County, Nevada" (Brocher et al., 1990) was published during the reporting period. In addition, eight other geophysical reports were in various stages of preparation and approval.

Technical procedure GP-18, "Magnetotelluric Surveys," was revised and a preliminary draft was prepared for SP-14, "Shallow Seismic Reflection Profiling (Mini-Sosie)."

Activity 8.3.1.17.4.3.2 - Evaluate Quaternary Faults within 100 Km of Yucca Mountain. The air-photo interpretation of Quaternary faulting in the western part of Las Vegas 1° x 2° quadrangle was completed.

2.2.13.12 Study 8.3.1.17.4.4 - Quaternary Faulting Proximal to the Site within Northeast-Trending Fault Zones

The first draft of Study Plan 8.3.1.17.4.4 was in the final stages of preparation.

2.2.13.13 Study 8.3.1.17.4.5 - Detachment Faults at or Proximal to Yucca Mountain

Study Plan 8.3.1.17.4.5 was in review by the DOE.

2.2.13.14 Study 8.3.1.17.4.6 - Quaternary Faulting within the Site Area

Response was made to DOE verification review of Study Plan 8.3.1.17.4.6, and preparation of responses to DOE comments continued.

Activity 8.3.1.17.4.6.1 - Evaluate Quaternary Geology and Potential Quaternary Faults at Yucca Mountain. Separation and purification were completed of about 25 carbonate samples from the Crater Flat, Amargosa Desert, and Busted Butte areas for eventual U-series dating.

Personnel from USGS and SNL field-checked photogeologic interpretations of faults and lineaments at Yucca Mountain. Potential applications of cation-ratio dating of geomorphic surfaces cut and offset by faults to the problem of estimating slip-rates were also evaluated. Surfaces cut by the Windy Wash, Fatigue Wash, and Stagecoach Road faults appear amenable to dating by this method. Work continued on prototype digitized geologic maps of Yucca Mountain (1:24,000), Yucca Mountain (1:48,000), and Crater Flat (1:62,500). While problems remain in scaling symbols and labels, it appears that the methodology for producing and maintaining continuously-current digital geologic, surficial geologic, and fault maps of Yucca Mountain is in place, and that the activity is ready to incorporate new data in the data base.

The central section of the south wall of Trench 14 was mapped from previously acquired stereophotographs, digitized using the DSR-11 (Kern Analytical Plotter), sent to the GIS database, then translated to the Kork Digital Mapping System. The south wall of Trench 14D was examined and the existing mapping verified. Carbonate veins from Trench 14 were analyzed for uranium series, and work continued on the new computer system for alpha counting.

A field trip was conducted at Yucca Mountain, Crater Flat, and Travertine Point on January 29 and 30. The field trip was designed to acquaint members of the NAS Panel on Coupled Processes with tectonic and hydrologic features of the Yucca Mountain area. Preparation for the field trip included reconnaissance of the Fatigue Wash Fault scarp, and the Windy Wash fault trenches. The scarp appears very youthful--perhaps Late Pleistocene or Holocene, judging from its geomorphic expression. During the field trip, slickensides were found at Trench CF-2 (Windy Wash fault) indicating left oblique slip.

2.2.13.15 Study 8.3.1.17.4.7 - Subsurface Geometry and Concealed Extensions of Quaternary Faults at Yucca Mountain

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

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

An annotated outline for Study Plan 8.3.1.17.4.9 was completed.

2.2.13.18 Study 8.3.1.17.4.10 - Geodetic Leveling

Comment resolution on Study Plan 8.3.1.17.4.10 was completed October 15, 1990.

Activity 8.3.1.17.4.10.1 - Relevel Base-Station Network, Yucca Mountain and Vicinity. Approximately 45 percent of the leveling was completed. A second set of software documents was submitted. A preliminary draft was prepared for technical procedure, GP-06, "Geodetic Leveling and Trilateration Surveys."

2.2.13.19 Study 8.3.1.17.5.11 - Characterization of Regional Lateral Crustal Movement

No progress was made in this study 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

Activity 8.3.1.17.4.12.1 - Evaluate Tectonic Processes and Tectonic Stability at the Site. Staff prepared for and participated in the October 18-20 field trip to Yucca Mountain, Crater Flat, and Death Valley, leading the discussion at Yucca Mountain Crest, at Artist's Drive, and at the Badwater Turtleback. The three-day excursion was organized for the NAS Panel on Coupled Processes.

YMP personnel attended a demonstration of software designed to produce balanced cross-sections, hosted by GeoLogic, Inc. of Boulder, Colorado. A principal topic of the demonstration was a presentation and discussion of a balanced cross-section of Yucca Mountain. Using data from the Scott and Bonk (1984) map of Yucca Mountain, a balanced cross-section was developed, featuring listric faults merging with a detachment at 4-kilometer depth. Faults must be listric to accommodate the roll-over structure in the hanging wall, as mapped by Scott and Bonk (1984).

Staff participated in a performance assessment meeting at DOE Las Vegas, on January 15, 1991. The meeting was devoted to discussion of tectonic event trees.

2.3 REPOSITORY OVERVIEW

In this WBS element, analysis methods in the disciplines of geomechanics, seismic hazards, ventilation, and safety are studied. The scope of work for these disciplines ranges from code and methodology development through verification/validation of these codes and methodology and includes benchmarking and parametric studies. This work is applied to design, and pre- and postclosure performance assessment.

2.3.1 Geomechanical Analyses (SCP Section 8.3.2.1.4.1)

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

Work continued on documenting the codes required for ESF Design Analyses. Code validation analyses are being planned in conjunction with the tests performed under WBS 1.2.4.2.1.3. A preliminary draft user's and theory manual for JAC-3D, a 3-D computer code for structural analyses, was completed. The report will be submitted for internal review in the near future.

An integral part of the strategy for model validation requires acceptance of the methods used by the international scientific community.

SAND90-2817C, "Experiment and Analysis Comparison in Support of the Yucca Mountain Project" (Chen et al.), was submitted to the YMPO for policy review. The paper will be presented at the 7th Conference of the International Association for Computer Methods and Advance in Geomechanics to be held in Cairns, Queensland, Australia, on May 6-10, 1991.

Work continued to streamline the compliant-joint model, so that it will be able to run more efficiently, and thus become a more useful analysis tool.

The study to include the block interlock capability into the current compliant joint model was initiated. Under large shear loads, the present model allows unlimited joint slippage, which is unrealistic given the blocky structure of the rock mass. However, by gaining the capability to treat physically more realistic problems, the model will become mathematically more complex. Analytical treatment of block interlock has been studied and exercised in code calculations. Added numerical complexities tend to increase computations and slow down code executions. In addition, a major problem involves setting the limit of slippage due to the lack of experimental data.

SNL staff attended three-day and four-day software QA workshops sponsored by the YMPO. The workshops were convened to identify problems with software quality assurance and to attempt to develop solutions to those problems. An action plan was developed to address the identified problems. A presentation was made to YMP management at the close of the second meeting. S. J. Bauer will represent SNL at future meetings of the Project Software Advisory Group.

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

This is an out-year activity.

2.4.1.3 Design Activity 1.11.1.3 - Document Reference Three-Dimensional Thermal/Mechanical Stratigraphy of Yucca Mountain

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

2.4.1.4 Design Activity 1.11.1.4 - Preparation of Reference Properties for the Reference Information Base

Work to develop techniques to profile the surface of natural fractures of tuff and then to perform shear tests on those fractures continued at the University of Colorado at Boulder. Preliminary experiments are being run to shake down the system in order to initiate testing. This work will be used to support constitutive model development and to provide scoping data for the Reference Information Base (RIB).

Work is being planned that will focus on an analysis of fracture data for the Yucca Mountain thermomechanical stratigraphy. A Design Investigation Memo (DIM) to define and control this work is being drafted. The result of the analysis will be included in the RIB. Once the fracture data has been analyzed, other mechanical work mass properties will be empirically derived to support the ESF design. To further support the ESF design, a DIM, entitled "Assessment of Rock Mass Strength Criteria," was drafted.

The scope of work on this DIM will include a review of rock mass strength criteria. This review will result in a compilation of summaries of those criteria. As a means of comparison, the criteria will be presented in a manner such that the mechanism(s) of failure considered in each criterion is

delineated, as well as the bases for the criterion (for example, field observations, laboratory tests, field tests, theory, etc.). Using the above presentation method, an evaluation of the criteria will be made. The result of this evaluation may be adoption of specific criteria, or a strategy in which one criterion is used for certain physical situations and another criterion invoked for other physical situations. Following this last step, recommendations will be made for experiments to test the recommended criteria. These recommendations may be conceptual in nature. For their evaluation, the recommended criteria will be compared with analysis results from Problem Definition Memo (PDM) 71-032 (the Benchmark Problem). The work completed on this DIM will be summarized in a letter report.

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

Work continued on a report which 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. Prior to submitting this report for SNL technical review, the results from an ongoing effort regarding the refinement of scaling techniques applied to account for waste age and burnup will need to be incorporated.

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

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 due to lack of funding.

2.4.1.16 Design Activity 1.11.6.1 - Thermal Loading for Underground Facility

YMPO approval was received for SAND85-7101, "A Thermomechanical Far-Field Model of Yucca Mountain" (Brandshaug), and the document is currently being prepared for publication. SAND85-7101 presents far-field thermal and mechanical results obtained from 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 potential repository, and includes a simplified model of pore water boiling. The mechanical model simulates the tuff at Yucca Mountain as being an elastic/plastic, isotropic, heterogeneous continuum with one ubiquitous vertical joint set.

YMPO approval was received for SAND87-2909, "Determination of Equivalent Thermal Loadings as a Function of Waste Age and Burnup" (Mansure and Petney), and the document is currently being prepared for publication. SAND87-2909 summarizes an effort to develop a method for determining equivalent thermal loadings for each type of spent fuel planned for emplacement at the potential nuclear waste repository at Yucca Mountain. Equivalent thermal loads were defined as that thermal load which would produce thermomechanical effects similar to the effect produced by spent fuel assumed to represent the baseline. Two methods of scaling waste emplacement for waste age and burnup were considered: (1) equivalence of total energy transferred to the host rock over a given period of time, and (2) equivalence of maximum rock temperature response at a given location within the modeled region.

SAND89-1989, "Areal Power Density: A Preliminary Examination of Underground Heat Transfer in a Yucca Mountain Repository and Recommendations

for Thermal Design Approaches" (Hertel and Ryder), has been submitted to the YMPO for policy review. This report summarizes a series of sensitivity studies that calculated 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 a maximum areal power density based strictly on thermal goals and assumptions regarding maximum extraction ratios and minimum canister spacings. Based on the results of this study, a recommendation to increase the repository design-basis areal power density from 57 kW/acre to 80 kW/acre has been made. Pending an investigation of such an increase in thermal loading on mechanical and operational concerns, this recommendation must be considered preliminary.

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

YMPO approval was received for SAND87-7079, "A Sensitivity Study of the Thermomechanical Far-Field Model of Yucca Mountain" (Brandshaug), and the document is currently being prepared for publication. SAND87-7079 presents the results of a sensitivity study conducted regarding the predicted thermal and mechanical behavior of the far-field model of Yucca Mountain. The model input parameters investigated include areal power density, thermal conductivity, specific heat capacity, material density, pore water boiling, finite-element mesh, Young's modulus, Poisson's ratio, coefficient of thermal expansion, in situ stress, rock matrix cohesion, rock matrix angle of internal friction, rock joint 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

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

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

This is an out-year activity.

2.4.1.22 Design Activity 1.11.7.2 - Documentation of Compliance

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

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 this activity, intact and rock mass properties are studied and evaluated to support preparation of reference properties for the RIB. Also, methods are developed and evaluated to gain an understanding of rock mass response to thermal and mechanical loads.

Phase I of the Laboratory Large Block Test, to have been performed at the Waterways Experiment Station, was all but completed. Phase I work involved characterization of a "brick" material which was to have been used in a block test at some point in the future. Phase I was summarized in an SNL letter report and is currently in review. Future work on the test has been postponed due to budgetary constraints.

A study on assessment of the potential effects of creep deformation of the tuffs upon the exploratory shaft liner, under DIM-256, was defined and initiated. Research involved with the study was completed and a report was completed and submitted for peer review. This work will support the ESFDR as one of the eleven performance related analyses.

A study to provide analytical support for development of high-pressure testing capabilities using large flatjacks was completed. A successful experiment was completed in the welded tuff in the Demonstration Drift of G-Tunnel at the NTS in August 1989. The purpose of this analysis is to gain experience in the modeling of jointed rock mass behavior using currently available numerical models and property data for the G-Tunnel welded tuff. In addition, through comparison of experimental and analytical results, a determination of the validity of various approximations required to analyze a 3-D problem with 2-D finite element models can be made. Finally, the analysis provides feedback to the experimenters regarding the design and execution of the experiment. The analysis has been completed and a letter report documenting the results has been prepared. The letter report is currently under review.

A second set of analyses using the first of two 3-D finite-element models of the flatjack development test was completed. This model contained discrete sliding surface representations of the joints in the test area. Because no discrete joint-constitutive model is available in JAC3D, the analyses were conducted using sliding surfaces with friction. Coefficients of friction of 0.0, 0.3, and 0.6 were used. Most of the experimental results fall between the results of the analyses using coefficients of friction of 0.3 and 0.6.

Relative sliding between many of the rock blocks was observed. Interestingly, the maximum tensile stresses occur at the experimentally-observed failure location.

The size of the first finite element model of the flatjack development test was based primarily on the extent of the fracture mapping of the test area. To investigate possible boundary effects on the results, a second much larger model was created. Because fracture mapping of the larger areas was not available, the rock mass stiffness was used for the new areas. Attempts to use this new model for analyses have been unsuccessful because the solutions would not converge. The cause for this was isolated to a numerical round-off problem in which sliding surfaces that should be in contact initially are not quite in contact. This problem is being addressed by modifying the code to bring all sliding surfaces into contact before the analysis begins.

DIM-257, "Assessment of the Potential Extent of Fracturing for the Pad, Column, and Shaft for the Exploratory Shaft Facility," was written and completed review. The work on this DIM will support development of the ESFDR and constitute work on one of the eleven performance-related analyses.

Excavation stability in an underground nuclear waste repository is required during construction, emplacement, retrieval (if required), and closure phases to ensure worker health and safety, and to prevent development of potential pathways for radionuclide migration in the post-closure period. Stable excavations are developed by appropriate excavation procedures, design of the room shape, design and installation of rock support reinforcement systems, and implementation of appropriate monitoring and maintenance programs. In addition to the loads imposed by the in situ stress field, the potential repository drifts will be impacted by thermal loads developed after waste emplacement and, periodically, by seismic loads from naturally-occurring earthquakes and underground nuclear events. A priori evaluation of stability is required for design of the ground support system, to confirm that the thermal loads are reasonable, and to support the license application process.

Two papers which address the problem of excavation stability in mined openings have completed SNL management reviews. In these reports, a design methodology for assessing drift stability is presented. This is based on site conditions, together with empirical data and analytical methods. Analytical numerical methods are emphasized at this time because empirical data are unavailable for excavations in welded tuff either at elevated temperatures or under seismic loads. The analytical methodology incorporates analysis of rock masses that are systematically jointed, randomly jointed, and sparsely jointed. In situ thermal and seismic loads 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. This methodology is expected to evolve as excavation observation at the ESF demonstrates the controlling deformation mechanisms and allows site-specific evaluation of in situ properties. As more experience is gained at the site, design based on empirical and observational methods will emerge for application during construction of a repository.

A report on preliminary evaluation of 3-D far-field analysis for the ESF was completed by J.F.T. Agapito and Associates. This report describes a numerical study of the potential nuclear waste repository at the NTS. The objective of the study was to evaluate the temperatures and stresses at the exploratory shaft locations and in the vicinity of the ESF area, over a 10,000-year time span. The stresses change over time as a result of heat transfer from the waste to the surrounding rock mass. Of particular interest are the thermally-induced stresses in the vicinity of two shafts, the main drift, two midpanel drifts, both of which are part of the ESF exploratory drifting, two breakout horizons, and the potential repository horizon Main Test Level (MTL) excavations. The temperatures and thermally-induced stresses and strains at the locations of these eight structures have been computed with the STRES3D code. The results are presented in graphic form for 10 different times: 10, 35, 50, 100, 300, 500, 1,000, 2,000, 5,000, and 10,000 years after waste emplacement has begun. In addition, selected information is presented in tabular form. Local stress concentrations caused by individual excavation have not been considered. However, the primary intent of performing these analyses is to provide boundary conditions for subsequent investigation of the ESF excavations listed above. The major limitation of these analyses is the assumed homogeneous nature of the host rock. The properties of the welded tuff of the TSw2 unit were used for all analyses. The analysis results were used to support the ESFDR.

2.4.3.2 Design Activity 8.3.2.4.1.2 - Design Activity to Verify Air Quality and Ventilation

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

This is an out-year activity.

2.4.4.2 Design Activity 4.4.3.2 - Operations Plan to Accompany the License Application Design

This is an out-year activity.

2.4.4.3 Design Activity 4.4.4.1 - Repository Design Requirements for License Application Design

On September 11, 1990, direction was received from the YMPO to suspend work temporarily on the Repository Design Requirements, except for those interface components necessary to support the ESFAS. These interface requirements will be incorporated as part of the ESFAS documentation.

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

This is an out-year activity.

Activity 1.12.2.1.1 - Detailed Property Determination of Cementitious-Based and Earthen Materials. This is an out-year activity.

Activity 1.12.2.1.2 - Hydraulic Conductivity and Consolidation Testing of Crushed Tuff. This is an out-year activity.

2.5.1.2 Design Activity 1.12.2.2 - A Degradation Model for Cementitious Materials Emplaced in a Tuffaceous Environment

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

In the first area, the development of a conceptual framework to describe the degradation of sealing materials was initiated using the statistical methods of reliability-based design (see Harr, 1987). Because of the large number of variables involved in the prediction of the long-term performance of sealing materials, it is felt that the simple sensitivity analysis will not properly account for the possible variation of all inputs. The effects of humidity and creep on concrete volumetric stability were also quantified.

In the second area, preparations for laboratory scoping analyses of selected candidate sealing materials were initiated. Sources for all components for a selected concrete formulation have been located and have been or are being shipped to the laboratory. Preparation of laboratory work included the installation of an ultrasonic nebulizer on the DC Plasma (DCP) Spectrophotometer to improve its sensitivity. The DCP will be used to analyze for cations in water samples obtained from scoping experiments of concrete stability.

In the third area, two papers dealing with the geochemistry of cementitious materials were prepared. A conference paper entitled "Modeling Geochemical Stability of Cement Formulations for Use as Shaft Liner and Sealing Components at Yucca Mountain" was prepared, approved, and presented on November 27, 1990, at the 1990 Fall Meeting of the Material Research Society. This paper described the modeled geochemical interaction of three reference cements with the Yucca Mountain environment. Results showed that most of the mass loss accompanying the reaction of cement phases with J-13 water was caused by the loss of water derived from the water of cement hydration.

A second conference paper entitled "Estimating Geochemical Behavior of Concretes to be Placed at Yucca Mountain" was prepared and approved for presentation at the 1991 IHLRWM Conference to be held on April 28 through May 2, 1991, in Las Vegas, Nevada. This paper describes the projected changes in water chemistry and solid response to the interaction of concretes with J-13

water derived from Yucca Mountain. Results showed cement permeability changes that were less than a factor of two of the original concrete permeabilities. When these permeability changes were compared to those required for sealing elements at Yucca Mountain, it was concluded that these changes were small.

2.5.1.3 Study 1.12.2.3 - In Situ Testing of Seal Components

Limited efforts were spent in this area over the past six months. Meetings were held to discuss the testing input required to support the ESF. Three types of input will be prepared to support the ESF design. A test list, the location of each test, and the facilities requirements associated with the implementation of the test.

2.5.1.4 Design Activity 1.12.4.1 - Development of the Advanced Conceptual Design (ACD) for Sealing

To support the preparation of SAND91-0084, "A Strategy to Seal Exploratory Borehole for the Yucca Mountain Site," a draft section of the report was prepared. Areas covered included:

- o Design process for emplacing seals
  - Strategies Used in Sealing Boreholes
  - Design Process for Emplacing Seals
- o Technologies available for sealing
  - Removal of Casing, Monitoring, and Test Equipment
  - Reconditioning of the Borehole Wall and Selection of the Area to Place the Seal
  - Sealing Material
  - Placement of Seals
  - Summary of Emplacement and Material Selection Issues

Design Subactivity 1.12.4.1.1 - Define Subsystem Design Requirements. Sealing personnel have been involved in three different areas that support the development of sealing subsystem design requirements. These areas included: preparation of an International Atomic Energy Agency (IAEA) report, performance assessment calculations supporting the development of the ESF, and development of requirements for borehole sealing. The majority of effort was expended in the latter area.

Modifications of an IAEA report were made by an SNL staff member. This report deals with the performance of engineered barriers in deep geological repositories, and is in the draft stage.

In the second area of involvement, sealing personnel are responsible for one of the eleven performance assessment calculations supporting the ESFDR. The subject of this calculation deals with water entry into shafts through the rock mass surrounding shaft collar and liner. The primary conclusion of the analysis was that the water entry into the exploratory shaft by way of the

rock mass behind the shaft collar is estimated to be less than the storage and drainage capacity of the shaft sump under the host-rock conditions postulated in the report. For the conditions given in the report, it is not expected that there will be any performance implications associated with this water flow. For this reason, no design constraints are imposed on the shaft collar to limit the permeability of rock behind the collar.

While the assumed host-rock properties represent the site conditions in a conservative manner, there is a possibility that site properties will be outside the range investigated. If this proves to be the case, then the analysis will need to be repeated using the appropriate rock properties. It is also pointed out that should significant water entry occur behind the shaft collar as a result of shaft excavation, remedial measures can be applied. These remedial measures include grouting the fractures near the collar and restoring the pad area at closure using the strategies to control infiltration given in SAND85-0598, "Selected Analyses to Evaluate the Effect of the Exploratory Shafts on Repository Performance at Yucca Mountain" (Fernandez et al., 1985).

Sealing personnel are also contributing to the performance assessment calculations that support the Systems Design-ESF document. A review of four ESF performance analyses was initiated during the past month. These analyses described the effects of water used for construction, dust control, and testing on potential repository performance.

The third area under this activity involves the preparation of an SNL report on a strategy to seal exploratory boreholes. Numerous calculations were performed to develop design requirements. The results of these calculations, together with the results prepared under Information Need 1.12.3, will be presented in this report (to be SAND91-0084). The specific calculations and efforts performed to support this report are described below.

Specific efforts included (1) completion of the air dispersion calculations, (2) initiation of the borehole conductivity calculations, (3) progress on the alluvial and surficial borehole calculations, (4) initiation of the 15-meter standoff calculations, (5) ongoing work on casing corrosion, (6) potential for lateral spreading below a drift, (7) tabular summaries of boreholes, and (8) development of cementitious mix formulations. These efforts are discussed below.

Effort 1 - Several meetings were held to review the dispersion-model literature, the Defense Nuclear Agency literature, and other information sources to select a dispersion model for air flow. It was determined that the model TDAST was appropriate for analysis. The computer code was converted to a Macintosh II computer and a subroutine written performing Gaussian quadrature integration. The computer code was verified against tabulated information and used to perform preliminary analysis over a range of dispersion properties and average linear velocities for the three conductivity models adapted in previous analyses. Several additional CALMA products were prepared in the selection of average linear velocities.

Effort 2 - A technical approach to compute air conductivity of borehole seals was developed. Utilizing the approach, preliminary calculations were

performed. From these calculations, the relative importance of various boreholes with respect to airflow was determined.

Effort 3 - About one dozen drainage areas for flooding calculations were identified. All areas were planimetered, and spreadsheets to calculate water heights and extent of flooding of borehole areas were completed. Travel-time calculations using the Green and Ampt solution were also prepared and a preliminary analysis performed using previously determined properties. A review of properties (initial moisture content, suction potential, etc.) was made to refine the properties selection.

Effort 4 - Work was initiated on determining the potential of rock failure surrounding a borehole located in close proximity to a drift. To provide the assessment, it was necessary first to assess the rock-mass strength. The second step in the approach was to compare the rock-mass failure envelopes with the induced state of stress. This was achieved as follows:

The technical approach to evaluating the separation distance assessed the stability of borehole casing and seal stability near drifts at the proposed repository horizon. The analysis ignores the effects of the borehole excavation on the stress field around tunnels because the size of the borehole is small in comparison with the drift. Based upon a review of St. John (1987, p. 57, Figure 20), the region of potential joint activation or movement extends about seven feet into the rock mass. It is obvious that a borehole should not be located in this region.

At specified times of 0, 10, 35, and 100 years, the state of stress was obtained directly from the finite-element analysis from St. John (1987) for the unventilated case. The analysis assumes these stresses are far-field stresses, and input to the Kirsch solution (Goodman, 1980). The solution considers a generalized plane strain case that does not include an out-of-plane shear stress component for the borehole. However, this out-of-plane shear stress is small and does not affect the results significantly. The state of stress around the perimeter of the borehole is not symmetric, and the analysis considers two sampling points around the casing or seal perimeter.

The analysis results are compared to the Mohr-failure envelopes determined for a range of rock-mass properties at the levels of the roof, sidewall, and floor. The compressive stresses evolve as heating causes thermal stresses to develop in the roof, sidewall, and floor. In the floor and sidewall, the horizontal compressive thermal stresses from radioactive heat generation are higher, and result in higher compression at the open borehole at these locations. At the roof, the compressive thermal stresses are somewhat lower, resulting in lower compression at this location. The results show that compressive stresses develop initially at the floor level, then at the sidewall level, and finally at the roof level. Note that the results are preliminary in that rock mass strength is estimated and the comparisons are based upon an elastic analysis that does not account for potential redistribution of stresses that might accompany spalling at the borehole surface.

Effort 5 - A technical approach was defined to assess the corrosion of the borehole casing. As part of this approach, specific information is

required. This includes information on casing materials and the physical system, the environment (ground-water chemistry, porosity, and saturation), a bounding corrosion evaluation, and the strategy for dealing with the corrosion issues. A review of existing information was made to define the corrosion calculation. A meeting was held to discuss the factors affecting corrosion (moisture content, resistivity, capillarity, and permeability) and to define the calculations for corrosion.

Effort 6 - Spreadsheet calculations were prepared to assess anisotropy in the permeability tensor. This was used in a flow net calculation to determine the potential for lateral spreading below a flooded repository room. Calculations indicate that the vertical fractures are dominant and the strike of the fractures with respect to the room axis is not significant.

Effort 7 - Tabular summaries of existing and proposed borehole information for the potential repository, the extended repository, and the restricted area were prepared. These tables support Section 2.1 of the borehole sealing strategy report for characterizing these boreholes. The technical status section of this report presents these tabular summaries. Several inconsistencies were encountered in the CALMA-system data base compared to the EG&G data base, especially for proposed borehole lengths. Several meetings were held between SNL, EG&G, and RSN personnel to support this effort.

Effort 8 - Several cement formulations were defined. Factors considered included such construction features as workability, slump, and set time. Other important factors were fracture apertures to be sealed and the cement composition that in analytical studies was projected to give the best long-term performance.

Design Subactivity 1.12.4.1.2 - Perform Trade-Off Studies to Support Advanced Conceptual Design Development. No progress during the reporting period due to lack of funding.

Design Subactivity 1.12.4.1.3 - Develop Advanced Conceptual Design for Seals. 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. This is an out-year activity.

Design Subactivity 1.12.4.2.2 - Perform Trade-Off Studies to Support License Application Design Development. This is an out-year activity.

Design Subactivity 1.12.4.2.3 - Develop License Application Design for Seals. 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

A systems engineering analysis has been completed for the Waste Management System. The effort has identified the functions, requirements, and constrained architecture down to the Engineered Barrier System (EBS) level. A draft of the Waste Package Plan Milestone 1, the EBS Mission Statement, has been released to the YMPO for review.

A design study methodology has been developed. It is a tailored approach that allows multiple design concepts to be developed subject to major constraints, requirements, and assumptions. The concept development is being carried out using a group of knowledgeable technical specialists reflecting expertise in engineering, metallic and non-metallic materials, chemistry, geomechanics, hydrology, and geochemistry. The iterative process used in this method develops a traceable hierarchic, preliminary design concept set that satisfies both technical and nontechnical (e.g., programmatic and policy) needs.

A presentation entitled "Using a System Engineering Process to Develop Engineered Barrier Design Concepts" (Jardine) was given to the Waste Management '91 Conference in Tucson, Arizona, on February 25, 1991.

2.6.1.2 Study 1.10.4.1 - Characterize Chemical and Mineralogical Changes in the Post-Emplacement Environment

Revision of the Geochemistry Study Plan (8.3.4.2.4.1), based on YMPO comments, continued. The revision will bring the Study Plan into full compliance with QA requirements.

Modifications to the Activity Plan as a result of review comments are complete.

Activity 1.10.4.1.1 - Rock-Water Interactions at Elevated Temperatures. LLNL staff gave presentations at the DOE-NRC Technical Exchange on Mineral Stability and Applicability of Laboratory Data to Repository Transport Calculations held in Los Alamos, New Mexico, on March 20-21, 1991.

Activity 1.10.4.1.2 - Effect of Grout, Concrete, and Other Repository Materials on Water Composition. Review of the proposed new Study Plan for Man-Made Materials (Geochemistry Study Plan Sections 8.3.4.2.4.1.2 and .6) is in progress.

A change request to add Man-Made Materials as a separate WBS element 1.2.2.2.5 was submitted to the CCB, and approval was received in March.

C. Wittwer has been hired on a consulting basis through LBL to conduct a search of the existing literature on colloids formed by man-made materials in the near field environment.

Activity 1.10.4.1.3 - Composition of Vadose Water from the Waste Package Environment. No progress during the reporting period due to lack of funding.

Activity 1.10.4.1.4 - Dissolution of Phases in the Waste Package Environment. XRD analyses have been completed on the reacted tuff water samples and secondary minerals that precipitated directly from solution during the last two hydrothermal interaction experiments. The wafers were analyzed prior to breaking, which is required to prepare electron microprobe cross-section mounts. Plots were completed of the final aqueous phase chemistry data and the solution model EQ3/6 calculations (speciation/ solubility and in situ pH).

An HP gas chromatograph (GC) was installed. It is being configured to run not only the light hydrocarbons, but also the so-called "permanent" gases such as H_2, N_2, O_2, CO_2, CO, CH_4, and the simple organic acids such as formic acid and acetic acid. The GC is being used to analyze CO_2, H_2, and other gases which are of immediate interest in the near-field environment.

The HP HPLC (liquid chromatograph) was received. Also received were the Waters conductivity detector and an ADC (analog-to-digital converter) to allow ion chromatograph analyses as well as liquid chromatograph analyses. These two instruments will allow study of the effects of organic aqueous species on the inorganic aqueous species and minerals of interest to not only the Geochemistry/Mineralogy Task, but also the Man-Made Materials Task. Inorganic aqueous anion analyses will now be possible and should significantly improve the electrical balance calculations, particularly for higher-temperature runs. These electrical balance calculations are used as a measure to evaluate the analyses.

The Final Report for subcontract B077712/2033103 with Yale University, entitled "Kinetics Studies" (Lasaga et al.), was reviewed and forwarded for publication. In this work, the dissolution and precipitation rates at 80°C of gibbsite, kaolinite, and albite were experimentally studied as a function of the degree of saturation of the liquid.

Activity 1.10.4.1.5 - Effects of Radiation on Water Chemistry. No progress during the reporting period due to lack of funding.

Activity 1.10.4.1.6 - Effects of Container and Borehole Liner Corrosion Products on Water Chemistry. Described in Activity 1.10.4.1.2 above.

Activity 1.10.4.1.7 - Numerical Analysis and Modeling of Rock-Water Interaction. Modeling of zeolite solid solution/sorption processes continued. Calculations to estimate the effect of hydration water properties on thermodynamic properties of clinoptilolite have been started.

Time was spent regaining the capability to model glass/water interaction using EQ3/6 and modeling the hydrothermal experiments done in support of the Glass Waste Form Task. The completed Tpt vitric tuff hydrothermal experiments can now be modeled using the results from dissolution kinetics measurements made on a simple glass as a guide to an appropriate dissolution rate for Tpt glass. Full reaction progress calculations using kinetics will be made.

2.6.1.3 Study 1.10.4.2 - Hydrologic Properties of Waste Package Environment

Activity 1.10.4.2.1 - Single-Phase Fluid System Properties. Most of the LLNL hydrology work in this period was in the two-phase fluid system properties activity, Activity 1.10.4.2.2.

Activity 1.10.4.2.2 - Two-Phase Fluid System Properties. The fracture healing experiment continued to determine the effect on permeability of steam flowing through the fractured Topopah Spring tuff sample. The experiment also measured the concentration of elements in the water that condensed from the steam that flowed through the sample.

LLNL staff made presentations on Nonequilibrium Fracture/Matrix Flow at the PACE 90 NRC Technical Exchange at SNL, held November 28-29. Although the model results presented were originally intended primarily for the human intrusion "exploratory drilling" scenario, the results were presented in a broader context which included an overview of the three principal approximations to fracture/matrix interaction. In particular, a comparison was made between the zeroth order approximation (which assumes the fractures and matrix blocks are in capillary equilibrium) and the second order approximation (which accounts for the nonequilibrium between fractures and matrix blocks by discretely accounting for flow within each continuum). The LLNL study looked at the consequences of maintaining a ponded condition in the potential repository for a period of time sufficient to see a breakthrough of an infiltration front at the water table. The analysis includes all of the hydrostratigraphic units from the middle of the proposed repository horizon down to the water table. Apertures (b) of 50, 100, 200, 400, and 1000 mm were considered. The width of the wetting front (orthogonal to the fracture) was demonstrated to be a strong function of fracture aperture. For fracture-dominated flow regime I (in which the matrix has imbibed less than one equivalent fracture pore volume), the dependency is b-1. For flow regime II (in which matrix imbibition has become significant), the dependency is b-3. These results also corroborated earlier dimensionless analyses of this class of problems. At the NRC Exchange, this work was very favorably received by all who commented. The LLNL study convincingly demonstrated that nonequilibrium behavior between the fracture and matrix porosities should be considered in any hydrological performance analysis.

Calculations of episodic infiltration events between the potential repository and the water table were continued after the PACE90 NRC Exchange. Given the available matrix data for Yucca Mountain, the critical fracture aperture was identified (i.e., where flow transitions from fracture-dominated to matrix-documented) for the TSw2, TSw3, CHnv, and CHnz units. These values of critical fracture aperture corroborate the critical fracture apertures theoretically determined by Nitao (1990) in a paper entitled "Theory of Matrix

and Fracture Flow Regimes in Unsaturated, Fractured Porous Media" to be presented at the IHLRWM Conference in Las Vegas, April 30.

Calculations are also being conducted investigating fracture-matrix flow from the ground surface to the proposed repository horizon and on to the water table. The calculations assumed parallel sets of vertical fractures, contiguous from the ground surface to the water table. The calculations considered a large range of fracture spacings. Because vertically-connected fracture pathways between the ground surface and the water table are not likely to be widely present, large fracture spacings were emphasized where the wetting zones between neighboring wetting fractures do not coalesce. Due to its high matrix permeability, the vitric nonwelded CHnv is of particular importance to nonequilibrium fracture flow below the potential repository. The CHnv is thought to underlie approximately 50 percent of the area under the potential repository site. Where it is present, it has the capacity of greatly attenuating fracture flow. For fracture apertures which give rise to fracture-dominated flow period II (see Nitao and Buscheck, 1989), the travel time for the wetting front in the fracture can vary over two orders of magnitude, depending on whether the CHnv is present or absent. For fracture-dominated flow period II flow along a vertically contiguous, constant aperture fracture, the travel time for the wetting front from the ground surface to the potential repository is two to four orders of magnitude greater than the travel time from the potential repository to the water table. These calculations have two important implications. First, the calculations can be used to determine the combinations of idealized fracture morphology, matrix properties, and water ponding duration which appear to meet regulatory limits on release rates and ground water travel time, particularly as consequences of the performance assessment human intrusion scenarios that directly inject water into the proposed repository horizon. Second, the calculations show that quantifying both fracture and matrix properties in the rock above the proposed repository horizon is required to calculate its effectiveness as a barrier limiting the amount of water reaching the engineered barrier system. The acceptable combinations of fracture morphology and ponding duration above the potential repository will probably be less stringent than for below the repository.

Another important finding in the study was that in the high permeability nonwelded units, it is not necessary to have a vertically connected fracture pathway to facilitate fracture-dominated flow. In the units where the matrix permeability is sufficiently high, fracture-to-matrix-to-fracture flow may constitute a potential high conductivity preferential pathway for liquid flow.

Two papers by T. Buscheck were presented at the NRC-sponsored "Fifth Workshop of Flow and Transport through Unsaturated, Fractured Rock--Related to High Level Radioactive Waste Disposal" at the University of Arizona on January 7-10: "Nonequilibrium Fracture-Matrix Flow During Episodic Infiltration Events in Yucca Mountain" and "Modeling Hydrothermal Flow in Variably Saturated, Fractured, Welded Tuff During the Performance Engineered Barrier System Field Tests of the Yucca Mountain Project."

Three papers were submitted to the IHLRWM Conference in Las Vegas in April 1991: "Theory of Matrix and Fracture Flow Regimes in Unsaturated, Fractured Porous Media" (Nitao), "Variation of Permeability with Temperature

in Fractured Topopah Spring Tuff Samples" (Lin), "Laboratory Determined Suction Potential of Topopah Spring Tuff at High Temperature" (Lin and Daily).

Two papers were submitted to the Focus/91 Nuclear Waste Packaging Conference in Las Vegas, September 29-October 2: "The Impact of Episodic Nonequilibrium Fracture-Matrix Flow on Geological Repository Performance" (Buscheck et al.) and "Temperature Measurements from a Horizontal Heater Test in G-Tunnel" (Lin et al.).

An abstract entitled "Role of Steam in Fracture Healing of Topopah Spring Tuff Sample" (Lin) was submitted to the AGU Spring Meeting to be held in Baltimore, Maryland, May 28-June 1, 1991.

The first draft of the Hydrology section of the Near-Field Environment Report was completed.

The first draft of the revised Study Plan for the Laboratory Near-Field Hydrology Task was completed.

Activity 1.10.4.2.3 - Numerical Analysis of Flow and Transport in Laboratory Systems. No progress during the reporting period due to lack of funding.

2.6.1.4 Study 1.10.4.3 - Mechanical Attributes of the Waste Package Environment

Activity 1.10.4.3.1 - Waste Package Environment Stress Field Analysis. Completed Section 1.0 (Introduction), Section 2.0 (Rationale), and Section 3 (Methodology) of the Study Plan for Characterization of Mechanical Attributes of the Waste Package Environment (Study Plan 8.3.4.2.4.3) incorporating the review comments received from the YMPO.

A request was submitted for core samples from the NTS for preliminary lab experiments on Unit TSw2. The approval was received in February.

Input was revised for the draft of the Near-Field Environment Report.

2.6.1.5 Study 1.10.4.4 - Engineered Barrier System Field Tests

Activity 1.10.4.4.1 - Repository Horizon Near-Field Hydrologic Properties. The paper entitled "Thermocouple Psychrometer Measurements of In Situ Water Potential Changes in Heated, Welded Tuff" (Mao), UCRL-ID-104729, was submitted to the YMPO for approval in January.

LLNL comments on the paper "Prototype Engineered Barrier System Field Tests (PEBSFT) - Final Report" (Buscheck et al.) were resolved during the period, and the paper was submitted to the YMPO in February.

Review comments were incorporated for the paper entitled "Air Injection Field Measurements to Determine the Effect of a Heat Cycle on the Permeability of Welded Tuff" (Lee), UCRL-ID-105163, and it was subsequently submitted to the YMPO.

The following papers were submitted to the IHLRWM Conference in Las Vegas in April 1991: "Yucca Mountain Near-Field Environment Considerations for Engineered Barrier System Design and Performance" (Wilder), and "Microwave Measurements of the Water Content of Bentonite" (Latorre).

An abstract entitled "Field Air Injection Tests to Determine the Effect of a Heat Cycle on the Permeability of Welded Tuff" (Lee and Ueng) was submitted to the Focus/91 Nuclear Waste Packaging Conference in Las Vegas, September 29-October 2.

The University of Nevada/Reno proposal entitled "Application of Long Horizontal Cooling Enhancement for a Nuclear Waste Repository" (Danko) was reviewed by LLNL staff.

The first draft of the Near-Field Environment Report is complete and was QA graded on March 15.

Activity 1.10.4.4.2 - Repository Horizon Rock-Water Interaction. No progress during the reporting period due to lack of funding.

Activity 1.10.4.4.3 - Numerical Analysis of Fluid Flow and Transport in Repository Horizon Near-Field Environment. Staff developed an isothermal unsaturated flow code solving Richard's equation and conducted successful comparison calculations with V-TOUGH for discrete fracture-matrix flow problems. This code has the capability of running many times faster than V-TOUGH for isothermal fracture flow problems. The code currently runs on the SUN workstation and will eventually be ported to the CRAY computer. Work began on a radionuclide transport code which will post-process the flowfields generated by the unsaturated flow codes.

Work continued in debugging and enhancing pre- and post-processors for the V-TOUGH code. The use of PVWAVE was also extended to color graphical representation of pressure and saturation contour plots.

LLNL staff continued work on preliminary analysis of the radionuclide diffusion experiments using analytical double porosity models. The V-TOUGH code was to used to model radionuclide diffusion and adsorption. Preliminary work continued on a dual porosity fracture/matrix model.

An Individual Software (QA) Plan for V-TOUGH is currently being developed. The first draft of the software requirements document for an extensive enhancement to the software used to post-process V-TOUGH output has been completed. Revisions are currently being made in response to comments provided by code users.

A prototype enhanced version of V-TOUGH has been completed which produces efficient and very flexible time histories of all primary and secondary variables calculated by the code. This capability will enhance data extraction from V-TOUGH output and will reduce storage requirements for output. Enhancements have also been added to this prototype, including the capability of accommodating time-dependent Dirichlet boundary conditions.

Requests for copies of the V-TOUGH code were received from Dr. T. Rasmussen of the University of Arizona and Dr. W. Lee of the University of California. Copies were sent to Drs. Rasmussen and Lee in December 1990.

2.6.2 Characteristics and Behavior of the Waste Form (SCP Section 8.3.5.10)

2.6.2.1 Activity 1.5.1.1 - Integrate Waste Form Data and Waste Package Design Data

Subactivity 1.5.1.1.1 - Integrate Spent Fuel Information. The first draft for the Waste Form Characterization Report (WFCR) was submitted by the staff to the Technical Area Leader. This draft will be assembled in graphic file formats on a hard disk to ease the editing of the report and to permit subsequent additions.

A draft report "Preliminary Waste Form Characteristics" (ORNL/TM-11681) arrived and is being reviewed at LLNL. This report will provide data for the WFCR.

A revised Scientific Investigation Plan (SIP) is being prepared for Spent Fuel Waste Form Testing.

A report 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 Project" (Cunningham) was received from the Materials Characterization Center (MCC).

Subactivity 1.5.1.1.2 - Integrate Glass Waste Form Information. Work continued on the preliminary WFCR. A draft of the glass portion of the WFCR includes the important glass-related information in the form of tables and figures. The three areas examined by Argonne National Laboratory (ANL) include the effect of fracturing on glass reaction, the effect of radiation on glass reaction, and the estimation of glass reaction rates under a variety of conditions. The glass reaction rates reported were based on long-term static leach tests to establish a "final" reaction rate, on vapor phase hydration reaction at repository-relevant temperatures, and on long-term application of the unsaturated test method. Reaction rates were presented for a range of potential glasses to be produced by the Defense Waste Processing Facility (DWPF).

The processes of radionuclide release must be included during performance assessment and waste package design. The important parameters and processes that affect glass reaction and radionuclide release have been identified. Factors that affect glass reaction (both hydration aging and leaching in liquid water) include temperature, time, radiation, initial water composition, relative humidity, metal composition and treatment, waste form composition, surface area, volume of water, localized redox environment, nature of reacted layers, glass devitrification, surface roughness, pH, gas composition, water flow, and glass stress. Many of the factors are unimportant under unsaturated storage conditions, but are included for completeness.

A paper entitled "Temperature Effects on Waste Glass Performance" (Mazer) was reviewed and returned to ANL with comments.

Subactivity 1.5.1.1.3 - Integrate Waste Package and Repository Design Information. Reported in Subactivity 1.5.1.1.2 above.

2.6.2.2 Activity 1.5.2.1 - Characterization of the Spent Fuel Waste Form

Subactivity 1.5.2.1.1 - Dissolution and Leaching of Spent Fuel. The Activity Plan D-20-53a for Flow-Through Dissolution Tests on UO_2 (LLNL) has been approved, QA grading completed, a Readiness Review conducted, and testing initiated. These tests will solve the enormous variance in reported values for dissolution rates of both UO_2 and spent fuel.

A PNL test plan to perform a statistical matrix of hot cell tests on spent fuel (similar to the matrix of tests of UO_2) was completed and approved by LLNL (Activity D-20-53b). QA Grading of the LLNL portion of the activity was completed. The testing at PNL was initiated.

Publication and distribution was completed on the report entitled "Results from NNWSI Series 2 Bare Fuel Dissolution Tests" (Wilson, 1990), PNL-7169.

A manuscript entitled "Standard Gibbs Free Energies of Formation at 30°C of Four Uranyl Silicates: Soddyite, Uranophane, Sodium Boltwoodite and Sodium Weeksite" (Nguyen et al.) was completed and has been sent to the YMPO.

The PNL presentation entitled "Spent Fuel Grain Boundary Inventories and Testing the Congruency of UO_2 Matrix Dissolution of Spent Fuel" (Gray and Strachan) was reviewed by LLNL staff.

The paper entitled "Estimating the Time for Dissolution of Spent Fuel Under Unconstrained Conditions" (Leider) was submitted for the Focus/91 Nuclear Waste Packaging Conference in Las Vegas, September 29-October 2.

Subactivity 1.5.2.1.2 - Oxidation of Spent Fuel. The Activity Plans D-20-44 and D-20-45 for oxidation testing were updated.

A method was developed to calibrate thermocouples embedded in the dry bath fixtures enclosed in a hot cell. Based on this method, a procedure was written for comparisons of the measurement thermocouples in the dry baths to reference thermocouples in situ, and the procedure was used for three empty dry baths. The differences between the reference and measurement thermocouple measurements were found to be acceptable.

MCC spent fuel samples from ATM-104 (PWR fuel) and ATM-105 (BWR fuel) were loaded into the dry baths for oxidation testing. In addition, a modification of the dry bath tests will be run at 175°C and 195°C to determine the rate at which the various oxidation phases develop in a grain and the activation energies of the process. These data will be used as input to current LLNL oxidation models. These models can, in turn, be benchmarked against the data obtained in the original test (above) at 130°C and 110°C. Spent fuel of four types will be pulverized and oxidized at 175°C and 195°C for up to 4,000 hours this year. At approximately seven points in time (as the O/M ratio changes), small samples will be removed for XRD and

ceramographic examination. At an O/M of 2.25 (and in future years at 2.45 and 2.55), samples of sufficient size for leach testing will be removed.

Comments on the paper entitled "Nonuniform Oxidation of LWR Spent Fuel in Air" (Thomas et al.) were received from the editor of the Journal of Nuclear Materials and incorporated. Permission to publish has been received from LLNL and the YMPO.

The paper "Spent Fuel Waste Form Characteristics: Statistical Dependence of Grain and Fragment Size Distributions for Oxidation Rate" (Stout et al.) was submitted to the IHLRWM Conference in Las Vegas in April 1991. The model development in this paper describes the oxygen weight gain due to a U_4O_9 oxidation phase front propagating into large fragments of UO_2 spent fuel.

An abstract entitled "Effects of an Oxidizing Atmosphere in a Spent Fuel Packaging Facility" (Einzinger) was submitted to the Focus/91 Nuclear Waste Packaging Conference to be held in Las Vegas on September 29-October 2.

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

Subactivity 1.5.2.1.4 - Corrosion of and Radionuclide Release from Other Materials in the Spent Fuel Waste Form. No progress during the reporting period due to lack of funding.

Subactivity 1.5.2.1.5 - Evaluation of the Inventory and Release of Carbon-14 from Zircaloy Cladding. LLNL staff spoke at the ACNW meeting in Bethesda, Maryland, on October 26, on the subject of Carbon-14 release from a geologic repository, and urged changes in both the EPA and NRC regulations to allow higher Carbon-14 releases.

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 DWPF Glass

The N2 tests (SRL actinide-doped glass) continued as scheduled. These tests have now been in progress for over five years, with the anniversary date being February 3, 1991.

The N3 tests (ATM-10, a West Valley actinide-doped glass) continued as scheduled. The tests have been in progress for over three years.

Development work has continued with solutions from the N3 tests to examine the particulate material in solution and the distribution of actinides. Of particular interest is whether the alpha emitters are solely associated with the previously reported Ca-Th phosphate phase or whether there are some alpha emitters in the encompassing clay phase. To determine this, a match was made between the alpha tracks produced on the exposed film and a

backscatter electron image of the particle which produced the tracks. There is a general correspondence between the bright regions in the clay (these bright regions are the Ca-Th-phosphate) and the alpha tracks which indicate that the americium in the glass is preferentially incorporated into the phosphate phase. This is critical for determining the release rates of radionuclides from the waste form. Work is continuing with longer exposures (up to one month) to match, at a one-to-one correspondence, the alpha tracks with the inclusions.

Work to characterize the distribution of actinides in solution has continued. This work involves characterizing colloidal-sized filtered particles containing actinides. Exposure of the alpha-bearing filtered particles to nuclear emulsion has produced separate alpha tracks that can be vectored to discrete particles, which are then examined using transmission electron micropscopy (TEM). Additionally, many small particles of the clay substrate which contains the Ca-Th phosphate phase were mounted for XRD analysis. A successful XRD pattern has been obtained at several focal lengths and the patterns are being compared to those produced using electron diffraction in the TEM. A draft journal article was submitted describing these results. The results are significant because they indicate that the ratio of Am/Pu suspended in solution to that actually dissolved in solution is greater than 1000:1. These findings may affect the application of solubility-limit based performance assessment models and could influence the design of the engineered barrier system for radionuclide containment.

Static Leach Testing of WVDP and DWPF Glass

The Task Plan, "YMP Static Leach Tests," controlling the long-term static leach testing of DWPF glass at ANL has been revised to incorporate LLNL comments. The Task Plan has been returned to LLNL for comment, but since the tests are being supported by DOE/EM, no official response is required.

Parametric Studies of WVDP and DWPF Glasses

Four-year batch tests with ATM-1c and ATM-8 glasses were terminated as scheduled. While these glasses are not representative of any glass that will be produced by DWPF or WVDP, a considerable data base exists, and the results can be applied to model validation. These tests are part of the gamma radiation glass study, and were done without radiation to provide a comparative basis. The four-year period represents the longest time this glass has been reacted.

Experiments to study the hydration process are generally done at temperatures between 100 and 200°C (and at elevated pressure) in order to accelerate the reaction. It has been noticed that at the termination of these experiments, the glass surface is wet, with up to 0.03 mL accumulating per cm^2 of glass surface. To examine whether water accumulates and dripping could occur under potential storage conditions, samples of glass were vapor hydrated at 200°C for 56 days and then suspended in an open vessel which was placed in a humidity chamber set at 70°C and 95 percent relative humidity. The experiment was run in duplicate, with the samples then capped and subjected to an ice bath, then analyzed. The results of these tests will be detailed in a future technical report.

Subactivity 1.5.2.2.2 - Materials Interactions Affecting Glass Leaching

Studies of Glass Surface Layers and Precipitation

A Mettler autotitrator has been set up to determine the surface charge on simplified waste glass compositions by alkalimetric titration. Since atmospheric CO_2 gas interferes with the titration, a glove box is being procured to enclose the titrator in an atmosphere of N_2 or Ar.

To establish whether a mineral phase observed suspended in solutions from the N3 tests formed from solution or resulted from in situ restructuring of the glass during reaction followed by spallation from the surface during dripping water contact, a sample of WV 50 glass was prepared for analytical electron microscope (AEM) examination. The glass had been reacted in water vapor to accelerate the reaction process, and a thick layer had formed penetrating into the glass. In the center of the reacted layer is a band of discrete phases that are enriched in Ca, Th, and P. The identity of these phases can be obtained by electron diffraction. A match between the phase formed within the layer with that detected in solution would indicate a spallation source for the phase suspended in solution.

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 initiated. These samples were generated in scoping tests to establish the test matrix to be used in another activity. From the results of boron release for these solutions, it can be seen at equivalent SA/V*t, there is a significant variation in boron concentration in solution. By examining the structure of the reacted glass, it is believed that insight into the variation will be obtained. The samples were prepared for AEM examination using ultramicrotomy.

The papers "The Importance of Secondary Phases in Glass Corrosion" (Bates and Ebert) and "Overview of Chemical Modeling of Nuclear Waste Glass Dissolution" (Bourcier) were presented at the Materials Research Society (MRS) meeting in Boston, November 27-29, 1990.

The paper entitled "Mechanistic Interpretation of Glass Reaction: Input to Kinetic Model Development" (Bates) was submitted to the IHLRWM Conference in Las Vegas in April 1991.

Geochemical Interactions

The first draft of the Test Plan covering the flow-through glass dissolution tests was completed and is currently in review. This plan covers the flow-through tests of simple glasses using both pure and doped buffer solutions.

Work continued on readying the autotitrator for use in surface titrations of glasses. This work is aimed at understanding the pH dependence of glass dissolution rates in terms of the amounts of adsorbed hydronium and hydroxide species on the glass surface. Some bugs have been found in the software used to operate the titrator, and the manufacturer has been notified. Trial test runs are being done while waiting for the new software package.

Chemical compositions of glasses containing redox-sensitive elements (iron and manganese) were calculated. These glasses are to be used in dissolution tests under controlled redox conditions in order to examine the effect of redox state on glass dissolution rates and alteration types.

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

Work continued with SNL on defining the human intrusion scenario problem to be analyzed and the approaches to be used. The analysis has been refined to include all of the hydrostratigraphic units from the middle of the proposed repository horizon down to the water table.

A Memorandum of Understanding between LLNL and SNL is being prepared. LLNL and SNL discussed the management approach to resolve the problem definition document. It was agreed that SNL and LLNL staff will have joint authorship responsibilities. The document will have a common section on the selected initiating event and parameters. Separate sections by LLNL and SNL staff will detail modeling and site data assumptions and analysis approaches. The document will be called an Initial Problem Statement (IPS).

Several LLNL speakers participated in the NRC-DOE Technical Exchange on Performance Assessment. The LLNL topics included source term sensitivity, non-equilibrium fracture flow and the human intrusion scenario.

An analysis of stressed induced flow in vertical fractures penetrating the vadose zone at Yucca Mountain was initiated. A previous scoping study by Carrigan et al. ("A Scoping Study of Water Table Excursions Induced by Seismic and Volcanic Events") had shown that water table changes induced by seismicity will have an amplitude of less than 15 meters for earthquakes and hydrologic conditions thought to characterize the Yucca Mountain region. However, this model does not take into account flow in individual fractures that might act as pathways to transport ground water above the water table. The new effort will examine the balance between pumping of ground water into fractures by compressive stresses having a tectonic origin below the water table and the imbibition of fracture flow across fracture walls in the capillary transition zone. Assuming this balance as a basis for the model, the height of ground water rise will be determined in a parameter study as a function of parameters relevant to Yucca Mountain.

A report entitled "Water-Table Excursions Induced by Seismic and Volcanic Events at Yucca Mountain" (Carrigan et al., 1991) was completed as SAND91-0010J.

A paper entitled "Implications of Dike Intrusion for Water Table Response" (Carrigan) was presented at the Fall Meeting of the AGU in December 1990, San Francisco, California.

A Special Session in Hydrology and Tectonophysics for the YMP is being organized by LLNL staff for the Spring AGU meeting (May 1991). Its title is

"The Potential of Tectonism and Volcanism for Producing Significant Excursions of the Water Table." The paper "Models of Water Table Excursions Induced by Seismic and Volcanic Events at Yucca Mountain, Nevada" (Carrigan) will be presented at the meeting.

Three abstracts were accepted for presentation at the IHLRWM Conference to be held in Las Vegas, Nevada, April 28-May 2, 1991: "Preliminary Calculations of Release Rates of Tc-99, I-129, Cs-135, and Np-237 from Spent Fuel for an Example Condition in a Tuff Repository" (Apted et al.); "Diffusive Barrier Simplified Analysis: Design and Sensitivity Applications" (O'Connell and Ueng); and "Sensitivity and Uncertainty Analysis of EBS System Performance" (Thatcher et al.).

2.6.2.5 Activity 1.5.3.2 - Develop Geochemical Speciation and Reaction Model

Subactivity 1.5.3.2.1 - Develop Data Base for Geochemical Modeling. The relational GEMBOCHS thermodynamic data base was restructured and augmented. The restructuring facilitates generation of distinct database subsets. Augmentation includes new and revised data from the SUPCRT91 software package, the recent NEA-TDB data base for uranium species, and an extensive set of the standard molal volumes of minerals compiled by this subactivity from numerous literature sources; these additions significantly improve YMP modeling capabilities.

Parallel modifications to DOOUT, a program that accesses GEMBOCHS and generates input thermodynamic data files (DATA0 files) for the EQ3/6 package, were also completed. The updated program was used to create the suite of five distinct DATA0 files issued with EQ3/6 release version 3245.1090, first available for YMP and outside use during November 1990. Each of these five DATA0 files is designed to meet specific geochemical modeling needs. For a given modeling problem, the appropriate DATA0 file is determined on the basis of compositional complexity, required level of internal consistency, and desired formalism for calculating activity coefficients. The improved reliability, versatility, and comprehensiveness of this DATA0 suite relative to its single-file "composite" predecessor represents the most significant improvement in the modeling capabilities of the EQ3/6 package between release versions 3245.0888 (August 1988) and 3245.1090.

Development was completed of DBERROR, an automated INGRES-EMAIL-INTERLEAF system for submitting, processing, and filing GEMBOCHS Change Requests for YMP and outside use. The following laboratory work was done in support of the above activity:

Variable-Temperature Spectroscopy (Absorption, Photoacoustic and Photothermal Deflection)

Study of the praseodymium acetate system was initiated. Thirteen solutions spanning the ligand-to-metal ratio range of 0 to 20 were interrogated with the Guided Wave variable temperature spectrometer at five temperatures between 20 and 95°C. Approximately 85 visible spectra were acquired to monitor the complexation shift of the 482-nm absorption band. Data analysis was completed and final stability constants for the first and second complexes were obtained at the five temperatures.

The variable temperature spectrometer sample compartment was modified to a square well configuration to accommodate commercial 1 cm optical cuvettes. The thermal response of the system was evaluated using a digital potentiometer controller. The modification resulted in markedly improved data. Spectroscopic complexation data were collected at four temperatures for the americium hydrology system. To initiate the experiments, americium-243 was obtained and purified and a stock solution was prepared. The concentration of americium in the solutions used for the spectroscopic determination of americium complexation constants was determined, and a thin window Ge detector was set up and shielded. Calibration with NIST primary efficiency standards completed the validation of the gamma counting facility.

In another series of experiments, an americium solution was introduced into the flow cuvette system of the laser-induced photoacoustic spectrometer which is housed in the inert atmosphere box. The pH of the solution increased continually over several days, probably because of contact with the internal pump mechanism or the polymer tubing. Consequently, solutions were prepared to control the pH. Remote spectral interrogation of both metal and reference solutions was completed for this initial study. Data reductions and analysis were initiated.

Measurements of U(IV)/carbonate complexation were completed using the remote photoacoustic spectroscopy system. Measurements are complete of the 0.5 M HCO_3 series at CO_2 partial pressures of 10, 30, 50 and 100 percent.

Development of a second remote photoacoustic spectroscopy system has begun. This system will be located in a Pu glovebox.

A paper entitled "Development of High-Temperature UV-VIS-NIR Spectroscopy for the Measurement of Free Energies of Complexation at Elevated Temperatures" (Robouch et al.) was presented at the Symposium on the Scientific Basis for Nuclear Waste Management XIV. This paper presented the results of the Pr-diglycolate study.

The following abstracts were submitted to the Third International Conference on Chemistry and Migration Behavior of Actinides and Fission Products in the Geosphere, Migration, '91 to be held in Jerez de la Frontera, Spain, October 21-25: "Speciation Calculations of Pu, Np, Am and U in J-13 Well Water: Effects of Anion Concentration and pH" (Palmer et al.); "High Temperature Measurements of Americium Hydrolysis Using Absorption and Photoacoustic Spectroscopies" (Russo et al.); "Carbonate Complexation of Tetravalent Uranium" (Russo et al.).

Subactivity 1.5.3.2.2 - Develop Geochemical Modeling Code. The new code release, EQ3/6 version 3245.1090, was transmitted to Dr. W. Murphy of the Southwest Research Institute, fulfilling a request by the NRC. The new code package was also transmitted to LANL, fulfilling an outstanding request. Other users of the code are being contacted to arrange release of the code/database to them.

A sweep was made through the source codes of EQLIB, EQPT, EQ3NR, and EQ6 to standardize the format, and to improve the content of all error messages. The standardized format gives consistency of treatment, and permits extraction of error messages by existing software for inclusion in draft documentation.

The sweep also insures uniqueness of INCLUDE file names. All EQ3NR INCLUDE files now begin with "eq3" (e.g., "eq3aa.h), all EQ6 INCLUDE files with "eq6," all EQPT INCLUDE files with "eqt," and all EQLIB INCLUDE files with "eql."

Feedback from the external user community, which consists of about 200 users worldwide, has resulted in the elimination of a number of code and database bugs. The new release has been tested with a newly developed library of 68 test problems (42 for EQ3NR, 26 for EQ6). About half of these problems are taken from sources describing other codes or code comparison studies, and thus represent code-to-code verification. About a dozen and a half deal with systems that are directly tied to precise measurements, and thus represent validation. Most of these deal with brine mineral equilibria, and they overlap strongly with the set representing code-to-code verification. About a half dozen problems represent internal verification in which the input/output status of certain parameters is reversed from one problem to another. Other problems utilize capabilities not present in other codes or deal with systems or scenarios lacking precise measurements (e.g., processes occurring over long time periods). Verification and validation activities increase confidence in the calculations conducted with the code and database.

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. A model was developed that statistically describes the influence of grain and fragment size distributions on the aggregate dissolution rate of spent fuel. This model separately addresses the volume density of grain boundaries and grain volumes in spent fuel. The aggregate dissolution rate is given as a function of the inventory, the rate of material dissolution per unit area per unit time, and the associated surface area of the statistical distribution function of grain boundaries and grain volumes in a statistical volume of spent fuel pellet fragments. A paper entitled "Spent Fuel Waste Form Characteristics: Statistical Dependence of Grain and Fragment Size Distributions for Dissolution Rate" (Stout et al.) discusses this model and was submitted for the IHLRWM Conference in Las Vegas, April 1991.

2.6.2.7 Activity 1.5.3.4 - Generate Models for Release from Glass Waste Forms

Subactivity 1.5.3.4.1 - Generate Release Models for Glass Waste Forms. The EQ3/6 data base has been converted to a format that Gt, an alternate reaction path computer code, can use. Gt will be used both to perform verification studies of EQ3/6, and to model rock-centered flow-through experiments.

Eight EQ6 simulations of reactions of SRL-131, SRL-165, and SRL-202 glasses in EJ-13 (equilibrated J-13 water) and distilled water were performed. The results were sent to ANL to compare the secondary phases predicted by the model with those observed in experiments. Because of uncertainties in how to determine the amount of oxygen in the glass 'reactant' that is specified in the EQ6 input file, three different methods of calculating oxygen were used and the results compared: (1) simple addition of the amount of oxygen in each oxide component of the glass formulation, (2) calculating oxygen by mass balance from the elemental analysis, and (3) calculating oxygen by mass

balance from the elemental analysis after normalizing to 100 percent. The basic uncertainty is that although the oxide components entered into the glass are known before melting, some oxidation or reduction may take place in the glass during melting which would change the amount of oxygen (as oxide) in the glass. The three methods of calculating oxygen cover the range of expected oxidation state changes. The simulation results show only insignificant changes in the reaction paths; therefore, the effects can be ignored.

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. The simplified one-barrier diffusion model for release of radionuclides was extended from the pulse input case to the waste-matrix-alteration controlled case and the concentration controlled case. Application results agree closely with results from a two-barrier model developed by University of California at Berkeley. Sensitivity results using this model were presented as part of the NRC-DOE Technical Exchange meeting on November 28-29, 1990.

A more general two-barrier diffusion model for release of radionuclides was developed for the same three types of waste chemical controls on release. The model has a different geometric approximation for the far-field interface than a similar UC Berkeley model. The new model has an infinite series solution which allows easy integration of different matrix mobilization rates.

The draft specification of PANDORA-1.1's model for waste form alteration and release from the EBS has been developed. It covers three water contact modes, including the diffusion discussed above, and five types of radionuclides as distinguished by their chemical and physical response to water contact.

Work started on simplified models for the spatial and temporal distribution of liquid water flux impacting waste packages and on possible forms for the failure-time distributions of multiple components of the EBS.

LLNL participated in the November 1-2 NWTRB QA Panel in Arlington, Virginia.

W. O'Connell of LLNL was an invited participant to a symposium sponsored by the Institute for Resource Management in Airlie, Virginia, on December 1-2. The symposium was entitled "Reassessing U.S. Policies for the Disposal of the Nation's High Level Nuclear Waste." Industry, government, environmental, and research leaders were invited to assess the sources of impediments, to look for any areas of common agreement, and to look for innovative solutions.

A joint paper by LLNL, PNL, and UC Berkeley, entitled "Preliminary Calculations of Release Rates from Spent Fuel in a Tuff Repository," was submitted to the IHLRWM Conference to be held in Las Vegas in April.

Two abstracts, "Diffusive Barrier Simplified Analysis - Design and Sensitivity Applications" (Ueng and O'Connell), and "The Demands Placed on Waste Package Performance Testing and Modeling by Some General Results of Reliability Analysis" (Chesnut), were submitted to the Focus '91, Nuclear

Waste Packaging Conference to be held in Las Vegas, September 29-October 2, 1991.

The Performance Assessment staff reviewed the draft System Functional Analysis for function 1.4, "Dispose of Waste." Review effort focused on functions 1.4.2 (Isolate Waste) and 1.4.3 (Evaluate System Performance).

Subactivity 1.5.3.5.2 - Development of Uncertainty Methodology. The controlled sampling test system (CSTS) was used to compare the effectiveness of various sampling methods in reducing the variance of estimates, when the quantities being estimated are fractiles of an output variable's cumulative distribution function (CDF). Controlled sampling is the most effective of the methods tested, for all the simple models used as tests. In many cases, stratified sampling works about equally well. Latin hypercube sampling (LHS) was effective in variance reduction only for models which were algebraic sums of single-variable terms. For these models, stratified sampling was about as effective as LHS, and controlled sampling was substantially more effective than either stratified sampling or LHS. "Effective" in these examples meant a reduction by a factor between 1.8 and 5 in the number of calculations required for a given extent of statistical accuracy.

Subactivity 1.5.3.5.3 - Water Flow Into and Out of a Breached Container. No progress during the reporting period due to lack of funding.

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

Subactivity 1.5.5.2.2 - Application of Near-Field Transport Model to Waste Package Releases. No progress during the reporting period due to lack of funding.

2.6.2.11 Activity 1.5.5.1 - Determine Radionuclide Transport Parameters

Subactivity 1.5.5.1.1 - Radionuclide Distribution in Tuff Wafers. General planning and experiment 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.

Construction began 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. The high-pressure components were machined and assembled, and pressure safety testing was initiated. Equipment was acquired and installation began for the pore-fluid lines, solution delivery and collection systems, and computer control. Core material for the flow-through experiments was selected and received from the NTS, and adjacent sections were identified for characterization of the pore structure, fracture features, and imbibition behavior. A critical point dryer that will be used to prepare samples for analysis was also received and installed.

The capability to characterize the suspended particles or colloids that exist in the solution which evolves from interaction of the waste with ground waters was greatly expanded during this period. A photon correlation spectrometer was received, installed, and is being tested. It is used to determine the size distribution of particles less than 1 μm that may provide a transport mode for actinides in the near-field environment. Techniques to characterize small particle composition and mineralogy using TEM, electron diffraction, and energy dispersive spectroscopy were also refined on both colloids obtained from J-13 water and from particles found in uranium or actinide-doped glass-waste drip tests. Both sequential filtration and autoradiography were used to ascertain the location of actinides associated with particulates. The J-13 work was done in conjunction with a non-YMP project, while the doped-glass work was done in collaboration with ANL. Initial reports on both studies were prepared. In addition, literature searches, discussions with hydrologic modelers, and close contact with spent-fuel and glass experiments advanced conceptual understanding of the significance that colloids are likely to have in retarding or enhancing radionuclide transport.

Another area of emphasis was to develop capabilities to characterize the submicron to millimeter scale pore and fracture structure in the rock. The optical imaging software on the SEM was used to complement mercury intrusion porosimetry for pore-size characterization of samples. In addition, methods were selected and equipment assembled for 3-D 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. Instrument failures with the SEM and U.S. customs hold-up of supplies from Europe slowed progress in this area.

A low-level effort continues to develop capabilities to analyze rare earth elements (REEs) in silicious rocks in view of their potential as future in situ testing analogues of the actinide elements. Electron probe characterization, SEM analysis, photo documentation, and REE analysis with secondary ion mass spectroscopy (SIMS) of a banded chert analogue was completed. Intercalibration of REE standards on instrumental neutron activation analysis (INAA), ICP-MS, and SIMS has been slowed by difficulties in interpreting overlapping spectral features in the multi-element glass standards.

Analysis and data reduction of tuff-wafer and tuff-cup samples that had been exposed to actinide-bearing solutions continued. Compilation and corrections of existing SIMS data from the 1987-1990 analyses of wafer experiments was completed. This entailed writing and modifying programs to

interpret and transfer SIMS data files to spreadsheet format, recalculation of all processed SIMS data with revised standard values, generating files and plots of concentration vs. depth profiles for actinide distributions, and preparation of data reports. Four depth profiles of uranium, neptunium, technecium, plutonium and related trace element concentrations were determined in a tuff cup sample that had been exposed for 183 days. Results from this work were presented at conferences (see below), while work continued on additional manuscripts.

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, LLNL has participated in the effort to generate a library of standards and determine relative sensitivity factors (RSF) for materials analysis with SIMS. During the report period, U and Th implants were completed for trace elements in YMP materials, as was depth profiling analysis and data reduction of the U and Th ion implants. The software necessary to calculate RSF from standards was developed and testing began. Features added recently to increase the productivity of the instrument include automation for acquisition and reduction of large volumes of data. The Individual Software Plan for the CAMECA 3F ion microscope (i.e., SIMS) data acquisition was completed and reviewed.

Five technical papers were presented at conferences: "Characterization and Transport of Colloidal Particles in Groundwaters from the Nevada Test Site" (Buchholtz ten Brink et al.), AGU Fall meeting, December 3-7, 1990, San Francisco; "Heterogeneities in Radionuclide Transport: Pore-Size, Particle-Size, and Sorption" (Buchholtz ten Brink et al.), Concepts in Manipulation of Groundwater Colloids for Environmental Restoration Meeting in Manteo, North Carolina, October 15-18, 1990; "Actinide Transport in Topopah Spring Tuff: Pore Size, Particle Size and Diffusion" (Buchholtz ten Brink et al.), MRS Symposia, Scientific Basis for Nuclear Waste Management XIII, Boston, November 26-29, 1990; "Mineralogical, Textural and Compositional Data on the Alteration of Basaltic Glass from Kiluea, Hawaii to >300°C: Insights to the Corrosion of a Borosilicate Glass Waste-Form" (Smith), MRS Symposia, Scientific Basis for Nuclear Waste Management XIII, Boston, November 26-29, 1990; "Effects of Heterogeneity on Actinide Diffusion Rates in Tuffaceous Rock" (Buchholtz ten Brink et al.), IHLRWM Conference, Las Vegas, April 1991.

Subactivity 1.5.5.1.2 - Radionuclide Distribution in Tuff Cores. Activity in this area is reported under Subactivity 1.5.5.1.1.

2.6.3 Characteristics and Configurations of the Waste Packages (SCP Section 8.3.4.3)

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

2.6.4 Waste Package Production Technologies (SCP Section 8.3.4.4)

The Metal Barrier staff met with visiting Professors Dr. Bill Skaggs and Dr. Samir Moujaes from the University of Nevada, Las Vegas (UNLV), on November 13 to discuss work on waste package design concepts, material performance

issues, corrosion, and fabrication testing. The UNLV professors informally presented some of their design concepts being developed under separate YMP funding.

At a National Association of Corrosion Engineers (NACE) meeting in Los Angeles on November 5-6, D. McCright received the "Engineer of the Year" award for his work on container materials for the YMP.

D. McCright attended the MRS meeting in Boston, Massachusetts, November 26-30 and presented two papers entitled "The Technical Basis for Nuclear Waste Management" and "Container Materials for the Proposed Yucca Mountain Repository."

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)

The Activity Plan for E-20-18a (Electrochemical Parametric Studies) was revised. A key element is the self-calibration of potentiostats and other electrochemical testing instruments.

Work has begun on a task to model and calculate radiolytic yields in the waste package as part of the radiation effects program at ANL. The task plan was completed, a readiness review conducted, and start of work approved.

ANL, in support of LLNL, is conducting experiments involving radiation chemistry and corrosion. There are two tasks supporting characterization of the environment in the vicinity of the waste package: (1) The potential for surface alteration of tuff in an irradiated air/steam environment. A few scoping experiments will qualitatively establish if ionizing radiation and the radiolytic products generated in a moist air environment result in significant alteration of mineral phases present in tuff. (2) The formation of organic condensation products in a CO_2-H_2O vapor mixture. Experiments will establish the likelihood that the decomposition products of water vapor react with carbon dioxide to form higher molecular weight organic condensates. The initial data will be used to establish the overall potential for organic acid formation in the expected waste package environment.

Additionally, ANL work on the slow propagation of stress corrosion cracks has been renewed. Because of the very modest effort needed to keep the tests running and because of the value in accumulated exposure time, several samples had been maintained. Some 14,000 hours of exposure have already been logged. Measured crack growth rates are extremely small even under severe tension-tension cyclic loading at high stress intensity values.

As requested by the Appropriations Committee of the U.S. House of Representatives, information was transmitted to DOE/HQ and the YMPO on waste package activities involving deep drawing as a possible container fabrication process. This request was a deliverable mandated by the FY91 budget appropriation for the YMP.

LLNL staff attended a working session with DOE/HQ and YMP staff for the forthcoming DOE EBS Workshop planned for June 1991 and formulated a draft agenda.

Thirteen papers have been submitted to the Focus/91 Nuclear Waste Packaging Conference in Las Vegas, September 29 - October 2, 1990. They are as follows: "Candidate Container Materials for Yucca Mountain Waste Package Designs" (Clarke et al.); "Selection Process and Quantitative Criteria for YMP Container Materials" (Halsey); "Summary of Yucca Mountain Engineered System Concepts Workshop" (Clarke et al.); "Electrochemical Polarization Measurements on Pitting Corrosion Susceptibility of Nickel-Rich Alloy 825" (McCright and Fleming); "Degradation Mode Surveys of Nickel-Chromium-Molybdenum Alloys and Titanium Alloys Considered for High-Level Radioactive Waste Container Materials" (Gdowski and McCright); "Degradation Mode Surveys of YMP Site Characterization Plan Candidate Materials for High-Level Radioactive Waste Container Materials" (Farmer and Gdowski); "Stochastic Models for Predicting Pitting Corrosion Damage of HLRW Containers" (Henshall); "Predicting HLRW Container Failures Due to Pitting Corrosion Using a Deterministic Approach" (Henshall and Macdonald); "Effects of Ionizing Radiation on the Anticipated Waste Package Environment at Yucca Mountain" (Reed and Van Konynenburg); "Corrosion of Candidate HLW Container Metals in Irradiated Air-Steam Mixtures" (Reed and Van Konynenburg); "Gaseous Release of Carbon-14 from Spent Fuel Waste Packages in a Potential High Level Waste Repository: Why the Regulations Should be Changed" (Van Konynenburg); "Slow-Strain Rate Testing of Candidate Waste Container Materials" (Maiya et al.); "Crack-Growth Rate Testing of Candidate Waste Container Materials" (Park et al.).

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. Revision 1 of the Activity Plan for E-20-15 (Establishment of Selection Criteria) has been approved.

The "Preliminary Selection Criteria for the Yucca Mountain Project Waste Package Container Material" (Halsey, 1991) was issued as UCRL-ID-104552 and distributed throughout the YMP.

2.6.5.4 Activity 1.4.2.2 - Degradation Modes Affecting Candidate Copper-Base Container Materials

Subactivity 1.4.2.2.1 - Assessment of Degradation Modes in Copper-Based Materials. A paper entitled "Corrosion of Copper-Based Materials in Irradiated Moist Air Systems" (Reed and Van Konynenburg) was accepted for publication in the proceedings of the MRS conference that was held in Boston in November.

This activity was completed (refer to TSR-2, Section 2.5.5.4).

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. LLNL staff are modifying the General Electric Crack Growth monitoring system. Stress corrosion tests are also being performed using modified Wedge-Open Loaded specimens to obtain critical stress intensities for crack initiation. In order to prove the method, the tests are initially performed in solutions known to cause rapid crack initiation (e.g., ammonium sulfate for copper base materials; magnesium chloride for austenitic materials).

Work continues on developing an empirical relationship between the critical breakdown potential, solution pH, solution temperature, and the chloride ion concentration in solution for alloy 825. The purpose is to derive a parametric equation, similar to previously reported work on 316 stainless steel. Polarization curves were obtained for pH 2.5 and pH 11 solutions at 50 and 90°C. The low pH is relevant for some cases of microbiologically induced corrosion, since the metabolism products form microbes that are often acidic. Likewise, corrosion of iron or steel liners and plugs would yield ferric ions, which hydrolyze to acid pHs. The alkaline pH value is to simulate the modification of water by leaching of concretes or grouts used around the liner.

Work by ANL, in support of LLNL, is concerned with the gamma radiation effects on changing the chemical environment around the waste package and the subsequent effects of these changes on the performance of the container (see also Activity 1.4.1.1). The emphasis of the radiation effects work at ANL consists of (1) yield of NO_x/NH_3 in high water vapor air systems, and (2) Calculation of radiolytic yields in the waste package. Modeling work has been initiated and is on schedule. The range of existing data on the radiation chemistry of moist air systems is being summarized and related to a broad range of waste package design considerations. This will help focus future research efforts and provide input to preliminary design considerations in the context of their relationship to the radiolytic environment. A Test Plan was submitted, reviewed, and approved.

Experimental work on ammonia and condensable NO_x yields in high water vapor to air ratios has restarted. This experiment series will complete the long-term yield studies initiated three years ago. High water vapor concentrations are likely during the initial phase of the containment period. Based on preliminary data, the NO_x/NH_3 yields will be affected. This work supports the assessment of waste package performance and site characterization that is independent of waste package design.

All five sections of the degradation mode survey on Ni-Cr-Mo alloys are completed. The sections have been reviewed for technical content. Reviewer comments have been incorporated into the documents. The five sections are (1) introduction, (2) phase stability, (3) stress corrosion cracking and localized corrosion in chloride environments, (4) corrosion in marine atmospheres and brines, and (5) stress corrosion cracking in hydrogen environments. The entire report (all five sections) will receive management and QA reviews as a single document.

A paper entitled "Degradation Mode Survey of High Performance Candidate Container Materials" (Gdowski and McCright) was accepted for the IHLRWM Conference in Las Vegas in April 1991.

A paper was written on Ni-Cr-Mo and titanium and an oral presentation of this paper was made by G. Gdowski at the NACE Corrosion/91 Conference, March 11-15, 1991, in Cincinnati, Ohio.

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 System

This activity was on hold during the reporting period.

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

Efforts continue on improving stochastic models. The generation of uniformly random variables lies at the heart of Monte Carlo calculations so that use of a reliable random number generator is key. Discussions were held between Metal Barrier Task and Performance Assessment Task investigators to identify several suitable routines.

Two quantitative results from the stochastic model are the induction time, which is the amount of time elapsed before the first stable pit forms, and the number of pits produced in a given amount of time. Analytical expressions have been developed (in the published electrochemical literature) that relate the statistically expected induction time, the expected number of stable pits, the probability for birth of a pit embryo, the probability of the embryo death, and the critical age for an embryo to become a stable pit. Errors in computing embryo births and deaths have been corrected.

A series of plots has been drafted as the outcome of actual or numerical "stochastic experiments." These "survival probability plots" give the natural logarithm of the probability that a stable pit will not appear as a function of time. A "stochastic experiment" is one in which many different test samples are subjected to the same conditions (temperature, applied electrochemical potential, solution chemistry, etc.) but have different outcomes (induction time, number of stable pits) because of the stochastic nature of the physical process. Similarly, for a "numerical experiment," the input data (birth rate, death rate, critical time) remain the same from simulation to simulation, but the outcomes vary due to the use of Monte Carlo methods to do the calculations. Considerable effort has been spent in developing a computer program that correctly makes such calculations based on the stochastic model and then analyzes the results so that a survival probability plot can be quickly constructed.

Work with stochastic pitting models is continuing, particularly the models of Williams et al. (1984). During January, the predictions from a computer model for Pit Initiation and Growth Stochastic Model #1 (PIGS1) have been compared with simulation results and experimental data from the Williams work. These predictions are concerned with pit survival rates, since more pits are nucleated than eventually grow. The predictions from the computer model best correlate with the experimental work when the pit survivabilities are large. This correlation suggests that the statistical population size is an important factor in prediction, since there were very few pits present in some of the experimental work.

2.6.5.8 Activity 1.4.3.3 - Models for Degradation of Ceramic-Metal, Bimetallic/Single Metal, and Coatings and Filler Alternative Systems

This activity was on hold during the reporting period.

2.6.5.9 Activity 1.4.4.1 - Estimates of the Rates and Mechanisms of Container Degradation in the Repository Environment for Anticipated and Unanticipated Processes and Events, and Calculation Failure Rate as a Function of Time

Subactivity 1.4.4.1.1 - Deterministic Calculation of Rates of Container Degradation in the Repository Environment. No progress during the reporting period due to lack of funding.

Subactivity 1.4.4.1.2 - Probabilistic Calculation of Rates of Container Degradation and Distribution of Time to Initiation of Release of Radionuclides from the Waste Packages. No progress during the reporting period due to lack of funding.

2.6.5.10 Activity 1.4.5.1 - Determination of Whether the Substantially Complete Containment Requirement is Satisfied

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

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 papers "Actinide Transport in Topopah Spring Tuff: Pore Size, Particle Size and Diffusion" (M. Buchholtz ten Brink) and "Mineralogical, Textural and Compositional Data on the Alteration of Basaltic Glass from Kiluea, Hawaii to >300°C: Insights to the Corrosion of a Borosilicate Glass Waste Form" (Smith) were submitted to the MRS Symposia, Scientific Basis for Nuclear Waste Management XIII, Boston, Massachusetts, November 26-29, 1990.

A paper entitled "Effects of Heterogeneity on Actinide Diffusion Rates in Tuffaceous Rock" (Buchholtz ten Brink) was submitted to the IHLRWM Conference in Las Vegas, April 1991.

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, SAND87-2777) 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 Environmental Monitoring Program was restarted in January of 1991. Activities included air sampling, placement of thermoluminescent dosimeters and radon measuring devices, and ground and soil surveys.

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.

General Model Validation Activities

Experiment Procedure (EP)-0036, "Field Research Program for Unsaturated Flow and Transport Experimentation" (Glass et al.), was completed and approved. The Field Research Program is designed to support both SNL's development of conceptual models and validation activities for performance assessment in the current period before the opening of the ESF. The program emphasizes the use of inexpensive surface-based experimentation in natural analogue sites to address a variety of questions of critical importance to SNL's performance assessment activities.

Scoping studies are under way to choose suitable reactive tracers for chemical transport experiments designed to validate flow and transport models. Proper choice of a tracer requires consideration of probable chemical behavior of candidate tracers in a relevant chemical system and identification of an analytical technique for the tracer with proper sensitivity. It is unlikely that radioactive tracers will be used in these validation experiments. Evaluation of the use of uranium and nickel as potential tracers is currently under way. This evaluation will be based in part on the similarity of the proposed tracers to radionuclides in commercial high-level waste.

A critically-evaluated data base of chemical equilibrium constants is required for chemical speciation calculations and transport calculations that will compare the behavior of the proposed tracers to important waste radionuclides, such as plutonium. A major focus of work has been verification and compilation of a data base for equilibrium constants for aqueous plutonium complexes. These and other data will be used with the HYDRAQL computer code to simulate the behavior of plutonium, uranium, and nickel in alternative experiment designs.

Evaluation of spectrofluorometric analysis for uranium tracers is under way. It is hoped that the proposed analytical method will be compatible with the experimental setup previously designed under this task for measurements of moisture content in sands.

Design and analysis of transport experiments involving complex chemistry with reactive tracers requires a coupled flow/chemical reaction code. Adaption of the LEHGC code to the needs of the validation experiments was started. The code was transferred from the CRAY computer to a workstation. The code will be used to model the results of a caisson-scale tracer experiment that will be carried out under the direction of LANL. SNL's

potential role in the caisson experiment also could be to provide meter-scale laboratory experimental support in analogue materials and chemical analysis.

Papers SAND90-2216C, "Research Program to Develop and Validate Conceptual Models for Flow and Transport Through Unsaturated Fractured Rock" (Glass and Tidwell), and SAND90-2105C, "Compilation/Validation of Thermodynamic Data for Plutonium for Nuclear Waste Disposal" (Siegel), were written for presentation at the IHLRWM Conference to be held in Las Vegas, Nevada, in April 1991.

Specific Experimental Results

Experimentation to test the validity of scaling finger properties in unsaturated, porous media was carried out. These experiments, in conjunction with other experiments and modeling that investigate the effects of initial moisture content, heterogeneity structures, and pore-size distribution, bound the occurrence of gravity-driven instability in unsaturated, porous media and allow the assessment of its occurrence at Yucca Mountain.

SAND91-0258A, "Miller Scaling of Finger Properties" (Glass et al.), will be presented at the Workshop for the Characterization of Transport Phenomena in the Vadose Zone, April 2-5, 1991, in Tucson, Arizona. Final experiments to validate theory to predict finger width and velocity as a function of porous media properties were presented at the workshop.

The Rotating Test Stand (RTS) apparatus, which incorporates optical methods of determining moisture content and solute concentration in thin slabs of porous media and fractures, was completed. Experimentation began to systematically explore gravity-driven fingering in analog-glass, unsaturated fractures using the RTS. Flow rate feeding the fracture as well as the angle of the fracture plane with respect to the vertical, were varied systematically to determine the effect on finger width and velocity.

Design and prototype testing of techniques for systematically investigating fracture-matrix interaction was initiated. The purpose of this experimentation was to develop a fundamental understanding of the processes and mechanisms that govern the transfer of fluids and solutes between fractures and porous host rock. Such an understanding was necessary to evaluate the validity of related conceptual and mathematical models that may be used in performance assessment exercises.

Efforts have been made to design and build analog rock materials. The intent is to fabricate "rocks" that have controlled hydraulic properties and that allow the transmission of light. The simplest means of producing such materials is by the sintering of glass beads. Molds for sintering are being designed, and a process to pack the glass beads in a homogeneous manner is being developed. Progress to date includes the construction of a graphite mold to be used in the sintering process, purchase of soda-lime silicate glass beads, and the development of a process to pack the beads in the mold without introducing unwanted heterogeneity into the fabricated plates.

Experiments to calibrate the optically-based, 2-D moisture content visualization technique were initiated. A sequence of experiments are planned to compare optical, gamma, and X-ray techniques for measuring transient

moisture-content fields in thin slabs of porous media (both analog and tuff material).

Scoping experiments continued to develop an X-ray technique for the measurement of transient moisture-content fields in thin slabs of heterogeneous tuff. With the help of the SNL Nondestructive Testing Division, X-ray images were taken of a transient wetting front as it migrated through a thin slab of homogeneous sand. X-ray absorption was used to monitor rock saturation as a function of time. Data were gathered in the form of photographic images, which are being digitized and analyzed using video-imaging techniques. The goals of the analysis are to develop a calibration technique for use with X-ray adsorption and to help design future experiments. Efforts have also been made to develop a means of calibrating the technique to produce accurate estimates of the absolute moisture content.

Subactivity 1.6.2.1.2 - Development of Calculational Models. No progress during the reporting period. Resources redirected to 1.2.1.4.7.

2.7.5.2 Activity 1.6.2.2 - Verification and Validation

Subactivity 1.6.2.2.1 - Verification of Codes. SAND90-2542, "NORIA-SP, A Finite Element Computer Program for Analyzing Liquid Water Transport in Porous Media" (Hopkins et al.), was completed during the reporting period. The report documents the equations used to model the flow processes and the numerical techniques used to solve them. The structure and logic of the code are also discussed. The report functions as the users' manual for the code and enumerates the various options available to the user with detailed instructions on the preparation of the input data. A sample problem is provided for user training.

SAND85-0004, "Total Systems Performance Assessment Code (TOSPAC) Vol. 2: User's Guide" (Gauthier et al.), has been submitted to the YMPO for review.

The TOSPAC, Ver. 1.0, and NORIA-SP, Ver. 1.0, computer codes were qualified for use in QA calculations per QAIP 3-2. NORIA-SP, a 2-D finite-element code for single-phase flow of liquid in a partially saturated, porous media, was qualified conditionally for use in quality-affecting calculations per the requirements of QAIP 3-2. TOSPAC, a 1-D finite-difference code for single-phase flow and transport of radionuclides, was qualified conditionally for use in quality-affecting calculations in accordance with the requirements of QAIP 3-2. Both codes were used in QA calculations in support of the ESFDR.

SAND90-2726, "The Technical Summary of the Performance Assessment Calculations Exercises for FY90 (PACE90)" (Barnard and Dockery), was submitted for YMP review.

A preliminary Total Systems Analyzer (TSA) code was assembled and scoping sample calculations of total system performance were obtained of three representative event tree scenarios. The TSA is designed to incorporate uncertainty about parameter values and process models into performance calculations. Random sampling from distributions of parameter values is used to construct multiple realizations of each scenario that is simulated. Output

from the analyzer is a cumulative complementary distribution function for radionuclide releases to the accessible environment. Results of the sample calculations will be presented at the IHLRWM Conference in Las Vegas, Nevada, April 28 through May 3, 1991.

A data base of hydrologic flow and transport computer codes was established. The data base contains descriptions of features and capabilities of codes. The data base may be queried for code listings as well as specific code attributes.

Subactivity 1.6.2.2.2 - Validation of Models. No progress during the reporting period due to lack of funding.

2.7.5.3 Activity 1.6.3.1 - Analysis of Unsaturated Flow System

Preliminary analyses of the unsaturated flow system have been performed as part of the work described as Subactivity 1.6.4.1.2.

Subactivity 1.6.3.1.1 - Unsaturated Zone Flow Analysis. (See Subactivity 1.6.4.1.2).

Subactivity 1.6.3.1.2 - Saturated Zone Flow Analysis. (See Subactivity 1.6.4.1.2).

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. Reported under Subactivity 1.6.4.1.2.

Subactivity 1.6.4.1.2 - Sensitivity and Uncertainty Analyses of Ground-Water Travel Time. Workers at Purdue University continued work to validate the latest Point Estimate Methods (PEMs). SNL staff are writing the software to implement these PEMs. An RS/Explore procedure will be used as an alternative to the LHS for generating input decks for performance assessment ground-water travel-time simulation. Ultimately, SNL will run independent validation exercises of methodology and the incorporate the method as part of the overall performance assessment methodology.

SNL staff attended PACE meetings on the nominal case and disturbed scenarios. Work commenced to revise the nominal-case hydrostratigraphy created for the early PACE exercises. Staff are reviewing hydrologic, mechanical, and bulk property data from the Yucca Mountain site to determine whether hydrologic data can be estimated from other tuff properties. Several hydrologic parameters were analyzed as functions of porosity.

SNL staff presented "Unsaturated Zone Ground Water Travel Times Performance Assessment" to the Unsaturated Hydrology Peer Review Panel in Las Vegas, Nevada, on June 6, 1990. The presentation emphasized the probabilistic basis for current calculations.

SNL staff investigated the effects of meter-sized heterogeneities on predominantly 1-D flow to determine whether effective material properties exist for the 1-D case. Multiple realizations have been calculated for randomly-distributed spatial distributions of rock with assigned permeabilities that vary up to six orders of magnitude. An abstract of these results has been written for presentation at the November Computer Use by Engineers (CUBE) Symposium.

Subactivity 1.6.4.1.3 - Determination of the Pre-Waste Emplacement Ground-Water Travel Time. Reported under Subactivity 1.6.4.1.2.

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 due to lack of funding.

2.7.5.6 Activity 1.6.5.2 - Definition of the Disturbed Zone

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

2.7.6 Total System Performance (SCP Section 8.3.5.13)

2.7.6.1 Activity 1.1.2.1 - Preliminary Identification of Potentially Significant Release Scenario Classes

Subactivity 1.1.2.1.1 - Preliminary Identification of Potentially Significant Sequences of Events and Processes at the Yucca Mountain Repository Site. Staff members participated in numerous working meetings to select significant features, processes, and events appropriate for scenarios to be used in the site suitability calculations. These meetings have been technical interchanges between SNL, USGS, PNL, SAIC, LBL, LLNL, and others. SNL staff have taken the lead role in eliciting and incorporating the important ideas, observations, and models of the other YMP Participants into scenarios that lead to posed problems. Dates, locations, and topics for these meetings were December 4, 1990, Albuquerque, New Mexico, volcanism; December 11, 1990, Berkeley, California, nominal flow; December 12, 1990, Livermore, California, human intrusion; January 15, 1991, Las Vegas, Nevada, tectonics; January 16, 1991, Las Vegas, Nevada, volcanism; January 29, 1991, Las Vegas, Nevada, nominal flow; January 30, 1991, Las Vegas, Nevada, human intrusion; January 31, 1991, Las Vegas, Nevada, source term.

SLTR90-2001, a progress report on the construction of event trees in support of scenario development, was distributed in March 1991.

SNL staff met with climate-prediction workers at the NCAR on August 7, 1990, in Boulder, Colorado. The meeting contributed to the coordination of the climate modeling with the needs of performance assessment. In particular, the performance assessment staff described their need to use future-climate information in selecting processes for their modeling; the NCAR staff discussed their ability to provide such information.

Subactivity 1.1.2.1.2 - Preliminary Identification of Potentially Significant Release Scenario Classes. Using results of the above interactions, work on the basaltic volcanism scenarios was started.

2.7.6.2 Performance Assessment Activity 1.1.2.2 - Final Selection of Significant Release Scenario Classes to be Used in Licensing Assessments

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

SAND91-0155, "A Simplified Radionuclide Source Term for Total System Performance Assessment" (Wilson), was submitted for technical review. This report fulfilled milestone M191.

Subactivity 1.1.3.1.1 - Development of Models for Release Along the Water Pathways. STAFF2D, a 2-D finite-element, isothermal flow and transport code, was purchased and installed. The acquisition was to implement saturated-zone models of current interest. A contract was placed to develop a 3-D version.

SAND90-2619, "Dual Porosity Models for Solute Transport at Yucca Mountain" (Dykhuzen), was submitted to the YMPO.

SNL staff participated in an adsorption workshop at LANL on September 11 and 12, 1990.

Subactivity 1.1.3.1.2 - Development of a Model for Gas-Phase Releases. A draft copy of SAND91-7034, "Numerical Studies of Rock-Gas Flow in Yucca Mountain" (Ross et al.), was submitted by Disposal Safety Incorporated (DSI). This report details the status of DSI gas-flow modeling of Yucca Mountain.

Subactivity 1.1.3.1.3 - Development of a Model of Releases Through Basaltic Volcanism. See Subactivity 1.1.2.1.2.

Subactivity 1.1.3.1.4 - Development of a Model of Releases Through Human Intrusion. A study on possible targets for human intrusion was initiated; the identification of such targets will help to establish the likelihood that future human activities would disrupt the potential repository site.

2.7.6.4 Performance Assessment Activity 1.1.4.1 - The Screening of Potentially Significant Scenario Classes Against the Criterion of Relative Consequences

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

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

This is an out-year activity.

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

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

This is an out-year activity.

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

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

This is an out-year activity.

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. 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. 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

This is an out-year activity.

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. This is an out-year activity.

2.7.9 Performance Confirmation (SCP Section 8.3.5.16)

This is an out-year activity.

2.7.10 NRC Siting Criteria (SCP Section 8.3.5.17)

This is an out-year activity.

2.7.11 Higher-Level Findings--Postclosure System and Technical Guidelines (SCP Section 8.3.5.18)

This is an out-year activity.

APPENDIX

3.0 SCHEDULES

In late November 1989, a new proposed program schedule was announced in the Secretary's report to Congress. 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, 1990k). Factors internal and external to the program, which include delays in the processing of environmental permits, study plan review, and funding levels, may continue to affect the program schedule.

This section presents the schedule for the scientific investigation program as of March 31, 1990. During the reporting period, the DOE finalized the schedule that was announced in the Secretary's report to Congress (DOE, 1989). That schedule was provided in the previous progress report. No changes were made to the schedule in this reporting period.

Table 3.1 presents the summary milestones for the scientific investigation program. 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 shaft construction, DOE plans to take advantage of early surface-based tests if site access is obtained.

Lower-level schedules for the exploratory shaft, surface-based testing, site programs, waste package design, seals design, repository design, and performance assessment are under development. Relevant aspects of lower-level schedules may be suitable for discussion in future progress reports.

Table 3.1. Summary Milestones for Scientific Investigation[1].

Waste Package

Start Waste Package Advanced Conceptual Design	10/92
Start Waste Package License	6/96
Provide Engineered Barrier System Data To Design	7/98

Site

Start New Surface-Based Testing	1/91
Complete Deep Unsaturated Zone Drilling	3/94

Repository

Start Repository Advanced Conceptual Design	10/92
Start Repository License Application Design	6/96

Regulatory

Obtain Site Access	12/90
Issue EIS Notice of Intent	10/97
Issue EIS Implementation Plan	2/98
Issue Draft EIS	10/99
Issue Final EIS	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	3/91
Start ESF Site Preparation	6/92
Start ESF Collar Construction	11/92
Complete ESF Connection	9/95
Complete ESF Geologic Drifting	11/97

[1] Table shows approved date as of March 31, 1990.

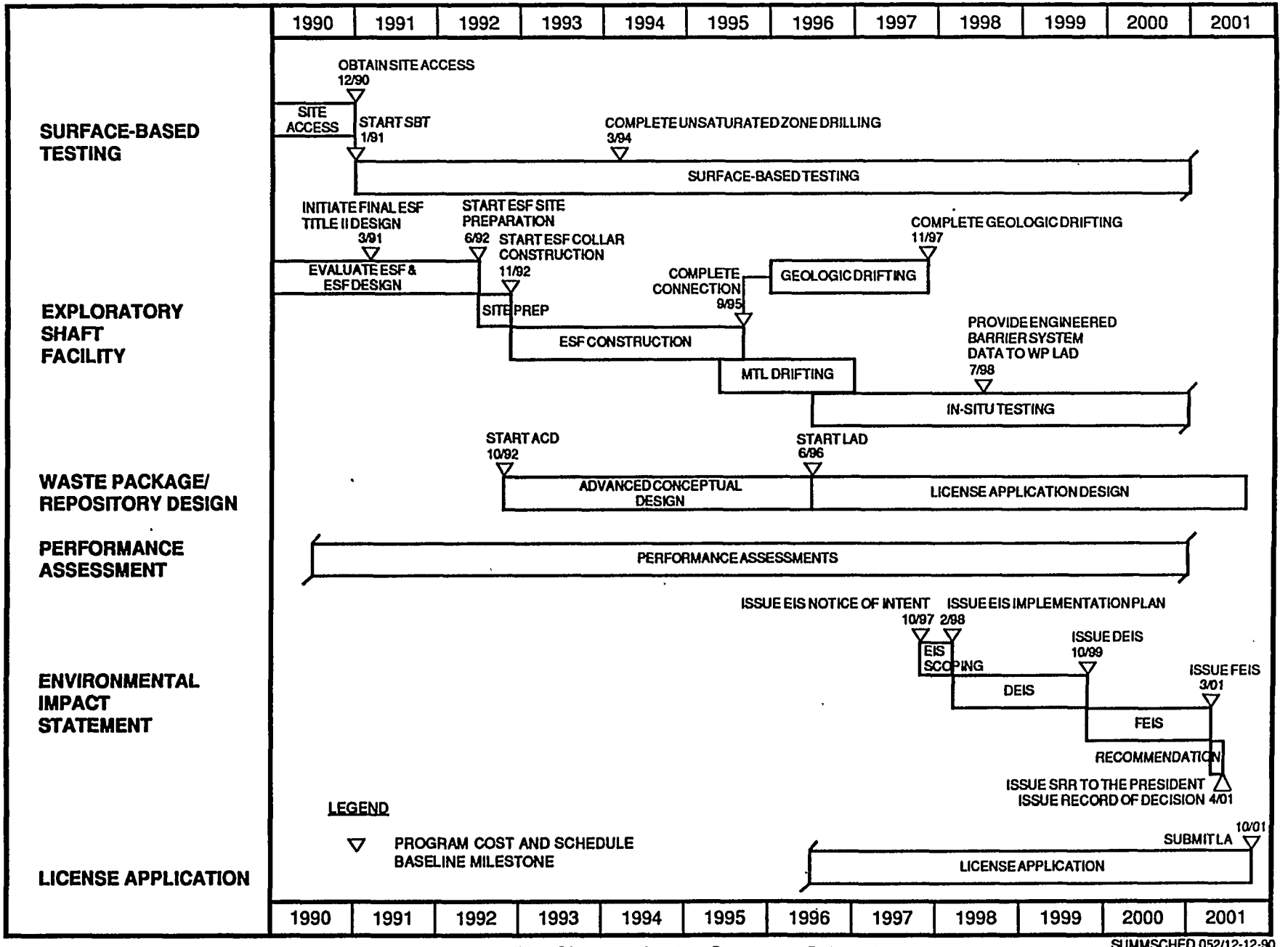

Figure 3.1. Site Characterization Summary Schedule.

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All technical reports and research products published by participating organizations on the Yucca Mountain Site Characterization Project 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 Yucca Mountain Site Characterization Project reports and other documents published by DOE and the participating organizations, which are available through OSTI, can be ordered from:

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

Annotated outlines of YMP-sponsored reports can be found in the Yucca Mountain Project Bibliography. Updates are published every six months. The bibliography segments released to date are as follows:

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ACRONYM LIST

ACNW	Advisory Committee on Nuclear Waste
ADAPS	automated data-processing system
A/E	Architect/Engineer
AEM	analytical electron microscope
AGU	American Geophysical Union
AIH	American Institute of Hydrology
ANL	Argonne National Laboratory
ANS	American Nuclear Society
APD	areal power density
APS	autocorrelation photon spectrometer
ATLAS	Alternative Licensing Application Strategy
ATM	Approved Testing Materials
BLM	U.S. Bureau of Land Management
BNL	Brookhaven National Laboratory
BRWM	Board on Radioactive Waste Management
BWR	boiling water reactor
CADSWES	Center for Advanced Decision Support for Water and Environmental Systems
CALMA	Trademark for Calvin and Mary products
CASY	Committee for the Advancement of Science in Yucca Mountain Project
CCB	Change Control Board
CDF	cumulative distribution function
CHn	Calico Hills nonwelded
CHRBA	Calico Hills Risk/Benefit Analysis
CNWRA	Center for Nuclear Waste Regulatory Analysis
COE	Corps of Engineer
CSTS	Controlled Sampling Test System
CTCN	Colloid Transport Code Nuclear
CUBE	computer use by engineers
DHLW	defense high-level waste
DIM	Design Investigation Memo
DISA	downhole instrument station apparatus
DOE	U.S. Department of Energy
DOE/HQ	U.S. Department of Energy/Headquarters
DP	detailed technical procedure
DRI	Desert Research Institute
DSI	Disposal Safety Incorporated
DVNM	Death Valley National Monument
DWPF	Defense Waste Processing Facility
EBS	engineered barrier system
EBSFT	engineered barrier system field test
EDXRF	energy dispersive x-ray fluorescence
EEI	Edison Electric Institute
EMI	Earth Mechanics Institute
EPA	U.S. Environmental Protection Agency
ERWM	Environmental Restoration Waste Management
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
EXAS	x-ray absorption spectroscopy
FOG	Field Operations Geologist
FY	fiscal year
GC	gas chromatograph
GCP	Ground-Water Characterization Program
GIS	Geographic Information System
GSA	Geological Society of America
GSIS	Geoscientific Information System
GWSI	ground-water site inventory
HRF	Hydrologic Research Facility
IAEA	International Atomic Energy Agency
IDAS	Integrated Data Acquisition System
IDS	Integrated Data System
IHLRWM	International High Level Radioactive Waste Management
INAA	Instrumental Neutron Activation Analysis
LANL	Los Alamos National Laboratory
LBL	Lawrence Berkeley Laboratory
LHS	Latin Hypercube Sampler
LLNL	Lawrence Livermore National Laboratory
M&O	Management and Operations
MCC	Materials Characterization Center
MGDS	Mined Geological Disposal System
MOU	Memorandum of Understanding
MPA	Mission Plan Amendment
MRS	Materials Research Society
MSIS	Management Systems Improvement Strategy
MT	magnetotelluric
MTL	Main Test Level
NAS	National Academy of Sciences
NCAR	National Center for Atmospheric Research
NIST	National Institute of Standards and Technology
NMR	nuclear magnetic resonance
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
ORNL	Oak Ridge National Laboratory
PAC	potentially adverse condition
PACE	Performance Assessment Calculational Exercises
PACS	Planning and Cost Scheduling
PAS	photoacoustic spectroscopy
PDM	Problem Definition Memo
PEM	Point Estimate Method
PNL	Pacific Northwest Laboratory
PR	Progress Report

psi	per square inch
PWR	pressurized water reactor
QA	quality assurance
QAAP	Quality Assurance Administrative Procedure
QAP	Project Quality Assurance Plan (NNWSI/88-9, Rev. 2)
QAPD	Quality Assurance Program Description
QAPP	Quality Assurance Program Plan
QAR	Quality Assurance Requirements
QARD	Quality Assurance Requirements Document
RDC	Reference Design Concept
RDR	Repository Design Requirements
REE	rare earth element
REECo	Reynolds Electrical and Engineering Co.
RIB	Reference Information Base
RSN	Raytheon Services Nevada
RTS	Rotating Test Stand
SAIC	Science Applications International Corporation
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
SIMS	Secondary Ion Mass Spectroscopy
SIP	Scientific Investigation Plan
SKB	Swedish Nuclear Fuel Supply Company
SNL	Sandia National Laboratories
SOBART	Southern Basin and Range Transect
SP	Socioeconomic Plan
SPANS	Spatial Analysis System
SPOC	submersible pressure outflow cell
SQAP	Software Quality Assurance Plan
SRL	Savannah River Laboratory
TDR	time-domain reflectometry
TEM	transmission electron microscopy
TL	thermoluminescence
T&MSS	Technical and Management Support Services
TPT	Testing Prioritization Task
TSA	Total Systems Analyzer
TSR	Technical Status Report
TU	tritium units
UIC	Underground Injection Control
UNE	underground nuclear explosion
UNLV	University of Nevada/Las Vegas
USGS	U.S. Geological Survey
UZ	unsaturated zone
VSP	vertical seismic profiling
WFCR	Waste Form Characteristics Report
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