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(Section 113)

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

October 1, 1989 - March 31, 1990

Number 2

U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Washington, DC 20585

FOREWORD

In accordance with the requirements of Section 113(b)(3) of the Nuclear Waste Policy Act of 1982 (Pub. L. No. 97-425), as amended, the U.S. Department of Energy has prepared this report on the progress of scientific investigation activities at Yucca Mountain in southern Nevada from October 1, 1989, through March 31, 1990. This progress report is the second of a series of reports that are issued at intervals of approximately six months during scientific investigation. The first progress report was issued in February 1990 (DOE, 1990c).

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EXECUTIVE SUMMARY

In accordance with the requirements of Section 113(b)(3) of the Nuclear Waste Policy Act of 1982 (Pub. L. No. 97-425), as amended, the U.S. Department of Energy (DOE) has prepared this report on the progress of scientific investigation activities at Yucca Mountain in southern Nevada for October 1, 1989, through March 31, 1990. This report is the second of a series of reports that are issued at intervals of approximately six months during the period of scientific investigation. This and future progress reports will be submitted to the Nuclear Regulatory Commission (NRC) and to the Governor and legislature of Nevada. It will also be made available to the Nuclear Waste Technical Review Board, affected units of local government, and the general public.

The progress report presents short summaries of the status of scientific investigation activities and cites 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 discussing major changes, if any, to the DOE's scientific investigation program. More detail on all studies and activities planned as part of the technical program described in Chapter 8 of the Site Characterization Plan can be found in the Technical Status Report (DOE, 1990b) that is produced twice-yearly by the Office of Civilian Radioactive Waste Management Project Office in Las Vegas, Nevada.

The progress report conveys information in a convenient summary form to be used for informational purposes only. It is not intended to be the mechanism for controlling and documenting technical or policy positions regarding changes in schedules or the technical program. Such changes are controlled through rigorous DOE change-control procedures. The progress report only describes such approved changes.

The publication of the Report to Congress on Reassessment of the Civilian Radioactive Waste Management Program (DOE, 1989) on November 29, 1989 was a significant event for the radioactive waste management program. This report identifies the results of a review of the OCRWM program by the Secretary of Energy that was conducted in response to Congressional concerns about schedule slips, management structure, and contractor efforts. The review resulted in a more realistic schedule that shows a slip for the expected start of repository operations from 2003 to approximately 2010. The review also led to a three-point action plan centered on restructuring OCRWM, initiatives to gain access to the Yucca Mountain site to continue the scientific investigations needed to evaluate the site's suitability for a repository, and an initiative for establishing integrated monitored retrievable storage with a target for spent-fuel acceptance in 1998.

Regarding scientific investigations at Yucca Mountain, the focus of the near-term activities at the Yucca Mountain candidate site will be on surface-based testing aimed specifically at evaluating whether any features or conditions exist at the site that would so adversely affect performance as to indicate that the site is not suitable for development as a repository.

The basic policies which govern the radioactive waste management program reflect the new emphasis and directions the Secretary has instituted within the DOE, including increased emphasis on safety, protection of the environment, institutional relations, and openness in communicating with the public. Those basic policies are:

- The protection of public health and safety and the quality of the environment is of paramount importance.
- The program must be distinguished by its technical integrity and excellence and directed

at reaching consensus in the scientific community, establishing public understanding and confidence, and obtaining the licenses needed for waste-management facilities.

- Opportunities and means must be provided for meaningful participation by affected and interested parties.

- The program must have efficient and cost-effective management.

Other highlights during the reporting period include the following:

On January 5, 1990, the Nevada Attorney General filed a petition for review in the U.S. Court of Appeals in San Francisco, charging DOE Secretary Watkins with violations of the Nuclear Waste Policy Act, as amended (NWPAA), by continuing to investigate Yucca Mountain as the potential site of a high-level nuclear waste repository. The suit seeks a declaration by the court that Nevada Assembly Bill 222, Assembly Joint Resolution 4, and Assembly Joint Resolution 6 constitute a valid notice of disapproval of the Yucca Mountain site under the Act. In addition, the State seeks to prohibit DOE from conducting any further studies at the site. Subsequent to this action by the State, DOE filed suit in U.S. District Court in Nevada on January 25, 1990, requesting a court order directing the State to act on three specific permit applications and prohibiting the State from unlawfully interfering with DOE's efforts to comply with the NWPAA. The DOE believes it is essential for this country to find out, as soon as possible, whether the Yucca Mountain site is suitable for a geologic repository. The DOE has conscientiously attempted to carry out the will of the Congress in this regard and would like to do so in cooperation with affected parties, including the State of Nevada.

A formal evaluation of configuration and construction alternatives for the exploratory shaft facility (ESF) was initiated during the October 1989-March 1990 period. The study began by establishing a formal decision methodology to evaluate the relative attributes of various exploratory shaft and ramp configurations at the Yucca Mountain site. In parallel, 17 options for the ESF configuration have been developed that incorporate shafts and ramps at various locations and have been integrated with conceptual layouts for the repository at Yucca Mountain.

In February 1990, the U.S. Fish and Wildlife Service (USFWS) issued a Biological Opinion finding that scientific investigation activities at Yucca Mountain would not jeopardize the continued existence of the desert tortoise. The Biological Opinion contained specific terms and conditions that the DOE is implementing to minimize the potential effects on the tortoise. Consultations with the USFWS are continuing to finalize details of conditions placed in the Biological Opinion.

The DOE continued efforts to qualify the quality assurance (QA) programs of the DOE Office of Civilian Radioactive Waste Management, the Yucca Mountain Project Office, and participating organizations. Following the November 1989 and March 1990 audits of Los Alamos National Laboratory, all primary participant QA programs are adequate for further implementation. In addition, all project participant QA Program Plans were accepted by the NRC during the reporting period.

A new Yucca Mountain Information office was opened in Las Vegas in March 1990. Both this office and the information office in Beatty are open daily to the public to provide additional information about the high-level waste management program and scientific investigation activities.

A report entitled "The Potential Use of Lead in the Waste Package for a Geologic Repository at Yucca Mountain, Nevada," was issued on February 9, 1990 (DOE, 1990a). This report was in response to a directive by the Senate Committee on Appropriations accompanying the Energy and Water Appropriations Act for 1989 that DOE evaluate the use of lead for this purpose. Conclusions were that although lead would be inappropriate for use in the reference conceptual design of the waste package, lead will be considered for potential applications in alternative design concepts for site conditions that are not expected but may warrant consideration.

The Nuclear Waste Technical Review Board issued its first report to Congress and the Secretary of Energy. The DOE will conduct a comprehensive review of all the 24 recommendations in the report.

A major product for the Rock Characteristics Program is a comprehensive report on the geophysical data available for the site, major results based upon it, and future plans for coordination and integration for acquisition of geophysical data.

Considerable progress was made regarding the characteristics and behavior of the waste form. A model to represent the stress dependence on the platelet orientation of hydride precipitates was completed. The model analytically represents both the deformation and thermodynamic responses of hydride precipitation kinetics.

1. INTRODUCTION

1.1 PURPOSE AND SCOPE OF THE PROGRESS REPORT

In accordance with the requirements of Section 113(b)(3) of the Nuclear Waste Policy Act of 1982 (Pub. L. No. 97-425), as amended, the U.S. Department of Energy (DOE) has prepared this report on the progress of scientific investigation activities at Yucca Mountain in southern Nevada for October 1, 1989, through March 31, 1990. This report is the second of a series of reports that are issued at intervals of approximately six months during scientific investigation. The first progress report was issued in February 1990 (DOE, 1990c).

This and future progress reports will be submitted to the Nuclear Regulatory Commission (NRC) and to the Governor and legislature of Nevada. It will also be made available to the Nuclear Waste Technical Review Board, affected units of local government, and the general public.

The DOE's plans for scientific investigation are described in the Site Characterization Plan (SCP) for the Yucca Mountain site (DOE, 1988c). The SCP has been reviewed and commented on by the NRC, the State of Nevada, the affected units of local government, other interested parties, and the public. More detailed information on plans for scientific investigation is being presented in study plans for the various scientific investigation studies and their component activities.

The progress report presents short summaries of the status of scientific investigation 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 major changes, if any, to the DOE's scientific investigation 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. More detail on all studies and activities planned as part of the technical program described in Chapter 8 of the SCP can be found in the Technical Status Report (DOE, 1990b) that is produced twice-yearly by the Office of Civilian Radioactive Waste Management Project Office in Las Vegas, Nevada.

The progress report conveys information in a convenient summary form to be used for informational purposes only. It is not the mechanism for controlling and documenting technical or policy positions regarding changes in schedules or the testing program. Such changes are controlled through DOE change-control procedures. The progress report only describes such approved changes.

The progress report consists of three sections: (1) an introductory section, (2) a section on the status of scientific investigation activities, and (3) a section providing updated schedule information relevant to scientific investigation. A list of the documents cited in the text (which are available for inspection at DOE public reading rooms in Washington, D.C., and the State of Nevada) and a list of acronyms are also provided. In addition, the report includes a selective annotated bibliography of recent publications relevant to scientific investigation.

1.2 BACKGROUND INFORMATION

As stated in Section 160 of the Nuclear Waste Policy Act of 1982 (NWPA), as added by the Nuclear Waste Policy Amendments Act of 1987 (the Amendments Act, Pub. L. No. 100-203), the Yucca Mountain site in Nevada has been selected

as the candidate site for detailed study to determine if it is suitable for the United State's first geologic repository for spent nuclear fuel and high-level radioactive waste. The Yucca Mountain site has not been selected for a repository; rather, it has been designated as the only candidate site for study to assess its suitability for development as a repository.

The purpose of this detailed study is to obtain the information necessary to determine whether the Yucca Mountain site is suitable for a geologic repository and, if so, to provide the information necessary to prepare a license application for submittal to the NRC. If during scientific investigation the Yucca Mountain site is determined to be unsuitable for development as a geologic repository, the DOE will, in accordance with the NWPA as amended, (1) terminate all scientific investigation activities at the site, (2) notify the Congress and the State of Nevada of such termination, and (3) reclaim the site to mitigate any significant adverse environmental impacts caused by scientific investigation studies. After the completion of scientific investigation, if the DOE believes that the Yucca Mountain site is suitable for development of a repository, a recommendation for approval of the site will be sent to the President. The recommendation will be accompanied by an environmental impact statement. After recommendation by the DOE, if the President considers the site qualified, the President will recommend the site to the Congress. The NWPA provides that Congress' affirmative approval of the recommendation is necessary for the recommendation to become effective only if the State of Nevada disapproves of the site recommendation. If the Presidential recommendation becomes effective, the DOE will submit a license application to the NRC to obtain authorization to construct a repository at the site.

1.2.1 Scientific investigation

The detailed study mentioned in the preceding section is referred to as scientific investigation. It is a comprehensive program of studies and component activities to collect information about the geology of the site. These activities are integrated with activities to design a potential repository, a repository seals system, and a waste package (i.e., the waste form and the container in which it is packaged for disposal) and with the activities associated with performance assessments.

The site information consists of data on the natural features of the site, such as those related to the geologic, hydrologic, geochemical, climatological, and meteorological conditions at the site. This information is obtained by conducting both surface-based and underground tests in the field as well as tests in the laboratory. The underground investigations will be conducted in an exploratory shaft facility (ESF). In the current conceptual design, the ESF consists of two exploratory shafts, excavated to the depth of the proposed repository horizon, providing access to underground testing rooms and tunnels. The ESF will also include various structures and buildings on the surface, such as a hoist house for the shafts and temporary buildings for laboratories and offices.

No significant adverse environmental effects are expected to result from scientific investigation (DOE, 1986). However, the DOE, in consultation with the State of Nevada and affected units of local government, will conduct activities during scientific investigation to monitor environmental conditions and will implement appropriate mitigation measures that may be necessary. Plans for environmental monitoring and mitigation are described in the Environmental Monitoring and Mitigation Plan (DOE, 1988a). In addition, in response to Section 175 of the NWPA, as added by the Amendments Act, the DOE submitted a report to the U.S. Congress identifying potential socioeconomic effects that may result from the repository program (DOE, 1988b). These potential effects will also be monitored. Results of monitoring activities will be reported semiannually in environmental and socioeconomic progress reports.

1.2.2 The Site Characterization Plan

In preparation for scientific investigation, the DOE issued the Site Characterization Plan (SCP) for the Yucca Mountain site (DOE, 1988c) in December 1988. An SCP overview (a summary of the SCP) and an informational public handbook

also were released. Notices of the availability of the SCP and the accompanying documents were published in the Federal Register, and the Nevada news media were notified. The NRC, the State of Nevada, other Federal agencies, interested parties, and the general public provided comments on the SCP. Efforts to review and evaluate all comments from all parties are continuing.

1.2.3 Interactions with government agencies and the public

During the reporting period, the DOE committed a significant level of effort in support of briefings, technical exchanges, meetings, and site visits with the NRC and Program oversight groups such as the Nuclear Waste Technical Review Board, the State of Nevada, and affected local governments.

The DOE participated in seven meetings with the Nuclear Waste Technical Review Board (NWTRB). The NWTRB was created by the Nuclear Waste Policy Amendments Act of 1987, and its members are appointed by the President to evaluate the technical and scientific validity of activities undertaken by the Secretary after the date of the enactment of the Nuclear Waste Policy Amendments Act of 1987, including scientific investigation activities and activities relating to the packaging and transportation of high-level radioactive waste or spent nuclear fuel. The full board contains several panels composed of experts that interface with various aspects of the DOE program. The four panel meetings held were: (1) a Hydrogeology and Geochemistry Panel meeting on December 11-12, 1989; (2) a Containers and Transportation Panel meeting on January 18-19, 1990; (3) a Structural Geology and Geoengineering Panel meeting on January 31-February 2, 1990, regarding exploratory shaft facility (ESF) alternatives and surface-based testing prioritization; and (4) a joint Risk and Performance Analysis and Structural Geology and Geoengineering Panel meeting on March 19-20, 1990. In addition, DOE participated in the following technical exchanges with the NWTRB: (1) a Structural Geology and Geochemistry Technical Exchange on November 20, 1989, regarding volcanology; (2) a Structural Geology and Geoengineering Technical Exchange on December 13, 1989, regarding the ESF; and (3) a Containers and Transportation Technical Exchange meeting on December 14, 1989.

On March 22, 1990, the NWTRB released its first Report to Congress and the Secretary of Energy, evaluating DOE's scientific and technical work at the Yucca Mountain site (NWTRB, 1990). Within the report, the NWTRB makes recommendations in three categories: technical and scientific; strategic technical and non-technical; and science policy. The recommendations are intended to assist the DOE in its efforts to improve the technical work being conducted at Yucca Mountain and to improve its overall study plan. The DOE will conduct a comprehensive review of the report. Initial observations by the Secretary of Energy are that the Report projects an overall impression that the program is moving in the right direction and there is no technical reason at this time to consider abandoning the Yucca Mountain site.

The DOE also participated in several interactions with the NRC, some of which involved visits to the Yucca Mountain site. Technical exchanges conducted over the reporting period included (1) discussions of ESF integration with the repository and related 10 CFR Part 60 (1987) requirements, (2) two exchanges on tectonics which included a site visit, (3) discussions of waste package container material, (4) discussions of seismic hazards, (5) a briefing on calcite-silica deposits which included a field trip to the site, (6) discussions of technical data management, and (7) discussions on the ESF geophysical anomaly Technical Assessment Review. Two formal meetings were held in November 1989 and March 1990 to schedule future interactions, and three bimonthly quality assurance meetings were held.

In addition, the DOE has supported several interactions with the Advisory Committee on Nuclear Waste (ACNW), an advisory body to the NRC. These interactions included (1) discussions about study plans and their schedule for submission to the NRC, (2) the ACNW review of a study plan on faulting near prospective surface facilities and discussion on criteria used by the NRC to select and review study plans, and (3) discussions on the U.S. Environmental Protection Agency's proposed revisions to 40 CFR Part 191

(1986).
In March 1990, personnel from the NRC, the Center for Nuclear Waste Regulatory Analysis (CNWRA), and the DOE visited the Lawrence Berkeley Laboratory to observe instrumentation, methodology, and experimental apparatus used in the simulation of thermohydrologic phenomena. The CNWRA is a dedicated, federally-funded research and development center that supports the NRC. The CNWRA will perform analysis and research to reduce regulatory uncertainties prior to the licensing process for a geologic repository for high-level waste.

The Nuclear Waste Policy Amendments Act of 1987 established a specific role in the repository program for the State of Nevada and affected units of local government (so far determined to be Nye County, Clark County, and Lincoln County). This role includes, among other things, review of (1) the DOE's technical documents, including the SCP; (2) the results of site characterization activities; (3) the designs for the repository and the waste package; and (4) the results of performance assessments. The DOE continues to seek to establish an effective working relationship with State and local governments. The State of Nevada and affected local governments also participate in meetings between the DOE and the NRC and NWTRB.

The DOE is working with American Indian groups having traditional and religious cultural ties with the Yucca Mountain area to protect and preserve their interests and practices. Interactions between the DOE and the American Indian groups are conducted under the Native American Cultural Resources Program.

In late March and early April 1990, the DOE conducted another round of public information meetings in Fallon, Tonopah, and North Las Vegas, Nevada. These Project Update Meetings discussed general issues and, in part, the status of the scientific investigation program. In addition, the status of the DOE responses to comments received at the March 1989 SCP Public Hearings was discussed. These responses are expected to be completed and released to the public during the third quarter of the 1990 calendar year.

Project Update Meetings will continue to be held at rotating locations around the State every six months. In addition to information about topics currently of public interest, the meetings also will provide updates on scientific investigation activities. Summaries of the comments and concerns raised by the public will be prepared and reviewed by Project scientists to ensure that all technical concerns are properly addressed.

A new Yucca Mountain Information office was opened in Las Vegas in March 1990. Both this office and the information office in Beatty are open daily to the public to provide additional information about the high-level waste management program and scientific investigation activities.

2. STATUS OF SCIENTIFIC INVESTIGATION

2.1 PREPARATORY ACTIVITIES

2.1.1 Quality assurance program

The U.S. Department of Energy (DOE) continued efforts to qualify the quality assurance (QA) programs of the DOE Office of Civilian Radioactive Waste Management (OCRWM), the Yucca Mountain Project Office (YMPO), and participating organizations. Consequent to the November 1989 and March 1990 audits of Los Alamos National Laboratory, all primary participant QA programs are now deemed adequate to support initiation of either Title II quality-affecting activities or work in support of new scientific investigation activities, with specific exceptions identified for each participant. The U.S. Nuclear Regulatory Commission (NRC) has informed the DOE at their bimonthly meetings that effective implementation of the QA programs must be demonstrated in greater detail prior to initiation of new scientific investigation.

All project participant QA Program Plans were accepted by the NRC during the reporting period.

In February 1990, a revision to the OCRWM Quality Assurance Requirements Document was issued. This revision incorporates QA requirements for high-level waste form producers, consolidates requirements specific to the Mined Geologic Disposal System, and incorporates software QA control requirements.

Throughout the reporting period, OCRWM actively engaged in prelicensing consultations with the NRC to discuss QA concerns. To ensure that the NRC is kept informed of OCRWM's progress in QA implementation, ongoing bimonthly QA program review meetings are held. These meetings provide a forum for the NRC, Edison Electric Institute, the State of Nevada, and other interested organizations to participate in resolving QA issues. The meetings provide information on the status, development, and progress of QA-related actions. The most pressing QA issue facing the program at the end of the reporting period was the qualification of the QA program for new scientific investigation activities.

Maintaining properly trained personnel within OCRWM is an ongoing process. Classes are held at regular intervals to cover all aspects of the QA program.

An effort to consolidate the QA Program Plans between OCRWM/Headquarters (HQ) and the YMPO began in February 1990. In addition, an evaluation of existing OCRWM/HQ and YMPO procedures was initiated to determine where procedures can be consolidated. Significant progress in QA Program Plan and procedural consolidation efforts is expected during the next reporting period.

2.1.2 Exploratory shaft facility design and construction

A formal evaluation of configuration and construction alternatives for the exploratory shaft facility (ESF) was initiated. An implementation plan for this ESF Alternatives study was completed on January 16, 1990, and became the basis for specific task direction. The study began by establishing a formal decision methodology to evaluate the relative attributes of various exploratory shaft and ramp configurations at the Yucca Mountain site. Objectives for this decision methodology are based on requirements in 10 CFR 60 (1987) and other applicable State and DOE requirements. These requirements have been identified, compiled, and categorized to form the basis for the objectives of the decision process.

In parallel, options for the ESF configuration have been developed that incorporate shafts and ramps at various locations and have been integrated with conceptual layouts for the repository at Yucca Mountain. Identification of

these options was formally completed on March 30, 1990, and presented to DOE management. These options were based on screening all historical options over the past decade and identifying new options that had the potential for addressing concerns raised by the Nuclear Waste Technical Review Board (NWTRB) and the NRC. A total of 17 options were identified that include various combinations of shafts and ramps in the northern and southern parts of the proposed repository block. This work was monitored by the NWTRB and the NRC.

The DOE met with the NWTRB Structural Geology and Geoengineering Panel on January 31, 1990, to discuss the history of the ESF and to outline the approach to the ESF Alternatives study. Input from the Panel was primarily in the area of decision processes. The ESF Alternatives study now will proceed to evaluate the identified options for location, configuration, and construction and to establish scores and weighting factors which can be used in the decision methodology to rank each option. The ranking of the options will allow important features of each option to be evaluated. This information can then be used to establish a preferred option for presentation to the DOE.

Proceeding in parallel with the ESF Alternatives Evaluation, during this same period, are three other studies: the Calico Hills Risk/Benefit Analysis (CHRBA), the prioritization of surfaced-based testing, and the alternative licensing strategies study. Interfaces created by each of these studies with the ESF Alternatives Evaluation are being factored into the selection process. Most significant of these three other studies to the ESF Alternatives Evaluation is the CHRBA. This effort will result in a "best" configuration by the end of June 1990 based on performance assessment concerns. This "best" Calico Hills characterization configuration will be integrated into each of the ESF configurations for scoring and evaluation. Should more than one "best" CHRBA configuration be selected, then the best fit for each of the ESF options will be integrated with that ESF configuration.

A second meeting with the NWTRB Risk and Performance Analysis and the Structural Geology and Geoengineering Panels was held on March 19-21, 1990, to review the strategy and basis for the development of repository and waste package design requirements, and the conceptual design possibilities for the repository system.

The ESF drawings showing the general arrangement of surface facilities and features and a portion of the design package dealing with site preparation were modified to incorporate the comments resulting from an August 1989 management review. The drawings contained in the second ESF design package dealing with the headframe, collar, and main test level layout were modified to incorporate the comments resulting from a September 1989 management review.

In November and December 1989, the ESF architect engineers made the transition from Title II design to technical support for the ESF Alternatives study. The design package dealing with site preparation was continued in order to complete a design control cycle and to support a DOE/NRC meeting on design control. The second ESF package is currently on hold awaiting the results of the ESF Alternatives study.

Revision 1 of the ESF Subsystem Design Requirements Document for Title II design was approved and issued in February 1990 (DOE, 1990d). This document presents the functional requirements and performance criteria for systems and subsystems within the scope of the ESF. Revision 1 included a review of Federal regulatory requirements to ensure they flow down to the applicable design requirements.

Two technical exchanges took place between the DOE and NRC: one on October 4, 1989, to discuss the flowdown of 10 CFR 60 (1987) requirements and ESF integration with the repository, and one on March 6-7, 1990, to discuss a geophysical anomaly (resistivity contrast) that occurs between the exploratory shaft sites.

The readiness review for the start of the Integrated Data System (IDS) Title II design was completed. Results of the review indicated that the design organization was not ready to commence design work. Due to reduced Project funding and schedule delays, the IDS design is on hold until March 1991.

2.1.3 Surface-based and underground testing program

An initiative identified in the Secretary of Energy's report to Congress (DOE, 1989) is the near-term focus on surface-based testing aimed specifically at providing information on site features and conditions that is needed to support early evaluation of the suitability of the Yucca Mountain site. In keeping with this new focus, the DOE is conducting an evaluation of surface-based testing prioritization. The objective of the task is to review the current plans for conducting the surface-based testing program, as described in the SCP, to ensure that activities are prioritized to study potentially adverse conditions early during scientific investigation. In addition, recommendations will be developed for methods that could support interim evaluations of site suitability during scientific investigation and, if the site has not been found to be unsuitable on the basis of these earlier evaluations, a final determination after site characterization is completed and prior to a decision on site recommendation. The task force to prioritize the surface-based program draws on expertise from the fields of performance assessment, geology, hydrology, and decision analysis. The task force has begun to develop influence diagrams, a draft methodology for prioritization, and decision and uncertainty trees. The task force will also consider the need for additional testing beyond that proposed in the SCP and identify duplicative or overlapping testing that might benefit from consolidation.

The DOE is also conducting a risk/benefit analysis of alternative strategies for characterizing the Calico Hills unit at Yucca Mountain. This unit is an important natural barrier between the repository horizon and the underlying groundwater table. The need for this analysis is a consequence of a formal NRC objection to the SCP/Consultation Draft issued in January 1988. The NRC staff maintained that plans for excavation and testing in the unit, in conjunction with the planned ESF excavations, were not based on an analysis of the risks and benefits of alternative methods for obtaining the needed information. The objection was resolved for the SCP issued in December 1988 on the condition that the analysis be performed and the NRC staff consulted before the results of the analysis are implemented.

A description of information needed from the Calico Hills unit is being developed, and the effectiveness of various techniques (e.g., drilling, mining) for providing access to the unit to obtain this information is being evaluated. A preliminary methodology for the risk/benefit analysis to evaluate each testing strategy has been developed from discussions between technical experts and decision analysts. Direct incremental cost and schedule information will be formulated for each strategy, independent of the technical assessments, for use in formulating the overall recommendations. The results from the Calico Hills risk/benefit analysis will be integrated with the ongoing study of alternative ESF configurations and the Surface-Based Testing Prioritization task.

The prototype testing in the G-Tunnel on the Nevada Test Site to develop concepts and methods for the planned subsurface testing was terminated in December 1989 due to budgetary constraints. The experience gained from the work performed in the G-Tunnel will be used in developing procedures for tests to be performed in the surface-based testing program and the ESF. A summary report by Los Alamos (1990) contains the status of the prototype testing activities.

2.1.4 Permits

During the reporting period, environmental regulatory compliance activities continued in an effort to obtain environmental regulatory approvals for scientific investigation activities at Yucca Mountain.

During the last reporting period, the U.S. Fish and Wildlife Service (USFWS) announced its intention to list the desert tortoise, which inhabits the desert areas of southwestern United States, including the Yucca Mountain area, as an endangered species under the Federal Endangered Species Act (ESA). As a result, the DOE prepared a biological assessment to evaluate the Project's potential effects on the tortoise and available alternatives for avoiding or minimizing

impacts to the tortoise. The biological assessment was submitted to the USFWS in October 1989. In February 1990, the USFWS issued its Biological Opinion, finding that scientific investigation activities at Yucca Mountain would not jeopardize the continued existence of the desert tortoise. The Biological Opinion contained specific terms and conditions that the DOE is implementing to minimize the potential effects on the tortoise. Consultations with the USFWS are continuing to finalize details of conditions in the Biological Opinion.

Discussions continue with the National Park Service (NPS) to address its concern that Project water use during scientific investigation may affect ground-water resources in Ash Meadows, Devil's Hole, and the Death Valley National Monument. The NPS is protesting all new applications in the region but has stated that establishing a monitoring program for the Ash Meadows area would satisfy its concerns. Consequently, a summary of the ground-water monitoring plan was prepared to address specifically the NPS concerns. The monitoring program was provided to the NPS on February 5, 1990.

The First Annual Report for the Programmatic Agreement on Historic Preservation, required by the Programmatic Agreement between DOE and the Advisory Council on Historic Preservation (ACHP), was completed and provided to the ACHP on March 13, 1990. The Programmatic Agreement identifies the actions DOE will take during scientific investigation to comply with the National Historic Preservation Act and other acts related to historic preservation and archeology.

On November 15, 1989, the U.S. Army Corps of Engineers (COE) notified the DOE that scientific investigation activities could be authorized under the COE nationwide permit program. This permit applies to projects with less than 10 acres of disturbance. The COE will not determine if the proposed activities can take place until consultations under Section 7 of the Endangered Species Act are completed with the USFWS regarding the desert tortoise.

On December 26, 1989, DOE's applications for three environmental permits that are required to proceed with scientific investigation work at Yucca Mountain (i.e., ground-water appropriation permit, air registration certificate, and an underground injection control permit) were returned by the State of Nevada with the statement that "(t)hese applications are now moot because the Yucca Mountain repository is prohibited."

On January 5, 1990, the Nevada Attorney General filed a lawsuit in the U.S. Court of Appeals in San Francisco charging DOE Secretary Watkins with violations of the Nuclear Waste Policy Act, as amended (NWPAA), by continuing to investigate Yucca Mountain as the potential site of a high-level nuclear waste repository. The suit seeks a declaration by the court that Nevada Assembly Bill 222, Assembly Joint Resolution 4, and Assembly Joint Resolution 6, which were adopted by the 1989 Nevada Legislature constitute a valid notice of disapproval of the Yucca Mountain site under the Act. In addition, the State seeks to prohibit DOE from conducting any further studies at the site.

Subsequent to this action by the State, DOE filed suit in U.S. District Court in Nevada on January 25, 1990, requesting a court order directing the State to act on the three permit applications and prohibiting the State from unlawfully interfering with DOE's efforts to comply with the NWPAA.

2.1.5 Land acquisition

Right-of-Way Reservation (ROWR) N-48602 was granted to the DOE by the Nevada State Office of the U.S. Bureau of Land Management (BLM) on October 10, 1989. It encompasses approximately 19,000 acres of land at the Yucca Mountain site under the jurisdiction of the Nellis Air Force Base Range. All scientific investigation activities described in the Site Characterization Plan can be conducted in this area subject to the conditions in the ROWR.

The land withdrawal application was amended on November 2, 1989, by deleting the use authorization provision. This provision was not necessary because ROWR N-47748 already provided that authority. The DOE had filed the land withdrawal application with the BLM in

early 1989.

Application was made to the Globe Ranger District of the Forest Service to acquire access to land near Apache Leap in Arizona to conduct prototype drilling. A special use permit was issued by the Forest Service on January 4, 1990.

The last four lode mining claims, Lucky #1-4, located on Yucca Mountain were abandoned on October 30, 1989.

2.1.6 Alternatives to license application strategy

Another initiative identified in the Secretary's report to Congress (DOE, 1989) is the evaluation of alternatives to the top-level strategies in the SCP to determine if the schedule for licensing and developing a repository can be improved without compromising waste isolation or decreasing protection of health and safety. A range of alternatives is to be considered, including options for evaluating site suitability and demonstrating regulatory compliance, alternative sets of licensing activities, alternative approaches to prioritization of testing, and options for repository and waste package design.

Implementation of the first phase of this effort began in January 1990 with an initial set of tasks to (1) develop a methodology for evaluation and comparison of alternative strategies and (2) identify general concepts that can serve as a basis for the development of detailed alternative strategies. The Alternative Licensing Strategy (ALS) methodology to be used was developed during the reporting period and is currently being used in feasibility studies and refined. Approximately 35 general concepts were developed including alternatives to the performance allocation in the SCP, alternatives to licensing activities and procedures, and alternatives to repository and waste package design.

In the second phase, detailed alternative strategies will be developed and evaluated using the ALS methodology. Later, these evaluations will be considered in developing an action plan for any modifications to the current strategy.

2.2 SITE PROGRAMS

The site programs consist of the planned field and laboratory investigations for obtaining the technical information needed to adequately characterize the Yucca Mountain site. This information is integrated with design and performance-assessment activities throughout scientific investigation. The field and laboratory investigations are organized into 16 distinct site programs, each with a specific technical focus (e.g., geohydrology, geochemistry, rock characteristics). Investigations are subdivided into studies comprised of specific activities. Refer to the SCP (DOE, 1988c) for a description of the objectives of each study and for a description of the activities that are included in each study.
During the reporting period, significant effort continued on the development, review, and approval of study plans. Study plans are the documents that describe site program studies and activities in greater detail than that provided in the SCP. They are the link between the studies described in the SCP and the technical procedures that will be used in conducting tests in the field and laboratory. There are 106 studies identified in the SCP for which study plans need to be developed. At the end of the reporting period, almost half of all SCP study plans were within the DOE review process.

The development of study plans for ongoing activities is a high priority. An activity is considered to be ongoing if it was in progress at the time the Yucca Mountain site was originally selected in 1986 as one of the three sites to be characterized. Examples of ongoing activities include hydrologic, meteorologic, and seismic monitoring at the site; geodetic surveys; and laboratory analyses of degradable and irreplaceable samples. Before the initiation of a new site activity, a study plan for the activity must be developed, reviewed, and approved by the DOE. All study plans will be submitted to the NRC for comment as they become available.

The Secretary's review of the program, published in the Secretary's report to Congress (DOE, 1989)

led to, among other things, a revised schedule for scientific investigation and a new focus on surface-based testing. This focus is aimed specifically at evaluating whether any features or conditions exist at the site that would so adversely affect performance as to indicate that the site is not suitable for development as a repository.

Specific progress made during the reporting period in the site programs is discussed in the sections that follow. Also, the status of NRC reviews of DOE-approved study plans that are part of the surface-based testing program are discussed where appropriate. Not all studies are addressed in the progress report as some studies have not been initiated, while others may not have produced results of programmatic significance during the reporting period. Those studies that are not addressed in the progress report are listed in Table 2.0.

Activities in the reporting period focused on preparations to begin new ground-disturbing scientific investigation activities at the Yucca Mountain candidate site. New scientific investigation activities will be initiated when (1) necessary activity authorizations (permits from the State of Nevada) have been obtained, (2) the necessary quality assurance controls are in place, and (3) appropriate study plans and procedures are completed.

2.2.1 Geohydrology (SCP Section 8.3.1.2)

Study 8.3.1.2.1.1 - Characterization of the meteorology for regional hydrology

A regional meteorology network measures precipitation, temperature, wind, and lightning. A network of 81 rain gages was installed to coincide with the location of neutron-moisture boreholes. Five precipitation events were documented by the network during the reporting period.

Study 8.3.1.2.1.2 - Characterization of runoff and streamflow

Routine operation of the streamflow and precipitation monitoring networks continued. Operation of 5 stream gages and about 13 peak-flow sites continued. Sites for the Yucca Mountain surface-water network gages were reconnoitered, selected, and mapped. Water-quality trailers, situated at strategic sites along Fortymile Wash, were equipped so that runoff samples can be collected for chemical and isotopic analyses. Monitoring of debris movement by surface-water runoff continued.

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

Routine operation of the potentiometric-level networks continued. Interpretation of the potentiometric surface in the vicinity of Pahute Mesa was revised. A discussion of regional and local flow systems near Yucca Mountain was prepared by Czarnecki and Luckey (1989).

Study 8.3.1.2.2.1 - Characterization of unsaturated-zone infiltration

Monitoring of natural infiltration continued in 74 shallow unsaturated-zone holes.

The digital-elevation model was used to facilitate geostatistical analysis of soil physical properties for Yucca Mountain. A personal-computer-based geographic information system was installed to establish a universal data base for surficial materials.

Feasibility testing of a ground-penetrating radar (GPR) system was conducted to determine its usefulness in mapping the thickness of alluvium at Yucca Mountain. Results indicate that GPR probably will not be useful because of difficulty in penetrating soil horizons and clay layers present in the alluvium. However, GPR may be useful for evaluating the nature of shallow fractures in the tuff because it penetrates fairly well into exposed bedrock. Several electromagnetic ground-conductivity (EMGC) surveys were conducted at the same locations as

the GPR surveys to determine the feasibility of using EMGC to delineate old alluvium-filled bedrock channels. These preliminary surveys were largely successful, but additional studies are needed to determine the usefulness of EMGC in characterizing other hydrogeologic properties. It is possible that a methodology combining GPR and EMGC could successfully overcome the problem presented by highly conductive clay layers.

Study 8.3.1.2.2.2 - Water movement tracer tests

The study plan was sent to the NRC in February 1989.

The results of the chlorine-36 studies at Yucca Mountain that pertain to matrix and fracture flow in the unsaturated zone were presented to the NWTRB meeting on December 11-12, 1989, in Denver, Colorado. Three samples (one reagent blank and two chemistry blanks) were prepared for the chlorine-36 accelerator mass spectrometry analyses that were scheduled at the University of Rochester's tandem accelerator. Problems with the injector control forced premature termination of the run before these three samples were analyzed.

A paper (Norris, 1990) on the use of chlorine isotopic measurements to trace water movements at Yucca Mountain was published in the proceedings of the American Nuclear Society (ANS) Nuclear Waste Isolation in the Unsaturated Zone FOCUS '89 conference. Measurements from chlorine-36 bomb pulse in tuffs from the unsaturated zone show potential for tracing recent water flow in faults and fractures.

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

Laboratory experimentation continued on the influence of scale on sorptivity values derived from imbibition experiments (movement of liquid water into rock matrix) using welded and non-welded tuff. Sorptivity is an important flux-related matrix property because it is related to relative permeability. The experiments demonstrated that there is no difference in sorptivity values derived from 1.0-inch diameter cores (petroleum industry standard) and 2.5-inch diameter cores, which will be obtained from future unsaturated-zone drillholes. Work began on a paper to document final results of the imbibition/sorptivity experiments. A formal laboratory demonstration of the rock-matrix imbibition process was conducted for the U.S. Geologic Survey Unsaturated Zone Interest Group meeting. Based on a review of the soil-science literature, an evaluation of mathematical models of relative permeability that require moisture retention characteristics was conducted. Because these models were developed for other rock types and soils, modifications will be required before application to tuffaceous rocks.

An overview of the matrix-property testing program was presented to the Hydrology and Geochemistry Panel of the NWTRB. The presentation included summaries of historical, double-cap infiltrometer data collected on Yucca Crest; recently collected water-retention data; and recently modeled, unsaturated hydraulic-conductivity data.

An overview of plans for in situ monitoring of the fluid-flow potential field in the unsaturated zone was presented to the Hydrology and Geochemistry Panel of the NWTRB. Results and observations from the prototype UZ-1 monitoring and from G-Tunnel prototype drillhole instrumentation experiments were also presented.

Study 8.3.1.2.2.6 - Characterization of gaseous-phase movement in the unsaturated zone

Ongoing monitoring activities continued with gas and water-vapor sample collection for chemical analysis, and well-head measurements of air movement in and out of boreholes UZ-6 and UZ-6s.

A paper by Thorstenson et al. (1990) emphasized the potential for gaseous-phase transport of radionuclides to the accessible environment during the lifetime of the repository.

Study 8.3.1.2.2.7 - Hydrochemical characterization of the unsaturated zone

Ongoing monitoring activities continued with the collection and analysis of gas samples from existing boreholes. Analyses of water samples from various cores continued in order to determine the source of water and related transport mechanism (fracture and/or matrix). Values of moisture content from a G-Tunnel core that included three fractures were analyzed. There was no systematic variation in moisture content with distance away from the fractures into the matrix material.

Relative to the investigation of primary versus secondary permeability and transport determination, water samples were collected from shallow neutron holes, and the transport mechanism of this water was investigated. One neutron borehole (UE-25UZN2) was investigated in detail. A field search of Pagany Wash was conducted, and at least three fracture systems within the wash were located, two of which intersect near borehole UE-25UZN2 and may be the mechanism for water inflow into that borehole. Equipment to monitor the flux of water was designed and installed.

Prototype testing of equipment and methodologies for determination of appropriate tracers continued. To date, a bromide compound (calcium or sodium bromide) and a borate compound (boric acid or sodium borate) appear to be the most conservative of the tracers analyzed.

A paper (Mower et al., 1990) on triaxial and uniaxial compression testing methods developed for extraction of pore water from unsaturated tuff from Yucca Mountain was published in the proceedings of the ANS Nuclear Waste Isolation in the Unsaturated Zone FOCUS '89 conference.

Study 8.3.1.2.2.9 - Site unsaturated zone modeling and synthesis

Work continued with hypothesis testing of existing conceptual models using available field and laboratory testing data in conjunction with testing relevant alternative conceptual models and with numerical modeling of the site hydrogeologic system. The results of this work have been presented by Hoxie (1990).

An overview of the geology and hydrology of the Yucca Mountain area was published (Wilson, 1989).

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

Water-table levels in boreholes were monitored regularly to record fluctuations in water levels over time. Efforts continued to improve the quality, reliability, and availability of data from the automated continuous water-level network. Analysis of selected water-level anomalies possibly caused by earth tides, barometric-pressure changes, earthquakes, fault creep, and underground nuclear explosions continued (Galloway and Rojstaczer, 1989).

Mean annual water levels were calculated for all zones and wells. Regional and local saturated-zone flow systems near Yucca Mountain were discussed by Czarnecki and Luckey (1989).

Study 8.3.1.2.3.2 - Characterization of the saturated-zone hydrochemistry

Considerable research was conducted to formulate specifications and preliminary design for a downhole, hydrochemical sampling system that will be used to obtain water samples from WT- and H-series holes at Yucca Mountain. The conceptual design of the system includes an in situ hydrochemical tool, downhole pump, inflatable packers, pressure transducers, umbilical, hoist unit, surface support trailer, and data acquisition system. Considerable investigation was done of the system developed and field tested by the Swedish repository program (SKB and SwedPower), elements of which are likely to be adapted for use at Yucca Mountain. However, because of the high cost of the Swedish system, less expensive domestic alternatives also were investigated, including the possible fabrication of a system similar to the C-Hole multiple-packer system that would incorporate the Swedish in situ hydrochemical tool. Alternative strategies for

characterization of saturated-zone hydrochemistry were discussed at the January 1990 DOE-SKB technical exchange and field trip that was conducted at Yucca Mountain.

Study 8.3.1.2.3.3 - Saturated hydrologic system synthesis and modeling

Preliminary analysis began of measured strain-induced hydrologic responses. The FEHMS code which simulates coupled hydro-mechanical processes was used to simulate water-level and fluid-pressure responses in the C-holes and well UE-25 p#1 to earth tides and atmospheric loading.

2.2.2 Geochemistry (SCP Section 8.3.1.3)

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

The study plan was sent to the NRC on November 30, 1989. The NRC had started its review but had not yet completed its start-work review during the reporting period.

Separation techniques for trace minerals are being developed for characterizing the distribution of these minerals in the repository host rock and the zeolitic Calico Hills tuff below. These trace minerals may control the ground-water chemistry which in turn affects radionuclide retardation potential.

Work during this reporting period consisted of continued characterization of existing core material and samples from the site using x-ray optical and scanning electron microscopy techniques. Thin-section studies of volcanic glass preserved in drill core samples indicate that preservation of volcanic glass in the cores will be difficult to use as a criterion for marking water table elevations. These studies have found local areas of preserved volcanic glass within the zeoloitic tuffs both above and below the water table.

Future work in this study will focus on completing the mineralogic characterization (both the fracture filling minerals and the bulk rock) of existing samples and support to the laboratory testing studies. Work will continue to determine if mineral distributions can be used to identify past levels of the ground-water table.

Current understanding of the natural barrier below the repository and information on the thermal stability of zeolites and clays (sorptive minerals) was presented in a paper by Bolivar et al. (1990).

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

During this reporting period a paper (Levy and O'Neill, 1989) was presented on the moderate temperature hydrothermal alteration of a portion of the Topopah Spring Tuff (repository host rock) containing a high proportion of volcanic glass (the upper vitrophyre). Oxygen isotope measurements were used to estimate the temperature at which secondary quartz was formed as a product of mineral reactions involving volcanic glass and the minerals heuluridite, clinoptilolite, and smectite in an interval of altered rock below the candidate repository host rock. The isotopic data indicates that the alteration temperatures were probably between 40-100°C. The alteration is thought to have been associated with devitrification of the cooling rocks shortly after deposition.

Work on long-term heating experiments continued to determine if significant alteration of clay and zeolite minerals is to be expected from waste emplacement. Work is also continuing on the alteration of volcanic glass. These long-term alteration studies are aimed at determining the stability under post-emplacement conditions of minerals important to retarding radionuclide movement along ground-water flow paths from the repository.

Study 8.3.1.3.4.1 - Batch sorption studies

During this reporting period, sorption and desorption laboratory tests were completed using pure minerals, neptunium, and technetium in ground water from borehole J-13. A paper by

Meijer et al. (1990) addressed the technical areas important to the applicability of laboratory sorption data for estimating radionuclide retardation; specifically, the use of crushed tuff versus solid rock samples in testing, variations in water/rock ratios, and the use of oversaturated stock solutions.

Study 8.3.1.3.4.2 - Biological sorption and transport

Laboratory testing of the chelating agents produced by microorganisms are being performed to increase the production and purity of the chelating agents produced by the microorganisms so that these agents can be used in further tests. Some tests have been performed to determine the extent to which these chelating agents bind iron in solution. These experiments with iron are the first step in determining the behavior of radionuclides.

In terms of radionuclide retardation effects from microorganisms, work is continuing on the agglomeration rates of suspended materials as affected by microorganisms. Agglomerating suspended materials that may contain radionuclides is a mechanism by which they are removed from the ground waters and their movement from the repository is retarded.

Study 8.3.1.3.5.1 - Dissolved species concentration limits

Work during this reporting period focused on the development of specialized instrumentation needed to perform the laboratory testing. Solubility limiting compounds for neptunium, americium, and plutonium were analyzed.

Study 8.3.1.3.5.2 - Colloid behavior

In a paper by Hobart et al. (1990), evidence was presented that colloidal plutonium (IV) is structurally similar to plutonium dioxide and electrochemically reactive.

Study 8.3.1.3.6.1 - Dynamic transport column experiments

During this reporting period, work was initiated on radionuclide transport through columns of crushed pure minerals. The effects of dispersion were examined in tests using crushed, intact, and fractured tuff columns, and results were reported in a paper by Rundberg et al. (1990). Comparison of batch and column test results for several radioactive tracers were completed showing a marked effect of time-dependent dispersion.

Study 8.3.1.3.7.1 - Retardation sensitivity analysis

Three-dimensional simulations of radionuclide migration (using the TRACRN code) from the repository, using limited available data, indicated that a three-dimensional modeling approach is most useful for identifying migration pathways. These modeling studies are reported in a paper by Birdsell et al. (1990). Additional work was performed during this reporting period on the completion of the colloid transport code CTCN, preliminary documentation publication for the TRACRN code, and verification work for the FEHMN/FEHMS code.

2.2.3 Rock characteristics (SCP Section 8.3.1.4)

Activity 8.3.1.4.1.2 - Integration of geophysical activities

The major product to date for the Rock Characteristics Program is a report on the integration of geophysical studies that are to be done as part of scientific investigation (DOE, 1990e). This report is known informally as the "Geophysics White Paper," and contains a compilation of the available geophysical data obtained through past work at the site, the major results based upon that data, and an integration of future plans for coordination of efforts to acquire additional data for those studies that depend on a great variety of geophysical data. The need for the report originated with an NRC comment on the Consultation Draft of the SCP

concerning the overall integration of the geophysical studies to be undertaken during scientific investigation.

Study 8.3.1.4.2.1 - Characterization of the vertical and lateral distribution of stratigraphic units within the site area

Initial preparation and study of electron microprobe mounts of samples from the Paintbrush Tuff was performed with the intent of using this procedure in modal analysis of the repository host rock. In related studies, graphs were prepared using clay-alteration, x-ray diffraction data from core samples obtained for specific intervals within the Paintbrush Tuff.

A new energy-dispersive, x-ray fluorescence machine was installed in December 1989; following installation, a tutorial for personnel who will be using the instrument was completed.

Methods to assess the alteration history of the host rock and past water-table levels were explored. Uranium-thorium-lead (U-Th-Pb) and rubidium-strontium (Rb-Sr) dating analyses were conducted on granitic xenoliths from the Prow Pass and Topopah Spring stratigraphic units at Yucca Mountain. Rb-Sr isotopic studies were completed for samples from both the Topopah Spring and Prow Pass units, with whole-rock samples prepared and ages calculated. Information obtained from this work will be used primarily in differentiating primary isotopic differences between those of the magma and those imposed by ground-water alteration.

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

Personnel met with the NWTRB in December 1989 to present information on compatibility of shaft excavation methods and underground geologic mapping techniques.

2.2.4 Climate (SCP Section 8.3.1.5)

Study 8.3.1.5.1.1 - Characterization of modern regional climate

Work began on the creation of a database on modern climate parameters for the western United States using recently acquired National Climate Data Center records.

Study 8.3.1.5.2.1 - Characterization of the Quaternary Regional Hydrology

Study plan 8.3.1.5.2.1 passed NRC start-work review on November 24, 1989. There were no NRC objections to beginning the study. NRC technical review comments are expected in May 1990.

A summary of floods that occurred in the region surrounding Yucca Mountain between 1983 and 1989 was prepared. Several sites in the vicinity of Yucca Mountain were reconnoitered or revisited to evaluate the state of preservation of evidence of flooding that occurred in August 1989 and during the summer of 1981. These evaluations of modern flooding throughout the region are critical to understanding the nature and effects of flooding that could occur in the washes at Yucca Mountain. They will provide input to an assessment of the potential for flooding in the vicinity of the conceptual surface facilities location. Paleoflood deposits in Titus Canyon (Death Valley) were reconnoitered to determine possible significance as evidence for regional paleoflooding and to target areas for data collection. Another site on the Amargosa River near Tecopa, California, was reconnoitered also. Recent severe head-cutting of the stream channel has exposed river sediments that may represent significant evidence of paleoflooding.

A conceptual model of lineament/fracture-zone-controlled regional ground-water flow in the vicinity of Yucca Mountain was presented at meetings of the American Geophysical Union (AGU) and Geological Society of America (GSA) (Sinton et al., 1989). Potential applications of three-dimensional Geographic Information Systems for regional ground-water flow system modeling were described in AGU and GSA

presentations (Turner et al., 1989; Turner and Kolm, 1989). An AGU abstract on the use of ostracodes as a source of quantitative paleohydrologic and paleohydrologic-environmental information was prepared and presented (Gutentag et al., 1989).

Quarterly sampling trips to the analog-recharge sites in central Nevada were conducted. Land access and environmental compliance approval was granted by the Yucca Mountain Project Office for installation of two weather stations near Rattlesnake Ridge at the Nevada Test Site.

A reference data base was constructed for soil-plant relationships and the hydrologic role of vegetation in southern Nevada. These data will be used to quantify past and present evapotranspiration in the vicinity of Yucca Mountain.

Research investigations continued to determine the character and origin of hydrogenic calcite-silica deposits located in the vicinity of Yucca Mountain. A variety of isotopic and paleontologic studies were carried out on sample suites of soil, vein, and outcrop samples to characterize deposits and develop genetic models. Based on preliminary results of analyses, it was found that strontium in soil carbonates is isotopically indistinguishable from Trench-14 vein carbonate and that veins are very different from the Paleozoic carbonates and Tertiary rocks, particularly those that host the veins. The same close fit of vein and soil carbonate is suggested by preliminary results of lead-isotope data.

Petrographic and geochemical studies of veins showed that opal-A, which has previously been found only in root casts, is also present in vein deposits. Some layers in veins had tectonic fabric, others did not. These variations, and more significantly chemical differences for microsite deposition, are not consistent with a saturated-discharge environment and suggest an intermittently wet environment where large-scale equilibrium would be inhibited.

Carbon and oxygen-isotopic compositions were found to be very similar for vein and soil carbonate samples. It was also found that ground waters in the vicinity of Yucca Mountain with carbon-14 ages in the range of 3,000-16,000 years could not produce the isotopic compositions of the veins without marked cooling prior to calcite precipitation. The combined carbon and oxygen-isotope data preclude a direct relationship between most of the waters and the veins. If the veins were deposited at typical surficial temperatures, deposition must have occurred from waters more concentrated in carbon and oxygen isotopes than presently exist in waters in the area. Such waters could have been typical in cooler (and possibly wetter) times.

The DOE and the NRC held a technical exchange on calcite-silica vein deposits on February 6-7, 1990. On February 6, 1990, technical discussions were held in Las Vegas, Nevada, between principal investigators, NRC, NWTRB, and State of Nevada representatives. February 7, 1990, was spent near the Yucca Mountain site at the locations of several calcite-silica deposits. The technical exchange provided a useful forum for presenting preliminary results of a wide variety of geochemical, geological, and paleontological studies directed towards identification and characterization of "hydrogenic" deposits in the Yucca Mountain area. Four possible modes of origin for these deposits were discussed: pedogenic (soil-forming processes), cold springs, hydrothermal, and coupled hydrologic/tectonic processes ("seismic pumping"). To date, the available evidence indicates that the deposits are probably pedogenic and almost certainly not hydrothermal in origin.

2.2.5 Postclosure tectonics (SCP Section 8.3.1.8)

Study 8.3.1.8.1.1 - Probability of a volcanic eruption penetrating the repository

Three new models have been developed for identifying potential structural controls of volcanic activity and quantifying the disruptive parameter in the probability calculations. One of the models involves Walker Lane structural control of the Crater Flat volcanic zone.

An image processor will be used to digitize geologic maps to determine volumes of volcanic

units for the probability calculations. The methodology of volcanic probability calculations has been revised (Crowe and Perry, 1990).

Study 8.3.1.8.5.1 - Characterization of volcanic features

Age determinations were completed for sample sites in the Sleeping Butte and Lathrop Wells volcanic centers. The ages have large analytical uncertainty. Three models are being developed for the possible chronology of eruptive events at the Lathrop Wells volcanic center.

A field trip was conducted with the NWTRB and representatives from the State of Nevada on November 20, 1989, to basalt centers in the Yucca Mountain region and to volcanic centers at the Cima volcanic field in California.

Samples from Lathrop Wells and Sleeping Butte volcanic cones, Crater Flats volcanic rocks, and volcanic cones of the Cima Volcanic field were prepared for potassium-argon (K-Ar) age dating and paleomagnetic study, and magnetic measurement was initiated for some of the samples.

Three K-Ar age determinations were completed for the Sleeping Butte volcanic centers (Little Black Peak and Hidden Cone centers). Paleomagnetic samples were analyzed for the Sleeping Butte centers.

Rock varnish studies have continued. Scanning electron microscope analyses continued to effectively decompose barium-titanium peak overlaps during analyses. These analyses will be used to derive rock varnish chemical compositions wherein the presence of barium within the rock varnish does not result in erroneously high concentrations of titanium being recorded. Tracor Northern SQ and MICRO Q EDS analytical programs were evaluated on the scanning electron microscope. Barium distribution in rock varnishes on geomorphic surfaces both of differing ages and at different elevations within southern Nevada were examined.

In addition, cation ratios corrected for barium were generated for two Holocene surfaces in the North Las Vegas Valley near Corn Springs. These points provide the initial calibration of the Yucca Mountain rock varnish dating curve into the Holocene. A paper (Harrington et al., 1990) presenting initial findings was given at the Geological Society of America annual meeting in St. Louis, Missouri, in November, 1989.

2.2.6 Meteorology (SCP Section 8.3.1.12)

Study 8.3.1.12.1.1 - Characterization of the regional meteorological conditions

New automatic weather stations are being catalogued as future sources of regional meteorological data.

Study 8.3.1.12.2.1 - Meteorological data collection at the Yucca Mountain site

Data collection from the meteorological monitoring program is ongoing.

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

Compilation of meteorological and climatological data from the Nevada Test Site and other local and regional sources is ongoing to quantify the extreme weather phenomena that may be expected at the Yucca Mountain site.

2.2.7 Offsite Installations (SCP Section 8.3.1.13)

Investigation 8.3.1.13.1 - Determination of nearby industrial, transportation, and military installations and operations (nuclear and nonnuclear)

A radiological monitoring program is being implemented according to the "Radiological Monitoring Plan for the Nevada Nuclear Waste Storage Investigations Project" (DOE, 1988d).

2.2.8 Surface characteristics (SCP Section 8.3.1.14)

Investigation 8.3.1.14.1 - Studies to provide the topographic characteristics of potential locations of surface facilities

Corrections of errors were completed on existing topographic contour maps A1, A2, B1, and B2 (Wu, 1985). Initial progress was also made in processing and construction of orthophotographic perspectives of the proposed repository, exploratory shaft, and Ghost Dance Fault areas.

Study 8.3.1.14.2.1 - Exploration program

Work began on the study plan for the "Exploration Program of the Soil and Rock Properties Near Prospective Surface Facilities" in October 1989. The study plan for SCP Study 8.3.1.14.2.3 has been combined with this plan to eliminate duplication of tests, maximize efficiency, and enhance coordination of activities while minimizing environmental effects. The goal of the study is to collect engineering rock properties necessary to characterize the materials in which the foundations of surface facilities will be built. The properties will then be used in design and performance assessment of those facilities.

2.2.9 Thermal and mechanical rock properties (SCP Section 8.3.1.15)

Study 8.3.1.15.1.1 - Laboratory thermal properties

A report on density and porosity data for tuffs from the unsaturated zone at Yucca Mountain (Schwarz, 1990) was published in March 1990. This report summarizes all density and porosity data collected by Sandia National Laboratory (SNL) for the Yucca Mountain Project before 1988 that are supported by records in the SNL Data Records Management System.

"Mineralogic and Chemical Data Supporting Heat Capacity Determination for Tuffaceous Rocks" (Connolly and Nimick, 1990) was published. The report contains data on 20 tuffaceous samples measured to determine heat capacity values for use in thermal analyses. The estimation process and the actual recommended values for heat capacity will be presented in a subsequent report.

"The Thermal Conductivity of Seven Thermal/Mechanical Units at Yucca Mountain, Nevada" (Nimick, 1990) was published. This report provides recommended values for rock-mass thermal conductivity of seven of the nine thermal/mechanical units that lie above the water table at Yucca Mountain. A companion report (in press) provides correlative information for the remaining two units that comprise the welded, devitrified portion of the Topopah Spring Member.

Study 8.3.1.15.2.1 - Characterization of the site ambient stress conditions

The study plan was submitted to the NRC on February 9, 1989.

2.2.10 Preclosure tectonics (SCP Section 8.3.1.17)

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

Ongoing characterization of the effects of underground nuclear explosions (UNEs) at the Nevada Test Site and ground motion studies continued. Ground motion studies model seismic-wave transmission to develop the capability of predicting ground motion from UNEs. Ground motion data were obtained at Yucca Mountain stations from UNE BARNWELL.

Study 8.3.1.17.4.1 - Historical and current seismicity

Ongoing operation of the Southern Great Basin seismographic network continued. Work continued on the upgrading of the seismic network covering Yucca Mountain and vicinity. Preparations were made to purchase new, more sensitive seismic stations, satellite-telemetry apparatus, and computer hardware and software

as part of the upgrade.

Work continued to update the seismic-event catalog through literature surveys and seismic-network reports.

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

This study plan passed NRC start-work review on November 24, 1989, and NRC technical review comments were provided to DOE on March 16, 1990. There were no NRC objections to beginning the study.

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

A literature search was conducted for published maps and reference material concerning the Southern Great Basin. Photogeologic interpretation of existing aerial photographs was conducted to identify faults with known or suspected Quaternary movement over the area of six 1:100,000-scale quadrangles.

Study 8.3.1.17.4.6 - Quaternary faulting within the site area

Work was initiated with aerial photographs to locate and identify lineaments and define other structural features associated with the Windy Wash fault system.

Modern analog studies of recent soil and Holocene fault scarps were completed in southern California.

Study 8.3.1.17.4.10 - Geodetic leveling

Compilation of baseline geodetic data for the southern Great Basin continued. This study will evaluate historical displacements across potentially significant Quaternary faults and establish rates of uplift and subsidence since the last survey.

Study 8.3.1.17.4.12 - Tectonic models and synthesis

A DOE/NRC technical exchange and site visit on tectonics was held in Las Vegas and Beatty, Nevada, on October 31-November 2, 1989. U.S. Geological Survey investigators showed attendees from other Yucca Mountain Project participants, OCRWM/HQ, the NRC, the State of Nevada, and the Nuclear Waste Technical Review Board field evidence for the existence of regional-scale detachment faults and regional geophysical data. These data were discussed primarily in the context of alternate conceptual tectonic models and potential impacts, if any, on repository performance.

Another DOE/NRC technical exchange on tectonic models was held in Denver, Colorado, on November 28-29, 1989. This meeting focused on data needed to discriminate among alternative tectonic models and on recent air photo analyses.

A DOE/NRC technical exchange on seismic hazards evaluation was held December 19-20, 1989, in Rockville, Maryland. The objective of this informal meeting was to discuss the DOE's comments on NRC's draft Technical Position on Seismic Hazards Evaluation and to discuss the technical approaches in DOE's program to resolving tectonics issues.

2.3 REPOSITORY DESIGN

The repository design program consists of the activities associated with designing both the surface and underground facilities of the proposed repository. These activities include the development of design criteria as well as design analyses. On March 19-20, 1990, a presentation was made to the Nuclear Waste Technical Review Board Panels on waste characteristics and inventory, areal power density, layout development, and overall area requirements of the repository. Questions and discussion centered on the impact on repository design of modifications in current thermal goals and plans for emplacing waste.

A policy review of a report entitled "Waste Package Emplacement Orientation

Recommendation" has been completed. This study evaluates the two emplacement orientation options (vertical vs. horizontal). The vertical emplacement option was found to have advantages over horizontal emplacement, both in terms of retrievability and the superior technology in driving vertical boreholes.

Experiments were initiated at the U.S. Army Corps of Engineers Waterways Experiment Station (WES) to develop technical procedures for laboratory mechanical testing of large blocks with simulated fractures and also to evaluate analytical techniques. Work at WES began in late February 1990 to identify candidate brick materials for block construction.

2.4 SEALS-SYSTEM DESIGN

The seals system program includes seals materials testing, design development, and design analyses. The DOE currently plans to seal all shafts, ramps, exploratory boreholes, and emplacement drifts as part of the permanent closure of the repository.

Work has been initiated to define the instrumentation and data acquisition systems used to support sealing component field tests. Included in this work is definition of the type and sensitivity of instruments available to measure specific properties of backfill and cementitious materials. Also involved is description of available acquisition systems and of currently used emplacement procedures.

Supplemental design requirements for the sealing program were defined, and the technical rationale for each were formulated. These new design requirements were developed for (1) a capillary barrier, (2) a vegetative cover over the shaft entries, (3) pad-slope restoration over the exploratory shaft pad area, (4) establishment of spacing between drifts and boreholes, (5) definition of in situ stress and thermal environments (constraints and assumptions for seals), and (6) pressure grouting and seal emplacement in the exploratory shaft.

An assessment of available technologies for sealing underground openings and exploratory boreholes was initiated. The first aspect of this activity was to review the available technologies for sealing underground openings, shafts, and ramps; to evaluate the adequacy of these technologies with respect to the Yucca Mountain Project; and to reach a preliminary determination on whether or not sealing can be performed using existing technologies. The second aspect is to develop a strategy for sealing exploratory boreholes drilled as part of the Yucca Mountain Project. As part of this strategy development, failure mechanisms of borehole seals will be defined, available technologies to clean boreholes and emplace seals will be evaluated, and a trade-off methodology will be defined.

A reconnaissance trip was conducted to G-Tunnel to define areas for future in situ sealing tests and to assist in the definition of field tests in support of ESF studies. As a result of this trip, areas for the field tests were defined and the procedures for the tests were outlined. However, the subsequent closure of G-Tunnel has resulted in uncertainties in the location of field tests of sealing components.

In continuing investigations on the emplacement of rockfill in underground openings, three mining operations were visited (the Billie Mine in Death Valley, California; the Apex Mine in St. George, Utah; and the Cannon Mine in Wenatchee, Washington).

During November 1989, a meeting was held in Vienna, Austria, to prepare an International Atomic Energy Agency (IAEA) publication entitled "Performance of Engineered Barriers in Deep Geological Repositories." The report was prepared by consultants representing the United States (task leader from the repository sealing program), Canada, West Germany, and Sweden. The preparation of this document represents the first step in the process. Typically, such IAEA documents undergo a significant number of modifications before publication.

A poster presentation on seal longevity and performance was presented at the Material Research Society Meeting in Boston in December 1989. The methods used in this prior work are similar to those used in "Analysis [using EQ3NR.EQ6] of the Geomechanical Effects of

Cementitious Materials on Ground Water and Tuff in the MPZ [modified permeability zone] and at the Base of the Shaft." Because this paper was well received by members of the scientific community, it is expected that the methodology will be acceptable.

2.5 WASTE-PACKAGE DESIGN

According to the current waste package reference design, the waste package consists of the waste form and the container in which the waste form is placed. The objective of the waste package design program, described in Section 8.3.4 of the Site Characterization Plan, is to develop a waste package that is compatible with the characteristics of the emplacement environment. The design of the waste package must be integrated with the performance assessment program to ensure that the waste package will contribute to meeting the performance objectives for waste containment and controlling the release of radionuclides from the engineered barrier system.

The waste package design program includes the development of waste package design bases, design analysis, container-material testing, the development of a reference design, waste-form testing, and the characterization of the waste package emplacement environment.

2.5.1 Postemplacement near-field environment

Characterization of chemical and mineralogical changes in the postemplacement environment continued as work was begun on an outline of proposed input to the Work Package Requirements Preliminary Environmental Report. The experiments begun nearly a year ago on rock-water interactions at elevated temperatures were terminated. These experiments were aimed at determining how a steady-state tuff-water system responds to perturbations in fluid composition. Solutions have been submitted for analysis.

In the area of phase dissolution in the waste package environment, dissolution, and precipitation kinetics experiments of both kaolinite and gibbsite at 80°C continued. Study of the dissolution and precipitation kinetics of cristobalite at 200°C continued. Steady-state concentrations of silica were achieved in the dissolution and precipitation experiments, but the steady-state value did not approach expected concentrations in all cases. Analysis of solid phases is in progress to determine the cause of the discrepancy.

With regard to the hydrologic properties of the waste package environment, work is continuing in the area of two-phase fluid system properties to verify (through the use of numerical models) the applicability of theoretical relationships which determine whether fracture or matrix-dominated flow is likely, on the detailed analysis of the rewetting behavior in the dried-out zone, and on modeling fracture imbibition.

Modeling work continued on developing scaling relationships (using dimensionless parameter groups) for near-field hydrothermal flow. An important outcome of this work is that net drying is dependent on the heat generation rate of the waste package. Modeling studies were conducted to confirm scaling relationships of near-field hydrothermal performance and work continued on both the detailed analysis of the rewetting behavior in the dried-out zone and on modeling fracture imbition. Modeling work was initiated to look at the effect of having zones of altered permeability (either increased or decreased) along the face of fractures. Investigations of one-dimensional imbibition in composite matrix blocks of finite thickness are being conducted first.

Presentations on the hydrologic properties of the waste package environment were made to the NWTRB panels: Hydrology and Geochemistry (December 12-13, 1989), Waste Package and Containers (January 18-19, 1990), and Risk and Performance Assessment and Structural Geology and Geoengineering (March 18-19, 1990).

Engineered barrier system field tests involving repository horizon near-field hydrologic properties have been the focus of activities in G-Tunnel. The horizontal prototype test was completed, including overcoring of selected instrumentation boreholes, logging of post-test core samples, and

measurements of core porosity. The analysis of data from the horizontal prototype test continues. Stand-alone reports are being completed on the neutron logging results (rock mass moisture content), temperature and gas permeability results, comparisons of modeling projections, psychrometer readings, and electromagnetic measurements (for rock mass moisture content).

Planning activities, including preparation of planning documents, continued for a proposed vertical emplacement prototype test. Some equipment ordered for this test was received. Vertical test activities were put on hold after the decision was announced to close G-Tunnel.

The hydrothermal model of the prototype test is able to accurately represent the temperature field observed throughout the test. The model is also able to accurately predict the dried-out zone surrounding the heater. Due to a lack of hysteretic characteristic curve data applicable to wetting conditions, the condensation halo surrounding the dried-out zone was overpredicted.

2.5.2 Characteristics and behavior of the waste form

Studies of the characteristics and behavior of the waste-form materials continued. Investigations continued on the dissolution and oxidation behavior of spent fuel and the corrosion and radionuclide release characteristics of zircaloy cladding. Also, spent fuel characterization parameters for the existing spent-fuel inventory and methods to extend the domain of parameters to the projected spent-fuel inventory are both being addressed.

During March 1990, a meeting was held in Vienna, Austria, to prepare an International Atomic Energy Agency publication entitled "Concepts for the Conditioning of Spent Fuel for Final Waste Disposal." The report was prepared by consultants representing the United States, Canada, West Germany, Sweden, United Kingdom, Spain, South Korea, China, France, Belgium, Finland, and the U.S.S.R. The preparation of this document represents the first step in the process. Several iterations will occur prior to publication.

By using a flow apparatus, preliminary experimental test results were obtained for the dissolution response of spent fuel in a variety of water chemistries (Wilson and Gray, 1989). Oven dry-bath spent-fuel oxidation testing activities continued. As part of the dry bath oxidation tests, interim weight gain measurements are conducted bimonthly. No deviations from expected values have been observed.

A preliminary model for oxidation kinetics of small fragments has been developed (Stout, Shaw, & Einziger, 1990). The model approach uses statistical concepts to represent the number densities of grain boundary and grain volume species. From experiments, it has been observed that grain boundaries oxidize more rapidly than grain volumes. By applying a statistical approach, the model development is consistent with this observation.

A model to represent the stress dependence on the platelet orientation of hydride precipitates was completed (Stout, 1990). The problem of hydrogen in Zircaloy cladding and its precipitation at low temperatures as zirconium hydride platelets is a possible cladding failure mechanism. The failure is considered highly probable when the tangential (hoop) stress of the cladding is sufficiently tensile to induce hydride platelets oriented in planes with their platelet normal vectors in the cladding tangential direction. In this orientation, the platelets may provide a brittle pathway for a crack to propagate through the cladding in the thickness direction. The model analytically represents both the deformation and thermodynamic responses of hydride precipitation kinetics. Thus, the model couples the work of the displacements induced from hydride precipitation (and the stress state) and the thermodynamic energy changes of hydride precipitation. The thermodynamic segment of the model uses nonequilibrium concepts to represent the dependence of hydride platelet orientation on the state of stress.

Modeling carbon-14 release from failed spent-fuel containers continued (Pescatore, 1989). The preliminary analysis based on this model supports the assumption that partly-failed containers may

offer a significant delay to gaseous carbon-14 release both during the substantially complete containment and the controlled release periods.

Several types of glass leach tests were initiated or were continued during this time period. Flow-through tests continued on SRL-165 analog glasses. These tests provided quantitative information on the effect of pH and temperature on glass dissolution rates (Knauss et al., 1989). Unsaturated (drip) tests on SRL-165 glass and ATM-10 continued during this period; these tests help identify the effects of intermittent fluid contact with the glass waste form. Hydration tests were initiated on SRL-165U and SRL-202U glasses at 200°C; these tests simulate water vapor-glass reactions under unsaturated conditions at various relative humidities. Some of the glass samples from the hydration tests were subsequently leached in MCC-1-type saturated tests to investigate the effect of the hydration reaction on later glass dissolution in liquid water.

Leached glass samples from several tests series have been analyzed using the analytical electron microscope (AEM). The compositions and identities of secondary phases and alteration layers have been identified. The AEM analysis is critical for input into the geochemical model of glass dissolution, which currently needs the composition of the surface alteration layer and the identities and compositions of secondary phases as input (Bourcier, 1990). A compilation of all J-13 water-tuff equilibrations was made to establish the variation in fluid compositions which result from these equilibration procedures. The purpose of this work is to determine how sensitive the glass dissolution rate is to anticipated variations in the leachant composition.

Several glasses to be used in leach tests have been obtained from Savannah River Laboratory as part of the effort on cooperative testing with waste producers. These glass compositions are those identified in the Waste Compliance Plan as glasses typical of those to be produced by the Defense Waste Processing Facility.

The findings in a previous report (Wilson and Bruton, 1989) which compared experimental and geochemical simulation results were that secondary phases precipitated during steady-state dissolution of spent fuel in a complex water chemical solution are similar to that expected in a repository at Yucca Mountain. The identification of such secondary phases, which are in small quantities, is experimentally very difficult. Also, their existence and unknown compositions mean that mechanistic model development for dissolution response cannot be readily performed. Therefore, simpler dissolution experiments and their concurrent analyses are being planned based on flow-through apparatus. In a flow-through test (Wilson and Gray, 1989), water chemistry at the inlet of a small cell containing a test sample of UO_2 fuel can be experimentally controlled. Thus, the chemical ingredients of a complex water solution can be investigated separately, and also additively, by mixing different controlled water chemistry solutions for the flow-through test. These distinct tests will provide input to develop models for spent-fuel dissolution response.

Glass dissolution modeling using EQ3/6 continued to use experimental data from the glass dissolution tests to constrain and quantify the glass dissolution kinetic model (Bourcier et al., 1989). Results of the flow-through tests at constant pH were used to provide a value for the rate constant for glass dissolution as a function of temperature and pH in a modified EQ3/6 model. Modeling results have shown a clear need for doing simple glass dissolution tests which can be used to identify and quantify the glass dissolution process. Two types of tests were designed and are currently in progress. These tests will provide a critical benchmark of the current model. The first is a flow-through type test in which the buffer solutions are doped with various elements present in the glass. This test will identify the role of solution composition and dissolution affinity in determining the glass dissolution rate. The second is a closed system test where nuclei of stable secondary phases are added to investigate how the presence of secondary phases affects the dissolution rate.

Prototype modeling for development of a system model for waste package performance assessment is underway. A paper on the status of waste package system performance assessment was approved for presentation at the International High-Level Nuclear Waste Conference to be held in Las Vegas, Nevada, in April 1990. Example

applications of PANDORA-1.0 have been performed. Development of uncertainty methodology is in progress. The uncertainty methodology will be used both for uncertainty propagation (from input to output of the performance assessment models) and for numerical integration over all the waste packages to form the source term and the engineered-barrier system (EBS) performance, which, in turn, will be compared to NRC performance regulations. Prototype analyses of radionuclide release rates from the EBS have been performed as part of a DOE performance assessment calculational exercise.

Work has started on identifying scenarios in, or affecting, the engineered barrier system in order to integrate scenarios for release from waste packages.

2.5.3 Characteristics and behavior of disposal-container materials

Waste package fabrication closure and inspection studies as well as characterization of container materials already fabricated are activities that have been placed on a hold status this period. Work was started to complete the selection criteria and their weighting factors under the new Quality Assurance Plan.

A degradation mode survey was published in February 1990 (Farmer, 1990). This report consisted of 8 bound volumes and an overview containing approximately 1200 relevant publications. Each volume discussed a unique mode of degradation, such as general oxidation and corrosion, localized corrosion, or stress corrosion cracking. The survey included both copper-based and austenitic alloys.

Laboratory studies continued to assess the susceptibility of each copper-based and austenitic alloy to stress corrosion cracking in both concentrated (20x) and non-concentrated (1x) simulated J-13 well water. In addition, the effect of radiolysis on alloy corrosion was also studied. Laboratory studies were started using electrochemical techniques to determine the propensity of the alloys to pitting corrosion. Equipment was installed and made ready to initiate a number of stress corrosion cracking tests, including long-term crack propagation measurements. Procurements were placed to fabricate these somewhat complex stress corrosion cracking specimens according to Quality Assurance procedures.

A number of models useful for the degradation of the candidate alloys by various corrosion modes were identified. These models were presented to the NRC and the NWTRB during program reviews. The first models to be applied will require the pitting potential laboratory data now being developed.

A report entitled "The Potential Use of Lead in the Waste Package for a Geologic Repository at Yucca Mountain, Nevada," was issued on February 9, 1990 (DOE, 1990a). This report was in response to a directive by the Senate Committee on Appropriations accompanying the Energy and Water Appropriations Act for 1989 that DOE evaluate the use of lead for this purpose. Conclusions were that although lead would be inappropriate for use in the reference conceptual design of the waste package, lead will be considered for potential applications in alternative design concepts for site conditions that are not expected but may warrant consideration.

2.6 PERFORMANCE ASSESSMENT

Performance assessment is the process of evaluating components, subsystems, or system behavior relative to radiological health and safety or the containment and isolation of radioactive wastes. The objectives of these assessments are to demonstrate compliance with the numerical criteria associated with 10 CFR Part 60 (1987), to support the development of the repository system, and to guide testing during scientific investigation.

Calculational exercises were initiated in FY 1990 to increase coordination among program participants; evaluate the availability and adequacy of models, codes, and data; and determine further needs for performance assessment activities. These exercises, called PACE-90, involve program

participants organized into three working groups.

Working Group 1 responsibilities include total system performance assessments, including the analysis of retardation processes as they affect the transport of radionuclides in the far field. The objectives of this working group during FY 1990 are (1) continued development of the total system performance assessment model including the evaluation of data and conceptual models for such a total system model; (2) scenario development and, through a series of PACE problems, evaluation of the consequence analysis methodology; (3) sensitivity and uncertainty analyses to assist in methodology development; and (4) guidance to the Exploratory Shaft Facility design program and the surface-based testing program.

Working Group 2 has responsibility for analyzing the performance of the engineered-barrier system (EBS), for estimating near-field environments, and for providing the information to define the source term for total system performance assessments. The objectives for Working Group 2 during FY 1990 focus on (1) improving the understanding of near field environments and, through sensitivity analyses, their importance to EBS performance; (2) continuing the development of models for evaluation of EBS performance measures; (3) exercising the EBS evaluation methodology and technology considering the scenarios defined for total system performance assessments; (4) developing models of EBS performance appropriate for use in total-system performance assessment and supplying information to define the source term for the total-system performance assessments; and (5) providing guidance to the design program and the surface-based testing program.

Working Group 3 has responsibility for the assessment of natural-barrier performance, including the development of conceptual models for liquid and gas flow through the saturated and unsaturated systems, evaluation of the effects on the flow of the repository and the waste packages, and the calculation of pre-waste-emplacement ground-water travel time. The FY 1990 objectives for Working Group 3 focus on (1) analyses to assist in the development of models appropriate for natural barrier performance assessment, (2) the development of model validation strategy and methodology, (3) the definition of a set of problems to exercise the the natural barrier performance assessment methodology and technology, and (4) initiation of those exercises. The performance measure of most interest for the natural barrier system is the pre-waste-emplacement ground-water travel time; however, the analyses conducted under this area of performance assessment also provide an understanding of the post-emplacement hydrology and provide information to support the specification of appropriate fluid velocity fields for the total system performance assessments.

A data set was assembled for PACE-90, including hydrologic/stratigraphic and sorptive properties for use by the working groups in the "nominal configuration" calculations. Work has begun on construction of a similar data set for the PACE-90 "perturbed configuration." The second set will include reference problems that will be based on currently developed disturbed scenarios. The disturbed scenarios to be addressed include basaltic volcanism, climate change, and human intrusion. These problems are not intended to represent real cases, but rather are intended to be the starting point for developing the tools necessary to calculate more complicated and realistic problems in the future.

Several studies concerning infiltration flow instability in porous media and fractures, and the potential impact on Yucca Mountain, are in progress. Glass and Yarrington (1989) reported results to date in these studies. Most conceptual models assume that infiltration flows are essentially stable. Irregularities in the flow fields are attributed to spatial variability in the hydraulic properties, initial conditions, or boundary conditions. However, gravity-driven instability of an infiltration flow (or "wetting front instability") can cause the flat wetting front to break into fingers as it moves through an unsaturated porous medium or a fracture. Thus the downward flow can bypass much of the vadose zone. This mechanism is also described in "Miller Scaling of Finger Properties in Sandy Soils," a paper presented by SNL staff at the U.S. Department of Agriculture conference, October 11-13, 1989, Riverside, California ; and in "Two-Phase Immiscible Displacement in Porous

Media: Stability Analysis of Three-Dimensional, Axisymmetric Disturbance," a paper submitted to Water Resources Research.

At the Intraval Symposium, an analysis of correlation structures found in data sets from the Las Cruces trench, the Apache Leap Tuff site, and Yucca Mountain was presented. Preliminary work has started to reduce the Apache Leap Tuff data provided at Intraval. The work is being conducted as the first step toward building a model for porosity distribution in tuffaceous rock that can be used to constrain input for performance assessment modeling of the Yucca Mountain site. A systematic difference has been observed between porosity measured on small versus large core samples. The difference, which must eventually be explained, does not appear to be the result of either a scale difference or a systematic error in the measurement technique.

A presentation was made to the NWTRB Hydrogeology and Geochemistry Panel on December 11-12, 1989, on "Conceptual Models for Fracture/Matrix Flow." Comments from the presentation appeared in the "First Report to the U.S. Congress and the U.S. Secretary of Energy," issued by the Nuclear Waste Technical Review Board on March 22, 1990 (NWTRB, 1990).

Work began in December 1989 to initiate identification of postclosure release scenarios. An event tree technique was chosen to construct the release scenarios and ultimately perform decision analysis. An event tree is constructed in a sequence beginning with a specific event or process that could conceivably lead to a radionuclide release to the accessible environment, such as basaltic volcanism. The tree then branches out indicating various subsequent parameter changes that might occur as a result of the initial disturbing condition. Each change is ultimately assessed in terms of the degree of effect on the repository postulated to occur.

A scenario is defined as a single, continuous path starting with the initial condition and ending with contaminant release. The initial trees will comprise as many scenarios as the staff can conceive for a particular change. Technical experts will then identify scenarios that have not been included and determine if some identified scenarios are either insignificant or not credible. The trees will be expanded to include the additional scenarios and the improbable scenarios will be deleted; those remaining will form the basis for performance assessment.

Table 2.0 - Studies and Activities not Addressed in Progress Report

Geohydrology (SCP Section 8.3.1.2)

Study 8.3.1.2.1.4 - Regional hydrologic system synthesis and modeling
Study 8.3.1.2.2.4 - Characterization of percolation in the unsaturated zone--ESF study
Study 8.3.1.2.2.5 - Diffusion tests in the ESF
Study 8.3.1.2.2.8 - Fluid flow in unsaturated, fractured rock

Geochemistry (SCP Section 8.3.1.3)

Study 8.3.1.3.1.1 - Ground water chemistry model
Study 8.3.1.3.3.1 - Natural analog of hydrothermal systems in tuff
Study 8.3.1.3.3.2 - Kinetics and thermodynamics of mineral evolution
Study 8.3.1.3.3.3 - Conceptual model of mineral evolution
Study 8.3.1.3.4.3 - Development of sorption models
Study 8.3.1.3.6.2 - Diffusion
Study 8.3.1.3.7.2 - Demonstration of applicability of laboratory data to repository transport calculations
Study 8.3.1.3.8.1 - Gaseous radionuclide transport calculations and measurements

Rock characteristics (SCP Section 8.3.1.4)

Activity 8.3.1.4.1.1 - Development of an integrated drilling program
Activity 8.3.1.4.1.2 - Integration of geophysical activities
Study 8.3.1.4.2.3 - Three-dimensional geologic model
Study 8.3.1.4.3.1 - Systematic acquisition of site-specific subsurface information
Study 8.3.1.4.3.2 - Three-dimensional rock characteristics models

Climate (SCP Section 8.3.1.5)

Study 8.3.1.5.1.2 - Paleoclimate study: lake, playa, marsh deposits
Study 8.3.1.5.1.3 - Climatic implications of terrestrial paleoecology
Study 8.3.1.5.1.4 - Analysis of the paleoenvironmental history of the Yucca Mountain region
Study 8.3.1.5.1.5 - Paleoclimate-paleoenvironmental synthesis
Study 8.3.1.5.1.6 - Characterization of the future regional climate and environments
Study 8.3.1.5.2.2 - Characterization of the future regional hydrology due to climate changes

Erosion (SCP Section 8.3.1.6)

Study 8.3.1.6.1.1 - Distribution and characteristics of present and past erosion
Study 8.3.1.6.2.1 - Influence of the effects of future climate on erosion
Study 8.3.1.6.3.1 - Evaluation of the effects of future tectonic activity on erosion

Postclosure tectonics (SCP Section 8.3.1.8)

Study 8.3.1.8.1.2 - Effects of a volcanic eruption penetrating the repository
Study 8.3.1.8.2.1 - Analysis of waste package rupture due to tectonic processes and events

Table 2.0 (continued)

Study 8.3.1.8.3.1 - Analysis of the effects of tectonic processes and events on average percolation flux rates over the repository
Study 8.3.1.8.3.2 - Analysis of the effects of tectonic processes and events on changes in water-table elevation
Study 8.3.1.8.3.3 - Analysis of the effects of tectonic processes and events on local fracture permeability and effective porosity
Study 8.3.1.8.4.1 - Analysis of the effects of tectonic processes and events on rock geochemical properties
Study 8.3.1.8.5.2 - Characterization of igneous intrusive features
Study 8.3.1.8.5.3 - Investigation of folds in Miocene and younger rocks of the region

Human interference (SCP Section 8.3.1.9)

Study 8.3.1.9.1.1 - An evaluation of natural processes that could affect the long-term survivability of the surface marker system at Yucca Mountain
Study 8.3.1.9.2.1 - Natural resource assessment of Yucca Mountain
Study 8.3.1.9.2.2 - Water resource assessment of Yucca Mountain
Study 8.3.1.9.3.1 - Evaluation of data needed to support an assessment of the likelihood of future inadvertent human intrusion
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

Meteorology (SCP Section 8.3.1.12)

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

Offsite installations and operations (SCP Section 8.3.1.13)

Investigation 8.3.1.13.2 - Potential impacts of nearby installations and operations

Surface characteristics (SCP Section 8.3.1.14)

Study 8.3.1.14.2.2 - Laboratory tests and material property measurements
Study 8.3.1.14.2.3 - Field tests and characterization measurements

Thermal and mechanical rock properties (SCP Section 8.3.1.15)

Study 8.3.1.15.1.2 - Laboratory thermal expansion testing
Study 8.3.1.15.1.3 - Laboratory determination of mechanical properties of intact rock
Study 8.3.1.15.1.4 - Laboratory determination of mechanical properties of fractures
Study 8.3.1.15.1.5 - Excavation investigations
Study 8.3.1.15.1.6 - In situ thermomechanical properties
Study 8.3.1.15.1.7 - In situ mechanical properties
Study 8.3.1.15.1.8 - In situ design verification
Study 8.3.1.15.2.2 - Characterization of the site ambient thermal conditions

Table 2.0 (continued)

Preclosure hydrology (SCP Section 8.3.1.16)

Study 8.3.1.16.1.1 - Characterization of flood potential of the Yucca Mountain site
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
Study 8.3.1.16.3.1 - Determination of the preclosure hydrologic conditions of the unsaturated zone at Yucca Mountain

Preclosure tectonics (SCP Section 8.3.1.17)

Study 8.3.1.17.1.1 - Potential for ash fall at the site
Study 8.3.1.17.2.1 - Faulting potential at the repository
Study 8.3.1.17.3.1 - Relevant earthquake sources
Study 8.3.1.17.3.2 - Underground nuclear explosion sources
Study 8.3.1.17.3.4 - Effects of local site geology on surface and subsurface motions
Study 8.3.1.17.3.5 - Ground motion at the site from controlling seismic events
Study 8.3.1.17.3.6 - Probabilistic seismic hazards analysis
Study 8.3.1.17.4.4 - Quaternary faulting proximal to the site within northeast-trending fault zones
Study 8.3.1.17.4.5 - Detachment faults at or proximal to Yucca Mountain
Study 8.3.1.17.4.7 - Subsurface geometry and concealed extensions of Quaternary faults at Yucca Mountain
Study 8.3.1.17.4.8 - Stress field within and proximal to the site area
Study 8.3.1.17.4.9 - Tectonic geomorphology of the Yucca Mountain region
Study 8.3.1.17.4.11 - Characterization of regional lateral crustal movement

3. SCHEDULES

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 3.0 presents the summary milestones for the scientific investigation program. Figure 3.0 shows the relationship of the summary milestones to the major activities.

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 time required to obtain Yucca Mountain site access; comments from the Nuclear Waste Technical Review Board, 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,1990f). 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.

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. When finalized, these schedules will be presented in future progress reports.

Table 3.0 - Summary Milestones for Scientific Investigation[1]

Waste Package

Start Waste Package Advanced Conceptual Design	10/92
Start Waste Package License Application Design	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.

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ACRONYMS

ACHP	Advisory Council on Historic Preservation
ACNW	Advisory Committee on Nuclear Waste
AEM	analytical electron microscope
AGU	American Geophysical Union
ALS	Alternative Licensing Strategy
ANS	American Nuclear Society
BLM	U.S. Bureau of Land Management
CHRBA	Calico Hills Risk/Benefit Analysis
COE	Corps of Engineers
CNWRA	Center for Nuclear Waste Regulatory Analysis
DOE	U.S. Department of Energy
EBS	engineered barrier system
EMGC	electromagnetic ground conductivity
ESA	Endangered Species Act
ESF	Exploratory Shaft Facility
GPR	ground penetrating radar
GSA	Geographic Society of America
IAEA	International Atomic Energy Agency
IDS	Integrated Data System
NPS	National Park Service
NRC	U.S. Nuclear Regulatory Commission
NWPA	Nuclear Waste Policy Act
NWTRB	Nuclear Waste Technical Review Board
OCRWM	Office of Civilian Radioactive Waste Management
OCRWM/HQ	OCRWM/Headquarters
PACE-90	Performance Assessment Calculational Exercises
QA	quality assurance
ROWR	Right-of-Way Reservation
SCP	Site Characterization Plan
SDRD	Subsystem Design Requirements Document
SNL	Sandia National Laboratories
UNE	underground nuclear explosion
USFWS	U.S. Fish and Wildlife Service
WES	Waterways Experiment Station
YMPO	Yucca Mountain Project Office

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In using models that depend upon uncertain parameters and variable data, the key issues are identification of the data that most affect the model predictions. Obtaining some of these data is difficult because of the complexity of the systems and the relatively long time periods of interest. It is important to evaluate quantitatively the effects of variations in input data on output results using sensitivity and uncertainty analysis. Sensitivity can be roughly defined as the change in output brought about by a specified change in input. The main purpose of sensitivity analysis is to determine which of several inputs maybe the most important and the extent to which each input affects the output. Sensitivity studies do not usually incorporate the error range or uncertainty of the output. This distinguishes sensitivity analysis from uncertainty analysis since the latter incorporates the input uncertainties with their sensitivities into output uncertainties. There are four approaches to perform the sensitivity analysis. These are: (1) graphical illustration, (2) mathematical approach, (3) statistical approach, and (4) adjoint technique. All four techniques can be applied to an analytical model. The mathematical and adjoint approaches require that the model equation must be differentiable analytically.

Argonne National Laboratory, 1989. "Comparison of the Layer Structure of Vapor Phase and Leached SRL Glass by Use of AEM [Analytical Electron Microscopy]," from the Materials Research Society Fall Meeting, Boston, MA, November 27-December 2, 1989, CONF-891119-106, Argonne National Laboratory, IL.

Test samples of 131 type glass that have been reacted for extended time periods in water vapor atmospheres of different relative humidities and in static leaching solution have been examined to characterize the reaction products. Analytical electron microscopy (AEM) was used to characterize the leached samples, and a complicated layer structure was revealed, consisting of phases that precipitate from solution and also form within the residual glass layer. The precipitated phases include birnes-site, saponite, and an iron species, while the intralayer phases include the U-Ti containing phase brannerite distributed within a matrix consisting of bands of an Fe rich montmorillonite clay. Comparison is made between samples leached at 40°C for 4 years with those leached at 90°C for 3-1/2 years. The samples reacted in water vapor were examined with scanning electron microscopy and show increasing reaction as both the relative humidity and time of reaction increases. These samples also contain a layered structure with reaction products on the glass surface.

Argonne National Laboratory, 1989. "The Reaction of Synthetic Nuclear Waste Glass in Steam and Hydrothermal Solution," from the Materials Research Society Fall Meeting, Boston, MA, November 27-December 2, 1989, CONF-891119-105, Argonne National Laboratory, IL.

Glass monoliths of the WVCM 44, WVCM 50, SRL 165, and SRL 202 compositions were reacted in steam and in hydrothermal liquid at 200°C. The glass reaction resulted in the formation of leached surface layers in both environments. The reaction in steam proceeds at a very low rate until precipitates form, after which the glass reaction proceeds at a greater rate. Precipitates were formed on all glass types reacted in steam. The assemblage of phases formed was unique to each glass type, but several precipitates were common to all glasses, including analcime, gyrolite, and weeksite. Reaction in steam occurs in a thin layer of condensed water which becomes saturated with respect to the observed phases after only a few days of reaction. The reaction in steam is accelerated relative to reaction in hydrothermal liquid in the sense that secondary phases from after a shorter reaction time, that is, after less glass has reacted, because of the smaller effective leachant volume present in the steam environment. A knowledge of the secondary phases which form and their influence on the glass reaction rate is crucial to the modeling effort of the repository program.

Barr, D. W., 1989. "Geologic Containment of Radioactive Waste," from the Conference on Technology-Based Confidence Building: Energy and Environment, Santa Fe, NM, July 9-14, 1989, LA-UR-89-2630, Los Alamos National Laboratory, NM.

This paper presents the results of work performed in resolving the uncertainties associated with the nature of the solubilities and speciation of actinides, the formation of radiocolloids, the sorption behavior of fission products and actinides and the transport mechanisms of advection, diffusion, and dispersion for radionuclides under environmental conditions thought to exist at Yucca Mountain, Nevada.

Barton, C. C., W. R. Page, and T. L. Morgan, 1989. Fractures in Outcrops in the Vicinity of Drill Hole USW G-4, Yucca Mountain, Nevada: Data Analysis and Compilation, USGS-OFR-89-92, Geological Survey, Denver, CO.

Fractures on outcrops in the vicinity of drill hole USW G-4 were studied in order to contribute to the characterization of fractures for hydrologic, geomechanical, and tectonic modeling of the Yucca Mountain block. Measurements were taken and recorded on 5000 fractures at 50 outcrop stations primarily in the upper lithophysal unit of the Tiva Canyon Member of the Miocene Paintbrush Tuff. Fracture orientation and surface roughness were recorded for each fracture. Additionally, notes were taken on fracture abutting, crossing, and offsetting relations, swarming, curvature, brecciation, slickensides, and fracture fillings. Frequency distributions of orientation and roughness were plotted and analyzed. Fractures with low roughness coefficients group tightly into two sets based on orientation. It is concluded that such fractures are cooling joints and that all other fractures are tectonic. The development of small-scale fractures adjacent, subparallel, and possibly related to the Ghost Dance fault has been addressed in a preliminary way based on data collected in this study. Such sympathetic fractures are abundant in the upper cliff unit but not in the upper lithophysal unit.

Bates, J. K., B. S. Tani, and E. Veleckis, 1989. "Identification of Secondary Phases Formed During Unsaturated Reaction of UO_2 with EJ-13 Water," from the Materials Research Society Fall Meeting, Boston, MA, November 27-December 2, 1989, CONF-891119-2, Argonne National Laboratory, IL.

A set of experiments, wherein UO_2 has been contacted by dripping water, has been conducted over a period of 182.5 weeks. The experiments are being conducted to develop procedures to study spent fuel reaction under unsaturated conditions that are expected to exist over the lifetime of the proposed Yucca Mountain repository site. One half of the experiments have been terminated, while one half are ongoing. Analyses of solutions that have dripped from the reacted UO_2 have been performed for all experiments, while the reacted UO_2 surfaces have been examined for the terminated experiments. A pulse of uranium release from the UO_2 solid, combined with the formation of schoepite on the surface of the UO_2, was observed between 39 and 96 weeks of reaction. Thereafter, the uranium release decreased and a second set of secondary phases was observed. The latter phases incorporated cations from the EJ-13 water and included boltwoodite, uranophane, sklodowskite, compreignacite, and schoepite. The experiments are continuing to monitor whether additional changes in solution chemistry or secondary phase formation occurs.

Bates, J. K., T. J. Gerding, and A. B. Woodland, 1989. "Parametric Effects of Glass Reaction Under Unsaturated Conditions," from the Materials Research Society Fall Meeting, Boston, MA, November 27-Decmeber 2, 1989, CONF-891119-3, Argonne National Laboratory, IL.

Contact of high-level waste glass stored under the unsaturated conditions anticipated at the Yucca Mountain site by water will be by slow intrusion of water into a breached container/canister assembly. Seven different sets of tests have been performed to investigate the effect of systematically varying parameters, such as glass composition, composition and degree of sensitization of 304L stainless steel, water input

volume, and the interval of water contact. Glass reaction has been monitored over a period of five years, and the parametric effects can result in up to a ten-fold variance in the degree of glass reaction.

Bates, J. K., W. L. Ebert, and T. J. Gerding, 1990. "Vapor Hydration and Subsequent Leaching of Transuranic-Containing SRL and WV Glasses," from the International Conference for High-Level Radioactive Waste Management, Las Vegas, NV, April 8-12, 1990, CONF-900406-4, Argonne National Laboratory, IL.

Prior to contact by liquid water and subsequent leaching, high-level nuclear waste glass subject to disposal in the unsaturated environment at Yucca Mountain, Nevada, will be altered through contact with humid air. Conditions could range from temperatures as high as 200°C to ambient repository temperature after cooling and relative humidities up to 100% depending on the air flow and heat transport dynamics of the waste package and near field environments. However, under any potential set of temperature/humidity conditions, the glass will undergo alteration via well-established vapor phase hydration processes. In the present paper, the results of a set of parametric experiments are described, whereby vapor phase hydrated glasses were subjected to leaching under static conditions. The purpose of the experiments was to (1) compare the leaching of vapor phase altered glass to that of fresh glass, (2) to develop techniques for determining the radionuclide content of secondary phases that formed during the hydration reaction, and (3) to provide a basis for performing long-term saturated and unsaturated testing of vapor hydrated glass.

Birdsell, K. H., K. Campbell, K. G. Eggert, and B. J. Travis, 1990. "Preliminary Integrated Calculation of Radionuclide Cation and Anion Transport at Yucca Mountain Using a Geochemical Model," from FOCUS 89: Nuclear Waste Isolation in the Unsaturated Zone, Las Vegas, NV, September 18-21, 1989, LA-UR-89-3503, Los Alamos National Laboratory, NM.

This paper presents preliminary transport calculations for radionuclide movement at Yucca Mountain, Nevada, using preliminary data for mineral distributions, retardation parameter distributions, and hypothetical recharge scenarios. These calculations are not performance assessments, but are used to study the effectiveness of the geochemical barriers at the site at mechanistic level. The simulations were run with TRACRN, a finite-difference porous flow and radionuclide transport code developed for the Yucca Mountain Project. Approximately 30,000 finite-difference nodes are used to represent the unsaturated and saturated zones underlying the repository in three dimensions. Sorption ratios for the radionuclides modeled are assumed to be functions of mineralogic assemblages of the underlying rock. These transport calculations present a representative radionuclide cation (Cs-135) and anion (Tc-99). The effects on transport of many of the processes thought to be active at Yucca Mountain may be examined using this approach. The model provides a method for examining the integration of flow scenarios, transport, and retardation processes as currently understood for the site. It will also form the basis for estimates of the sensitivity of transport calculations to retardation processes.

Bonano, E. J., S. C. Hora, R. L. Keeney, and D. von Winterfeldt, 1989. "The Use of Expert Judgments in Performance Assessment of High-Level Radioactive Waste Repositories," from the International Symposium on Safety Assessment of Radioactive Waste Repositories, Paris, France, October 9-12, 1989, SAND-89-0495C, Sandia National Laboratories, Albuquerque, NM.

This paper summarizes the formal use of expert judgments in the performance assessment of high-level radioactive waste (HLW) repositories. A generic process for the formal elicitation of expert judgments is presented, including available elicitation techniques that can be applied to: (1) scenario development and screening, (2) model development, (3) parameter estimation, (4) information gathering, and (5) strategic repository decisions.

Bradley, D. J., 1989. "Spent Fuel Performance in Geologic Repository Environments," from the Coordination Program Meeting on the Performance of Solidified High-Level Waste Forms and Engineering Barriers under Repository Conditions, Winnipeg, Canada, June 5-8, 1989, PNL-SA-17002, Pacific Northwest Laboratory, Richland, WA.

This paper discusses the current effort to define the behavior of irradiated spent fuel in repository environments. Spent fuel is of particular interest since it is expected to be the primary nuclear waste form disposed in a geologic repository. Current studies are directed toward understanding the rate and nature (such as valence state, colloid form if any, solid phase controlling solubility) of radionuclide release from the spent fuel. Due to the strong interactive effect of radiation, thermal fields, and waste package components on this release, current spent fuel studies are being conducted primarily in the presence of waste package components over a wide range of potential environments.

Brookhaven National Laboratory, 1990. "C-14 Release from Failed Spent Fuel Containers," from the International Conference for High-Level Radioactive Waste Management, Las Vegas, NV, April 8-12, 1990, BNL-43768, Upton, NY.

Partially failed containers may provide a meaningful barrier to the release of gaseous radionuclides. A modeling approach is outlined and sample calculations are provided that show the effects on release due to a limited perforation area, to decreasing temperature, and to the partial occlusion of the perforated area by corrosion products.

Callahan, G. D., A. F. Fossum, and D. K. Svalstad, 1989. Documentation of SPECTROM-32: A Finite Element Thermomechanical Stress Analysis Program, DOE/CH/10378-2-Vol.1 and 2, RE/SPEC, Inc., Rapid City, SD.

SPECTROM-32 is a finite element program for analyzing two-dimensional and axisymmetric inelastic thermomechanical problems related to the geological disposal of nuclear waste. The code is part of the SPECTROM series of special-purpose computer programs to address many unique rock mechanics problems encountered in analyzing radioactive wastes stored in geologic formations. This document presents the theoretical basis for the mathematical models, the finite element formulation and solution procedure of the program, a description of the input data for the program, verification problems, and details about program support and continuing documentation. The principle component models used in the program involve thermoelastic, thermoviscoelastic, thermoelastic-plastic, and thermoviscoplastic types of material behavior. Special material considerations provide for the incorporation of limited-tension material behavior and consideration of jointed material behavior. Numerous program options provide the capabilities for various boundary conditions, sliding interfaces, excavation, backfill, arbitrary initial stresses, multiple material domains, load incrementation, plotting database storage and access of results, and other features unique to the geologic disposal of radioactive wastes. Numerous verification problems that exercise many of the program options and illustrate the required data input and printed results are included in the documentation.

Campbell, K., D. E. Broxton, and J. Spaw, 1990. Status of Image Analysis Methods to Delineate Stratigraphic Position in the Topopah Spring Member of the Paintbrush Tuff, Yucca Mountain, Nye County, Nevada, LA-11694-MS, Los Alamos National Laboratory, NM.

The Topopah Spring Member of the Paintbrush Tuff is an ash-flow cooling unit that is the candidate host rock for a potential high-level nuclear waste repository at Yucca Mountain, Nevada. The repository workings will be mostly confined to the member's rhyolitic portion, which is chemically homogenous but texturally variable. This report describes the status of work to develop a useful internal stratigraphy for the rhyolitic portion of the member; the approach is to use an image analysis technique to map textural variations within the member as a function of stratigraphic height. Fifteen petrographic thin sections of Topopah Spring

rhyolitic tuff were studied in each of two drill holes (USW GU-3 and USW G-4). Digital color images were collected in transmitted light for two scenes 1 cm on a side for each thin section. Objects within a scene were classified by color, and measurements of area, elongation, and roughness were determined for each object. Summary statistics were compiled for all measurements for each color component within a scene, and each variable was statistically examined for correlations with stratigraphic position. Initial studies using image analysis have not yet produced a useful method for determining stratigraphic position within the Topopah Spring Member. Simplifications made in this preliminary application of image analysis may be largely responsible for these negative results. The technique deserves further investigation, and more detailed analysis of existing data is recommended.

Dagan, G., V. Nguyen, and E. Springer, 1989. "Analyses of Transport in the Upper Soil Layer and Interpretation of Caisson Experiments," from FOCUS '89: Nuclear Waste Isolation in the Unsaturated Zone, Las Vegas, NV, September 18-21, 1989, LA-UR-89-3355, Los Alamos National Laboratory, NM.

Transport experiments conducted in an intermediate-scale caisson are described. The results suggest that the solute spreading pattern has been dominated by the effect of spatial variability of hydraulic properties. A stochastic model of horizontally varying velocity distribution is employed in order to interpret the concentration data. A satisfactory match between the measured solute mass cross-sectional transfer in saturated flow and model is achieved for a standard deviation of the logconductivity of 1.2. The model may serve for interpretation of transport in unsaturated flow and for reactive solutes.

DOE (U.S. Department of Energy), 1989. Quarterly Report on Program Cost and Schedule: Third Quarter FY 1989, DOE/RW-0225-2, Office of Civilian Radioactive Waste Management, Washington, DC.

This report is intended to provide a summary of the cost and schedule performance for the Civilian Radioactive Waste Management Program. Performance data are presented for each of the major program elements. Also included in this report is the status of the Nuclear Waste Fund revenues and disbursements. This report includes cost and schedule data through June 1989.

DOE (U.S. Deparment of Energy), 1990. Office of Civilian Radioactive Waste Management System Engineering Management Plan (SEMP), DOE/RW-0263, Office of Civilian Radioactive Waste Management, Washington, DC.

To implement a program for the safe and permanent disposal of spent nuclear fuel and high-level radioactive waste, the DOE is developing an integrated waste-management system consisting of three elements: the transportation system, the monitored retrievable storage (MRS) facility, and the mined geologic disposal system (MGDS). The development of such a system requires management of many diverse disciplines that are involved in research, siting, design, licensing, and external interactions. The purpose of this Systems Engineering Management Plan (SEMP) is to prescribe how the systems-engineering process will be implemented in the development of the waste-management system. Systems engineering will be used by the DOE to manage, integrate, and document all aspects of the technical development of the waste-management system and its system elements to ensure that the requirements of the waste-management program are met.

DOE (U.S. Department of Energy), 1990. Quarterly Report on Program Cost and Schedule: Fourth Quarter FY 1989, DOE/RW-0225-3, Office of Civilian Radioactive Waste Management, Washington, DC.

The following major program accomplishments were reported for the fourth quarter of FY 1989: completed readiness review and all requirements for full operation of the Sample Management Facility (SMF) on July 31, 1989; two independent contracts were awarded to appraise the Yucca Mountain site for Payments-Equal-to-Taxes

(PETT) purposes; draft of the prototype excavation study was issued; the proposal from UNLV for work on the Licensing Support System (LSS) was submitted to YMPO in July undergoing review; quality assurance qualifications of Sandia National Laboratories and Reynolds Electrical and Engineering Company were completed; a final draft of the carbon 14 release position paper was submitted to YMPO; and initiated negotiations with owner of four mining claims.

DOE (U.S. Deparment of Energy), 1990. Yucca Mountain Project Technical Status Report, April-September 1989, NVO-334-1, DOE Nevada Operations Office, Las Vegas, NV.

This Yucca Mountain Project Technical Status Report (TSR) on scientific investigation is the first in a series of reports that will be issued at approximately six-month intervals during scientific investigation. Summary information on the technical status and progress of scientific investigation activities described in the Site Characterization Plan is reported in the TSR. In addition, progress made toward the initiation and conduct of scientific investigation activities is included. For this report, information on the technical progress made by Yucca Mountain Project participating organization has been compiled covering the period from April 16, 1989, through September 30, 1989.

Eaton, R. R., and A. C. Peterson, 1989. "Computed Distributions of Residual Shaft Drilling and Construction Water in the Exploratory Facilities at Yucca Mountain, Nevada," from the International Conference for High-Level Radioactive Waste Management, Las Vegas, NV, April 8-12, 1990, SAND-89-2018C, Sandia National Laboratories, Albuquerque, NM.

The Yucca Mountain Project is studying the feasibility of constructing a high-level nuclear waste repository at Yucca Mountain in southwest Nevada. One activity of scientific investigation is the construction of two exploratory shafts. This paper contains the results of engineering analytical calculations of the potential distribution of residual construction water in the exploratory shafts and drifts and numerical calculations of the movement of the residual water and how the movement is affected by drift ventilation. In all cases the increase in rock saturation resulting from the construction water was extremely small.

Eaton, R. R., N. E. Bixler, and R. J. Glass, 1989. "Predicting Flow through Low-Permeability, Partially Saturated, Fractured Rock: A Review of Modeling and Experimental Efforts at Yucca Mountain," from the International Geological Congress, Washington, DC, July 9-19, 1989, SAND-88-2626C, Sandia National Laboratories, Albuquerque, NM.

Mathematical models and experimental procedures are being developed to provide a better understanding of the hydrology of Yucca Mountain, Nevada. Modeling water flow in the vadose zone in soils and in relatively permeable rocks such as sandstone has received considerable attention for many years. The treatment of flow (including nonisothermal conditions) through materials such as the Yucca Mountain tuffs, however, has not received the same level of attention, primarily because it is outside the domain of agricultural and petroleum technology. This paper reviews the status of modeling and experimentation currently being used to understand and predict water flow at the proposed repository site. Several areas of research needs emphasized by the review are outlined. The extremely nonlinear hydraulic properties of these tuffs in combination with their heterogeneous nature makes it a challenging and unique problem from a computational and experimental viewpoint.

Fernandez, J. A., and T. E. Hinkebein, 1989. "A Description and Status of the Yucca Mountain Project Repository Sealing Program," from the International High-Level Radioactive Waste Management Conference, Las Vegas, NV, April 18-21, 1989, SAND-89-2135C, Sandia National Laboratories, Albuquerque, NM.

This paper presents a description of the Yucca Mountain sealing program including the sealing design options, design requirements, design constraints, and the identification of the proposed

sealing materials and field tests. Design options for the shafts include anchor-to-bedrock seals, shaft fill, and settlement plugs. In the underground facility, options include drift seals, drainage channels, sumps, and bulkheads. Design requirements are those quantitative requirements imposed on the sealing design options to achieve a desired level of performance. Constraints are restrictions placed on the repository design by the sealing design. The design requirements and constraints may be modified as (1) additional hydrogeologic data are obtained through scientific investigation, (2) approaches to allocating performance to various subsystems are refined, and (3) the exploratory shafts and the associated testing results are developed.

Fernandez, J. A., and T. E. Hinkebein, 1989. "The Yucca Mountain Project Repository Sealing Program," from the Institute of Nuclear Materials Management Annual Meeting, Orlando, FL, July 9-12, 1989, SAND-89-0590C, Sandia National Laboratories, Albuquerque, NM.

This paper presents a description of the current sealing design options, design requirements, and the design constraints. Design options for the shafts include anchor-to-bedrock seals, shaft fill, and settlement plugs; in the underground facility, they include drift seals, drainage channels, sumps, and bulkheads. Design requirements are those quantitative requirements imposed on the sealing design options to achieve a desired level of performance. For example, a design requirement could be a restriction on the hydraulic conductivity of a design option. Constraints are restrictions placed on the repository design by the sealing design. An example of a constraint could be establishing the drainage pattern to direct flow from emplacement drifts to nonemplacement drifts. As (1) additional hydrogeologic data are obtained through scientific investigation, (2) approaches to allocating performance to various subsystems within the Yucca Mountain Project are refined, and (3) the exploratory shafts and the associated testing results are developed, the design requirements and constraints may be modified and used in developing the License Application Design.

Fuentes, H. R., W. L. Polzer, E. H. Essington, and B. D. Newman,1989. Characterization of Reactive Tracers for C-Wells Field Experiments, LA-11691-MS, Los Alamos National Laboratory, NM.

Lithium (Li+) was introduced as lithium bromide (LiBr), as a retarded tracer for experiments in the C-wells complex at Yucca Mountain, Nevada. The objective was to evaluate the potential of lithium to sorb predominately by physical forces. Lithium was selected as a candidate tracer on the basis of high solubility, good chemical and biological stability, and relatively low sorptivity; lack of bioaccumulation and exclusion as a priority pollutant in pertinent Federal environmental regulations; good analytical detectability and low natural background concentrations; and a low cost. Laboratory experiments were performed with suspensions of Prow Pass cuttings from drill hole UE-25p#1 at depths between 549 and 594 m in J-13 water at a pH of approximately 8 and in the temperature range of 25°C to 45°C. Batch equilibrium and kinetics experiments were performed; estimated thermodynamic constants, relative behavior between adsorption and desorption, and potentiometric studies provided information to infer the physical nature of lithium sorption.

Gelbard, F., 1990. "Aerosol Particle Transport Modeling for Preclosure Safety Studies of Nuclear Waste Repositories," from the International Conference for High-Level Radioactive Waste Management, Las Vegas, NV, April 8-12, 1990, SAND-89-2026C, Sandia National Laboratories, Albuquerque, NM.

An important concern for preclosure safety analysis of a nuclear waste repository is the potential release to the environment of respirable aerosol particles. Such particles, less than 10^{-5} m in aerodynamic diameter, may have significant adverse health effects if inhaled. To assess the potential health effects of these particles, it is not sufficient to determine the mass fraction of respirable aerosol. The chemical composition of the particles is also of importance since different radionuclides may pose vastly different health hazards. Thus, models are needed to determine under normal and accident conditions the particle

size and the chemical composition distributions of aerosol particles as a function of time and of position in the repository. In this work a multicomponent sectional aerosol model is used to determine the aerosol particle size and composition distributions in the repository. A range of aerosol mass releases with varying mean particle sizes and chemical compositions is used to demonstrate the sensitivities and uncertainties of the model. Decontamination factors for some locations in the repository are presented.

Glassley, W., 1989. "Evaluation of the Post-Emplacement Environment of High-Level Radioactive Waste Packages at Yucca Mountain, Nevada," from Waste Management '89, Tucson, AZ, March 1, 1989, UCRL-100603, Lawrence Livermore National Laboratory, CA.

Laboratory studies, numerical simulations, and field experiments and tests are used to provide data necessary to evaluate the post-emplacement environment around high level radioactive waste containers. Results obtained to date demonstrate that the post-emplacement environment in the welded tuff at Yucca Mountain, Nevada maintains relatively benign chemical features (i.e., near neutral pH, low concentrations of dissolved species) for most scenarios. The hydrological environment appears to be one of low flow volume and rates for the expected condition of an unsaturated medium. Emplacement borehole stability will be a function of fracture density and orientation, which may be influenced by microcrack development. Field studies and numerical simulations are in progress that will extend the results of laboratory studies to long time periods. The extent to which chemical, hydrological and mechanical processes can be adequately coupled through numerical simulations remains a matter of concern.

Hinkebein, T. E., and J. A. Fernandez, 1989. "Initial Evaluation of Sealing Materials for the Yucca Mountain Project," from the Institute of Nuclear Materials Management Annual Meeting, Orlando, FL, July 9-12, 1989, SAND-89-0591C, Sandia National Laboratories, Albuquerque, NM.

The material selection process that has been used to determine candidate seal materials for the propsoed high-level nuclear waste repository at Yucca Mountain is described. The process includes the development of a logic for the initial selection and subsequent refinements in the selection of materials. Each refinement or screen examines whether candidate seal materials possess several physical and chemical properties that are determined from seal design requirements. Each screen provides a basis for materials performance, testing, and analysis. The first screen identified broad materials groups (such as cementitious and earthen materials) and explained why other materials (such as ceramics and metals) are not being evaluated in current testing. The second screen identified specific material types such as "high-temperature concrete" or "low-permeability crushed rock/clay" for each of the seal components that may be included in the design. A review of the properties of these candidate sealing materials is also presented. Finally a materials recommendation summary resulting from the second screen is presented.

Isayama, Y., P. L. Chambre, T. H. Pigford, and W. W. Lee, 1989. "Isotopic Effects on Solubility-Limited Mass Transfer," from the American Nuclear Society Winter Meeting, San Francisco, CA, November 26-30, 1989, LBL-27428, Lawrence Berkeley Laboratory, CA.

In previous theoretical analyses, solubility-limited mass transfer from waste solids applied if a species was at a constant elemental concentration in liquid at the waste surface. For an element with isotopes that decay appreciably during the time of interest, a solubility boundary condition results in a time-dependent boundary concentration of each isotope. This paper presents mass-transfer equations that include the effects of isotopic decay boundary conditions.

Johnson, K. I., C. F. Voss, and D. J. Sherwood, 1989. "A Sensitivity Study of Near-Field Thermomechanical Conditions in Tuff," from FOCUS '89: Nuclear Waste Isolation in the Unsaturated Zone, Las Vegas, NV, September 18-21, 1989, PNL-SA-16734, Pacific Northwest Laboratory, Richland, WA.

A study was conducted to investigate the response of a discontinuous rock mass to the combined mechanical and thermal loads from the excavation of repository openings and decay heating of radioactive waste forms. The ANSYS finite element code was used to calculate temperatures and thermal stresses near an emplacement hole as a function of time. The UDEC distinct element code was used to simulate a discontinuous rock mass around the emplacement hole using the finite element stress results as boundary conditions. This approach differs from previous work in its approximation of the near-field geosphere as an assemblage of blocks that are free to slide and rotate relative to one another. The physical properties of the rock joints and fractures were explicitly included in the analysis. Earlier efforts have used continuum models that included the effects of discontinuities by adjusting material properties (reducing elastic modulus and rock strength) or using ubiquitous joints. A range of parameter values were used to represent the upper, lower, and expected conditions for the Yucca Mountain site. Assuming worst case conditions, the calculated displacements around the emplacement hole were only a small fraction of the design air gap between the waste package and the wall of the emplacement hole. Overall, the results confirm that the retrieval option and waste package lifetime will not be adversely affected by borehole instability and excessive rock loads.

Lawrence Berkeley Laboratory, 1989. "A Broad View of Model Validation," from the International Symposium on Safety Assessment of Radioactive Waste Repositories, Paris, France, October 9-12, 1989, LBL-28094, Berkeley, CA.

The safety assessment of a nuclear waste repository requires the use of models. Such models need to be validated to ensure, as much as possible, that they are a good representation of the actual processes occurring in the real system. In this paper we attempt to take a broad view by reviewing step by step the modeling process and bringing out the need to validating every step of this process. This model validation includes not only comparison of modeling results with data from selected experiments, but also evaluation of procedures for the construction of conceptual models and calculational models as well as methodologies for studying data and parameter correlation. The need for advancing basic scientific knowledge in related fields, for multiple assessment groups, and for presenting our modeling efforts in open literature to public scrutiny is also emphasized.

Lawrence Berkeley Laboratory, 1989. "Analytical Methods for Predicting Contaminant Transport," from the International Symposium on Safety Assessment of Radioactive Waste Repositories, Paris, France, October 9-12, 1989, LBL-27400, Berkeley, CA.

This paper summarizes some of the previous and recent work on analytical solutions for predicting contaminate transport in porous and fractured geologic media. Emphasis is given to the theories for predicting near-field transport, needed to derive the time-dependent source term for predicting far-field transport and overall repository performance. New theories summarized include solubility-limited release rate with flow backfill in rock, near-field transport of radioactive decay chains, interactive transport of colloid and solute, transport of carbon-14 as carbon dioxide in unsaturated rock, and flow of gases out of and a waste container through cracks and penetrations.

Lawrence Berkeley Laboratory, 1989. "Modeling of Coupled Geochemical and Transport Processes: An Overview," from the International Symposium on Safety Assessment of Radioactive Waste Repositories, Paris, France, October 9-12, 1989, LBL-28048, Berkeley, CA.

Early coupled models associated with fluid flow and solute transport have been limited by assumed conditions of constant temperature, fully saturated fluid flow, and constant pore fluid

velocity. Developments including coupling of chemical reactions to variable fields of temperature and fluid flow have generated new requirements for experimental data. As the capabilities of coupled models expand, needs are created for experimental data to be used for both input and validation.

Lawrence Berkeley Laboratory, 1990. "Combined Analytical/Numerical Approaches to Solving Fluid Flow Problems in the Unsaturated Zone at Yucca Mountain," from the International Conference for High-Level Radioactive Waste Management, Las Vegas, NV, April 8-12, 1990, LBL-28358, Lawrence Berkeley Laboratory, CA.

Various analytical and numerical approaches are presented for the study of unsaturated flow processes in the vicinity of the Yucca Mountain, Nevada, the proposed site of an underground radioactive waste repository. Approximate analytical methods are used to study absorption of water from a saturated fracture into the adjacent rock. These solutions are incorporated into a numerical simulator as fracture/matrix interaction terms to treat problems such as flow along a fracture with transverse leakage into the matrix. An automatic fracture/matrix mesh generator is described; it allows for more efficient mesh generation for fractured/porous media, and consequently leads to large savings in computational time and cost.

Lawrence Berkeley Laboratory, 1990. Intermediate-Field Transport of Contaminants: Multiple Areal Sources in Fractured Rock and Point Sources in Porous Rock, LBL-27338, Lawrence Berkeley Laboratory, CA.

This report is about "intermediate-field" transport or the migration of contaminants from arrays of discrete waste packages or sources. In constructing nuclear waste repositories in rock, it may be necessary to place a waste package across a rock fracture, or a rock fracture may develop some time after waste packages have been emplaced. To predict the spatial and temporal distribution of contaminant species from a line of waste packages facing a rock fracture may be important, because such fractures may now be considered a preferential pathway for released radionuclides to re-enter the biosphere. In land disposal of hazardous wastes, individual barrels may contain especially toxic material whose dispersion special attention. We have published analytic solutions for the multidimensional advective transport of contaminants from arrays of waste packages and multiple areal sources into a planar fracture. The results show a near region in which the concentrations vary greatly in the direction transverse to ground-water flow, an intermediate region in which the array can be treated as an infinite plane source of dissolving species, and a far-field region in which the array can be treated as a plane source of finite extent. The array equations have been developed for both porous and fractured media. In this paper we summarize and compare the work with multiple areal sources facing a planar fracture and an array of point sources in porous media.

Lawrence Berkeley Laboratory, 1990. "Seismic Characterization of Fracture Properties," from the International Conference for High-Level Radioactive Waste Management, Las Vegas, NV, April 8-12, 1990, LBL-28333, Lawrence Berkley Laboratory, CA.

The purpose of this paper is to show that there is a relationship, both empirical and theoretical, between the measured seismic response, the mechanical stiffness (also referred to as specific stiffness) of fractures and their hydraulic conductivity. Laboratory measurements of the mechanical stiffness, hydraulic conductivity and seismic properties of natural fractures are summarized. A theoretical model for the amplitude and group time delay for compressional and shear waves transmitted across a single fracture is presented. Predictions based on this model are compared with laboratory measurements. Finally, the results for a single fracture are extended to multiple parallel fractures.

Lawrence Berkeley Laboratory, 1990. "Simulation of Reactive Chemical Transport in a Varying Thermal Field with Reaction-Flow Coupling," from the International Conference for High-Level Radioactive Waste Management, Las Vegas, NV, April 8-12, 1990, LBL-28328, Berkeley, CA.

A computer program, THCVP, simulates coupling between advective/diffusive solute transport and chemical reactions, coupling of the reactions to heat transport, and feedback from precipitation/dissolution reactions to fluid flow. A simple simulation of transport of dissolved silicic acid along a gradient of temperature shows how precipitation of quartz at low temperatures can drastically reduce advective transport of all solution components including trace contaminants.

Lawrence Berkeley Laboratory, 1990. "Study of Fractal Aperture Distribution and Flow in Fractures," from the International Conference for High-Level Radioactive Waste Management, Las Vegas, NV, April 8-12, 1990, LBL-28362, Lawrence Berkeley Laboratory, CA.

This study examines the roughness profiles and aperture distributions of fractures and faults by using concepts from fractal geometry. Simple models of flow of fluid in rough fractures are also discussed. A deterministic fractal representation of the roughness profile is presented which is shown to have many distinct advantages over other numerical methods, such as information compression, uniqueness and repeatability of surface simulation, retention of statistical information, and self-similarity over many scales. Also the fractal representation enables an isotropic surface and an aperture distribution to be simulated by examining a measured profile. Saturated fluid flow in fractures is then computed using a combined Navier-Stokes and Darcy equation.

Lawrence Berkeley Laboratory, 1990. "The Application of Vertical Seismic Profiling and Cross-hole Tomographic Imaging for Fracture Characterization at Yucca Mountain," from the International Conference for High-Level Radioactive Waste Management, Las Vegas, NV, April 8-12, 1990, LBL-28316, Lawrence Berkeley Laboratory, CA.

In order to obtain the necessary characterization for the storage of nuclear waste, much higher resolution of the features likely to affect the transport of radionuclides will be required than is normally achieved in conventional surface seismic reflection used in the exploration and characterization of petroleum and geothermal resources. Because fractures represent a significant mechanical anomaly seismic methods using are being investigated as a means to image and characterize the subsurface. Because of inherent limitations in applying the seismic methods solely from the surface, state-of-the-art borehole methods are being investigated to provide high resolution definition within the repository block. Therefore, Vertical Seismic Profiling (VSP) and cross-hole methods are being developed to obtain maximum resolution of the features that will possible affect the transport of fluids. Presented here will be the methods being developed, the strategy being pursued, and the rational for using VSP and crosshole methods at Yucca Mountain. The approach is intended to be an integrated method involving improvements in data acquisition, processing, and interpretation as well as improvements in the fundamental understanding of seismic wave propagation in fractured rock.

Lawrence Livermore National Laboratory, 1989. "A Lagrangian Reactive Transport Simulator With Successive Paths and Stationary-States: Concepts, Implementation and Verification, Revision 1," from the Materials Research Society Conference, Boston, MA, September 27-30, 1989, UCRL-100952-Rev.1, Lawrence Livermore National Laboratory, CA.

A geochemical software package which models static, single-path kinetic water-rock interactions, EQ3/6 has been modified to incorporate successive-paths and stationary states under high Peclet number transport conditions in a Lagrangian reference frame. These modifications permit calculation of reactive transport with reasonable computational requirements. Results from the new option in EQ3/6 have been compared with analytical results for the simple

HCl-SiO_2 system; excellent agreements were achieved. Results have also been compared with published results for a portion of the Al_2O_3-HCl-K_2O-SiO_2 system. The results are in good qualitative and, in some cases, good quantitative agreement. However, the values of some variables differ substantially; these differences can be attributed to use of a different set of Al and Si aqueous species.

Lawrence Livermore National Laboratory, 1989. "Current Status of Waste Package Designs for the Yucca Mountain Project," from the Institute of Nuclear Materials Management Annual Meeting, Orlando, FL, July 9-12, 1989, UCRL-100790, Livermore, CA.

Conceptual designs for waste packages containing spent fuel or high-level waste glass have been developed for use in a proposed repository at Yucca Mountain, Nevada. The basis for these designs reflects the unique nature of the expected service environment associated with disposal in welded tuff in the unsaturated zone. In addition to a set of reference designs, alternative design concepts are being considered that would contain and isolate the waste radionuclides in a more aggressive service environment. Consideration is also being given to the feasibility of a concept known as "heat tailoring" that employs the thermal energy released by the wasteforms to enhance and extend the performance of the containers.

Lawrence Livermore National Laboratory, 1989. "High Frequency Electromagnetic Tomography," from FOCUS '89: Nuclear Waste Isolation in the Unsaturated Zone, Las Vegas, NV, September 18-21, 1989, UCRL-101865, Lawrence Livermore National Laboratory, CA.

An experiment was conducted in G Tunnel at the Nevada Test Site to evaluate high frequency electromagnetic tomography as a method for in situ monitoring of hydrology in the near field of a heater placed in densely welded tuff. Tomographs of 200 MHz electromagnetic permittivity were made for several planes between boreholes. Data were taken before the heater was turned on, during heating and during cooldown of the rockmass. This data is interpreted to yield maps of changes in water content of the rockmass as a function of time. This interpretation is based on laboratory measurement of electromagnetic permittivity as a function of water content for densely welded tuff.

Lawrence Livermore National Laboratory, 1989. "Laboratory Study of Fracture Healing in Topopah Spring Tuff: Implications for Near Field Hydrology," from FOCUS '89: Nuclear Waste Isolation in the Unsaturated Zone, Las Vegas, NV, September 18-21, 1989, UCRL-100624, Livermore, CA.

Seven Topopah Spring tuff samples were studied to determine water permeability in this rock under pressure and temperature conditions similar to those expected in the near field of a nuclear waste package. Six of the seven samples were studied under isothermal condition; the other was subjected to a thermal gradient. Four of the six fractured samples contained a reopened, healed, natural fracture; one contained an induced tensile fracture and the other contained a saw-cut. The fracture surfaces were examined using scanning electron microscope (SEM) before and after the experiments and the water that flowed through the samples was sampled for chemical analysis. The experimental durations ranged from about 3 months to almost 6 months. Water permeability of the fractured samples was found to decrease by more than three orders of magnitude when the sample temperature increased to 150°C. The sharpest decrease in permeability occurred when the temperature was increased above 90°C. Permeability of the intact sample did not change significantly under the similar experimental conditions. When the temperature returned to room conditions, the water permeability did not recover. The mechanical strength of one healed sample was about half that of the intact rock. SEM studies of the fracture surfaces and water chemical analysis of the water suggested that both dissolution and deposition occurred on the fracture surfaces. Smoothing of fracture asperities because of dissolution and deposition was probably the main cause of the permeability decrease. Deposition of dissolved silica was probably the main cause of fracture healing.

Lawrence Livermore National Laboratory, 1989. "On the Infiltration of a Liquid Front in an Unsaturated, Fracture Porous Medium," from FOCUS '89: Nuclear Waste Isolation in the Unsaturated Zone, Las Vegas, NV, September 18-21, 1989, UCRL-100777, Lawrence Livermore National Laboratory, CA.

The unsaturated zone at Yucca Mountain, Nevada, is currently under scientific investigation as a proposed site for the permanent storage of high-level nuclear waste. A deeper understanding of fracture-matrix interaction needed for the prediction of water movement around and in the repository. We show that the liquid front movement can be classified into physically interpretable, distinctive flow regimes. Asymptotic solutions for the front movement are given for each flow period and comparisons with numerical solutions are made. In addition to applications in nuclear waste storage, the results of our study is relevant to hazardous waste disposal, petroleum recovery, and flow in soil macropores.

Lawrence Livermore National Laboratory, 1989. On the Movement of a Liquid Front in an Unsaturated, Fractured Porous Medium, Part 1, UCID-21714, Lawrence Livermore National Laboratory, CA.

The primary aim of this paper is to present approximate analytical solutions of the fracture flow which gives the position of the liquid fracture front as a function of time. These solutions demonstrate that the liquid movement in the fracture can be classified into distinctive time periods, or flow regimes. It is also shown that when plotted versus time using a log-log scale, the liquid fracture front position asymptotically approaches a series of line segments. Two-dimensional numerical simulations were run utilizing input data applicable to the densely welded, fractured tuff found at Yucca Mountain in order to confirm these observations.

Lawrence Livermore National Laboratory, 1989. "Statistical Model for Grain Boundary and Grain Volume Oxidation Kinetics in UO_2 Spent Fuel," from the Materials Research Society Fall Meeting, Boston, MA, November 27-December 2, 1989, UCRL-100859, Lawrence Livermore National Laboratory, CA.

This paper addresses statistical characteristics for the simplest case of grain boundary/grain volume oxidation kinetics of UO_2 to U_3O_7 for a fragment of a spent fuel pellet. It also presents a limited discussion of future extensions to this simple case to represent the more complex cases of oxidation kinetics in spent fuels.

Lawrence Livermore National Laboratory, 1990. Electrochemical Corrosion Studies on Copper-Base Waste Package Container Materials in Unirradiated 0.1 N $NaNO_3$ at 95°C, UCRL-21076, Lawrence Livermore National Laboratory, CA.

Three candidate materials were investigated in this study in terms of their electrochemical corrosion behavior in unirradiated 0.1 N $NaNO_3$ solutions at 95°C. Anodic polarization experiments were conducted to determine the passive current densities, pitting potentials, and other parameters, together with Cyclic Current Reversal Voltammetry tests to evaluate the stability and protectiveness of the passive oxides formed. X-ray diffraction and Auger Electron Spectroscopy were used for identification of the corrosion products as well as Scanning Electron Microscopy for the surface morphology studies.

Lawrence Livermore National Laboratory, 1990. On the Movement of a Liquid Front in an Unsaturated, Fractured Porous Medium, Part 2, Mathematical Theory, UCID-21743, Lawrence Livermore National Laboratory, CA.

A simplified equation of motion is derived for the flow of liquid through an idealized one-dimensional fracture situated in an unsaturated imbibing porous medium. The equation is valid for the case where the matrix material has a much lower saturated conductivity than that of the fracture and the capillary tension in the matrix is sufficiently stronger than gravity. Asymptotic solutions are given for the motion of the liquid front in a parallel fracture system. With the introduction of natural time constants

and dimensionless parameters, the flow behavior can be shown to possess various temporal flow regimes. This work is applicable to understanding some of the various physical parameters affecting liquid flow through a fracture in an unsaturated porous medium, and is particularly useful as a step in understanding the hydrological processes around a nuclear waste repository in an unsaturated environment as well as in other applications where unsaturated fracture flow conditions exist. The solutions are also relevant to numerical model verification.

Lawrence Livermore National Laboratory, 1990. Survey of Degradation Modes of Candidate Materials for High-Level Radioactive-Waste Disposal Containers: Overview, UCID-21362-OVERVIEW, Lawrence Livermore National Laboratory, CA.

Three iron- to nickel-based austenitic alloys and three copper-based alloys are being considered as candidate materials for the fabrication of high-level radioactive-waste disposal containers. The austenitic alloys are Types 304L and 316L stainless steels and the high-nickel material Alloy 825. The copper-based alloys are CDA 102 (oxygen-free copper), CDA 613 (Cu-7Al), and CDA 715 (Cu-30Ni). Waste in the forms of both spent fuel assemblies from reactors and borosilicate glass will be sent to the prospective repository at Yucca Mountain, Nevada. The decay of radionuclides will result in the generation of substantial heat and gamma radiation. Container materials may undergo any of several modes of degradation in this environment, including undesirable phase transformations due to a lack of phase stability; atmospheric oxidation; general aqueous corrosion; pitting; crevice corrosion; intergranular stress corrosion cracking; and transgranular stress corrosion cracking. Problems specific to welds, such as hot cracking, may also occur. A survey of the literature has been prepared as part of the process of selecting, from among the candidates, a material that is adequate for repository conditions. The modes of degradation are discussed in detail in the survey to determine which apply to the candidate alloys and the extent to which they may actually occur. The eight volumes of the survey are summarized in Sections 1 through 8 of this overview. The conclusions drawn from the survey are also given in this overview.

Lawrence Livermore National Laboratory, 1990. Survey of Degradation Modes of Candidate Materials for High-Level Radioactive-Waste Disposal Containers: Volume 1, Phase Stability, UCID-21362-Vol.1, Lawrence Livermore National Laboratory, CA.

Three copper-based alloys and three iron- to nickel-based austenitic alloys are being considered as possible materials for fabrication of high-level radioactive-waste disposal containers. The waste will include spent fuel assemblies from reactors as well as high-level waste in borosilicate glass and will be sent to the prospective site at Yucca Mountain, Nevada, for disposal. The copper-based alloy materials are CDA 102 (oxygen-free copper), CDA 613 (Cu-7Al), and CDA 715 (Cu-30Ni). The austenitic materials are Types 304L and 316L stainless steels and Alloy 825. The waste-package containers must maintain substantially complete containment for at least 300 yr and perhaps as long as 1000 yr, and they must be retrievable from the disposal site during the first 50 yr after emplacement. The containers will be exposed to high temperatures and high gamma radiation fields from the decay of high-level waste. This volume surveys the available data on the phase stability of both groups of candidate alloys. The austenitic alloys are reviewed in terms of the physical metallurgy of the iron-chromium-nickel system, martensite transformations, carbide formation, and intermetallic-phase precipitation. The copper-based alloys are reviewed in terms of their phase equilibria and the possibility of precipitation of the minor alloying constituents. For the austenitic materials, the ranking based on phase stability is: Alloy 825 (best), Type 316L stainless steel, and then Type 304L stainless steel (worst). For the copper-based materials, the ranking is: CDA 102 (oxygen-free copper) (best), and then both CDA 715 and CDA 613.

Lawrence Livermore National Laboratory, 1990. Survey of Degradation Modes of Candidate Materials for High-Level Radioactive-Waste Disposal Containers: Volume 2, Oxidation and Corrosion, UCID-21362-Vol.2, Lawrence Livermore National Laboratory, CA.

Three copper-based alloys and three iron- to nickel-based austenitic alloys are being considered as possible materials for fabrication of containers for disposal of high-level radioactive waste. This waste will include spent fuel assemblies from reactors as well as high-level waste in borosilicate glass and will be sent to the prospective site at Yucca Mountain, Nevada, for disposal. The containers must maintain substantially complete containment for at least 300 yr and perhaps as long as 1000 yr. During the first 50 yr after emplacement, they must be retrievable from the disposal site. Shortly after the containers are emplaced in the repository, they will be exposed to high temperatures and high gamma radiation fields from the decay of the high-level waste. This volume surveys the available data on oxidation and corrosion of the iron- to nickel-based austenitic materials (Types 304L and 316L stainless steels and Alloy 825) and the copper-based alloy materials [CDA 102 (oxygen-free copper), CDA 613 (Cu-7Al), and CDA 715 (Cu-30Ni)], which are the present candidates for fabrication of the containers. Studies that provided a large amount of data are highlighted, and those areas in which little data exists are identified. Examples of successful applications of these materials are given. On the basis of resistance to oxidation and general corrosion, the austenitic materials are ranked as follows: Alloy 825 (best), Type 316L stainless steel, and then Type 304L stainless steel (worst). For the copper-based materials, the ranking is as follows: CDA 715 and CDA 613 (both best), and CDA 102 (worst).

Lawrence Livermore National Laboratory, 1990. Survey of Degradation Modes of Candidate Materials for High-Level Radioactive Waste Disposal Containers: Volume 3, Localized Corrosion and Stress Corrosion Cracking of Austenitic Alloys, UCID-21362-Vol.3, Lawrence Livermore National Laboratory, CA.

Three iron- to nickel-based austenitic alloys (Types 304L and 316L stainless steels and Alloy 825) are being considered as candidate materials for the fabrication of high-level radioactive-waste containers. Waste will include fuel assemblies from reactors as well as high-level waste in borosilicate glass forms, and will be sent to the prospective repository at Yucca Mountain, Nevada. The decay of radionuclides in the repository will result in the generation of substantial heat and in fluences of gamma radiation. Container materials may undergo any of several modes of degradation in this environment, including atmospheric oxidation; uniform aqueous phase corrosion; pitting; crevice corrosion; sensitization and intergranular stress corrosion cracking (IGSCC); and transgranular stress corrosion cracking (TGSCC). This report is an analysis of data relevant to the pitting, crevice corrosion, and stress corrosion cracking (SCC) of the three austenitic candidate alloys. The candidates are compared in terms of their susceptibilities to these forms of corrosion. Although all three candidates have demonstrated pitting and crevice corrosion in chloride-containing environments, Alloy 825 has the greatest resistance to these types of localized corrosion (LC); such resistance is important because pits can penetrate the metal and serve as crack initiation sites. Both Types 304L and 316L stainless steels are susceptible to SCC in acidic chloride media. In contrast, SCC has not been documented in Alloy 825 under comparable conditions. Gamma radiation has been found to enhance SCC in Types 304 and 304L stainless steels, but it has no detectable effect on the resistance of Alloy 825 to SCC. Furthermore, while the effects of microbiologically induced corrosion have been observed for 300-series stainless steels, nickel-based alloys such as Alloy 825 seem to be immune to such problems.

Lawrence Livermore National Laboratory, 1990. Survey of Degradation Modes of Candidate Materials for High-Level Radioactive-Waste Disposal Containers: Volume 4, Stress Corrosion Cracking of Copper-Based Alloys, UCID-21362-Vol.4, Lawrence Livermore National Laboratory, CA.

Three copper-based alloys --- CDA 102 (OFHC

copper), CDA 613 (aluminum bronze), and CDA 715 (Cu-30Ni) — are being considered as possible materials for the fabrication of high-level radioactive-waste disposal containers. Waste will include fuel assemblies from reactors as well as borosilicate glass forms, and will be sent to the prospective repository at Yucca Mountain, Nevada, for emplacement. The three copper-based alloys discussed here are being considered in addition to the iron- to nickel-based austenitic materials discussed in Volume 3. The decay of radionuclides will result in substantial heat generation and in fluxes of gamma radiation. In this environment, container materials may degrade by atmospheric oxidation, uniform aqueous phase corrosion, pitting, crevice corrosion, transgranular stress corrosion cracking (TGSCC) in tarnishing environments, or intergranular stress corrosion cracking (IGSCC) in nontarnishing environments. This report is a critical survey of available data on the stress corrosion cracking (SCC) of the three copper-based alloys. The requisite conditions for TGSCC and IGSCC include combinations of stress, oxygen, ammonia or nitrite, and water. Note that nitrite is generated by gamma radiolysis of moisture films in air but that ammonia is not. TGSCC has been observed in CDA 102 and CDA 613 exposed to moist ammonia-containing environments whereas SCC has not been documented for CDA 715 under similar conditions. SCC is also promoted in copper by nitrite ions. Furthermore, phosphorus-deoxidized copper is unusually susceptible to embrittlement in such environments. The presence of tin in CDA 613 prevents IGSCC. It is believed that tin segregates to grain boundaries, where it oxidizes very slowly, thereby inhibiting the oxidation of aluminum.

Lawrence Livermore National Laboratory, 1990. Survey of Degradation Modes of Candidate Materials for High-Level Radioactive-Waste Disposal Containers: Volume 5, Localized Corrosion of Copper-Based Alloys, UCID--21362-Vol.5, Lawrence Livermore National Laboratory, CA.

Three copper-based alloys, CDA 102 (oxygen-free, high-purity copper), CDA 613 (aluminum bronze), and CDA 715 (Cu-30Ni), are candidates for the fabrication of high-level radioactive-waste disposal containers. Waste will include spent fuel assemblies from reactors as well as borosilicate glass, and will be sent to the prospective repository site at Yucca Mountain in Nye County, Nevada. The decay of radionuclides will result in the generation of substantial heat and in fluxes of gamma radiation outside the containers. In this environment, container materials might degrade by atmospheric oxidation, general aqueous phase corrosion, localized corrosion (LC), and stress corrosion cracking (SCC). This volume is a critical survey of available data on pitting and crevice corrosion of the copper-based candidates. Pitting and crevice corrosion are two of the most common forms of LC of these materials. Data on the SCC of these alloys is surveyed in Volume 4. Pitting usually occurs in water that contains low concentrations of bicarbonate and chloride anions, such as water from Well J-13 at the Nevada Test Site. Consequently, this mode of degradation might occur in the repository environment. Though few quantitative data on LC were found, a tentative ranking based on pitting corrosion, local dealloying, crevice corrosion, and biofouling is presented. CDA 102 performs well in the categories of pitting corrosion, local dealloying, and biofouling, but susceptibility to crevice corrosion diminishes its attractiveness as a candidate. The cupronickel alloy, CDA 715, probably has the best overall resistance to such localized forms of attack.

Lawrence Livermore National Laboratory, 1990. Survey of Degradation Modes of Candidate Materials for High-Level Radioactive-Waste Disposal Containers: Volume 6, Effects of Hydrogen in Austenitic and Copper-Based Alloys, UCID-21362-Vol.6, Lawrence Livermore National Laboratory, CA.

Six alloys are being considered as possible materials for the fabrication of containers for the disposal of high-level radioactive waste. Three of these candidate materials are copper-based alloys: CDA 102 (oxygen-free copper), CDA 613 (Cu-7Al), and CDA 715 (Cu-30Ni). The other three are iron- to nickel-based austenitic materials: Types 304L and 316L stainless steels and Alloy 825. Radioactive waste will include spent-fuel assemblies from reactors as well as

waste in borosilicate glass and will be sent to the prospective site at Yucca Mountain, Nevada, for disposal. The waste-package containers must maintain substantially complete containment for at least 300 yr and perhaps as long as 1000 yr. During the first 50 yr after emplacement, the containers must be retrievable from the disposal site. Shortly after emplacement of the containers in the repository, they will be exposed to high temperatures and high gamma radiation fields from the decay of high-level waste. This radiation will promote the radiolytic decomposition of moist air to hydrogen. This volume surveys the available data on the effects of hydrogen on the six candidate alloys for fabrication of the containers. For copper, the mechanism of hydrogen embrittlement is discussed, and the effects of hydrogen on the mechanical properties of the copper-based alloys are reviewed. The solubilities and diffusivities of hydrogen are documented for these alloys. For the austenitic materials, the degradation of mechanical properties by hydrogen is documented. The diffusivity and solubility of hydrogen in these alloys are also presented. For the copper-based alloys, the ranking according to resistance to detrimental effects of hydrogen is: CDA 715 (best) > CDA 613 > CDA 102 (worst). For the austenitic alloys, the ranking is: Type 316L stainless steel Alloy 825 > Type 304L stainless steel (worst).

Lawrence Livermore National Laboratory, 1990. Survey of Degradation Modes of Candidate Materials for High-Level Radioactive-Waste Disposal Containers: Volume 7, Weldability of Austenitic Alloys, UCID-21362-Vol.7, Lawrence Livermore National Laboratory, CA.

This volume surveys the effects of welding on the degradation modes of three austenitic alloys: Types 304L and 316L stainless steels and Alloy 825. These materials are candidates for the fabrication of containers for the long-term storage of high-level nuclear waste. The metallurgical characteristics of fusion welds are reviewed here and related to potential degradation modes of the containers. Three specific areas are discussed in depth: (1) decreased resistance to corrosion in the forms of preferential corrosion, sensitization, and susceptibility to stress corrosion cracking, (2) hot cracking in the heat-affected zone and the weld zone, and (3) formation of intermetallic phases. The austenitic alloys are ranked as follows in terms of overall weldability: Alloy 825 (best) > Type 316L stainless steel > Type 304L stainless steel (worst).

Lawrence Livermore National Laboratory, 1990. Survey of Degradation Modes of Candidate Materials for High-Level Radioactive-Waste Disposal Containers: Volume 8, Weldability of Copper-Based Alloys, UCID-21362-Vol.8, Lawrence Livermore National Laboratory, CA.

Three copper-based alloys, CDA 102 (oxygen-free copper), CDA 613 (Cu-7Al), and CDA 715 (Cu-30Ni), are being considered along with three austenitic candidates as possible materials for fabrication of containers for disposal of high-level radioactive waste. The waste will include spent fuel assemblies from reactors as well as high-level reprocessing wastes in borosilicate glass and will be sent to the prospective repository at Yucca Mountain, Nevada, for disposal. The containers must maintain mechanical integrity for 50 yr after emplacement to allow for retrieval of waste during the preclosure phase of repository operation. Containment is required to be substantially complete for up to 300 to 1000 yr. During the early period, the containers will be exposed to high temperatures and high gamma radiation fields from the decay of high-level waste. The final closure joint will be critical to the integrity of the containers. This volume surveys the available data on the metallurgy of the copper-based candidate alloys and the welding techniques employed to join these materials. The focus of this volume is on the methods applicable to remote-handling procedures in a hot-cell environment with limited possibility of postweld heat treatment. The three copper-based candidates are ranked on the basis of the various closure techniques. On the basis of considerations regarding welding, the following ranking is proposed for the copper-based alloys: CDA 715 (best) > CDA 102 > CDA 613 (worst).

Lee, W. W., T. H. Pigford, 1989. "Release Rates of Soluble Species at Yucca Mountain," from FOCUS '89: Nuclear Waste Isolation in the Unsaturated Zone, Las Vegas, NV, September 18-21, 1989, LBL-26828, Lawrence Berkeley Laboratory, CA.

Experimental leaching of spent fuel shows that some fission product species are preferentially released upon contact with water. The conservative case of bare spent fuel in contact with saturated tuff using diffusional mass transfer analysis was analyzed. For the parameters used, the Nuclear Regulatory Commission release rate limit is not exceeded, except for Tc-99. However, the presence of a container and the distribution of water contact over time will assist in meeting this criterion.

Light, W. B., T. H. Pigford, P. L. Chambre, and W. W. Lee, 1989. "Analytical Models for C-14 Transport in a Partially Saturated, Fractured, Porous Media," from FOCUS '89: Nuclear Waste Isolation in the Unsaturated Zone, Las Vegas, NV, September 18-21, 1989, LBL-26827, Lawrence Berkeley Laboratory, CA.

Interaction between fractures and rock matrix is considered in developing a criterion for treating fractured rock as a porous medium for the purpose of transport calculations. The value of a modified Peclet number determines the suitability of the equivalent porous medium approach. Using a porous medium mode, underground concentrations of $^{14}CO_2$ are predicted for the proposed nuclear waste repository at Yucca Mountain, Nevada. Maximum concentrations near the ground surface are comparable to the Nuclear Regulatory Commission limit for unrestricted areas; travel times are predicted to be hundreds to thousands of years for the assumed parameter values.

Los Alamos National Laboratory, 1989. The Yucca Mountain Project Prototype Testing Program: 1989 Status Report, LA-11665-SR, Los Alamos National Laboratory, NM.

A Prototype Testing Program is being conducted to ensure that Exploratory Shaft Facility (ESF) tests can be completed in the time available and to develop instruments, equipment, and procedures so the ESF tests can collect reliable and representative site characterization data. This report summarizes the prototype tests with emphasis on the ones which are required in the early stages of the ESF site characterization tests.

Los Alamos National Laboratory, 1989. "Wireline Sidewall Coring," from the International Symposium on Borehole Geophysics, Las Vegas, NV, October 2-5, 1989, LA-UR-89-4215, Los Alamos, NM.

In April 1989, a wireline sidewall coring machine was run in exploratory hole Ue4t at the Nevada Test Site. The sampling project goals were to recover material for geologic characterization and to determine the effectiveness of the tool for sampling various volcanic lithologies. If a wireline tool is found to be effective, fewer expensive continuously-cored holes will be needed. The tool has a maximum diameter of 5.25 inches and, with the gamma-ray unit included for stratigraphic correlation, is approximately 40 feet long. It weighs 850 pounds. All the downhole mechanical systems are hydraulic including the anchor shoe, the coring motor, the pressure on the bit and the core extraction system. Sonde functions are monitored and controlled at the surface. The tool is designed to run in fluid with the waterways in the diamond but creating circulation to keep the bit face clean. Up to 20 cores, measuring 0.91 inches in diameter by 2 inches long, can be recovered with each each. These cores are separated in the split-sleeve catcher tube by discs automatically inserted following each coring.

Los Alamos National Laboratory, 1990. "Basaltic Volcanic Episodes of the Yucca Mountain Region," from the International Conference for High-Level Radioactive Waste Management, Las Vegas, NV, April 8-12, 1990, LA-UR-90-371, Los Alamos, NM.

The purpose of this paper is to summarize briefly the distribution and geologic characteristics of basaltic volcanism in the Yucca Mountain region during the last 10 to 12 Ma. This interval largely

postdates the major period of silicic volcanism and coincides with and postdates the timing of major extensional faulting in the region. Field and geochronologic data for the basaltic rocks define two distinct episodes. The patterns in the volume and spatial distribution of these basaltic volcanic episodes in the central and southern part of the SNVF are used as a basis for forecasting potential future volcanic activity in vicinity of Yucca Mountain.

Los Alamos National Laboratory, 1990. "Prototype Testing for the Yucca Mountain Project," from the International Conference for High-Level Radioactive Waste Management, Las Vegas, NV, April 8-12, 1990, LA-UR-90-183, Los Alamos, NM.

The US Department of Energy, through its Yucca Mountain Project Office, has been conducting prototype activities in welded and non-welded tuff. These activities are in preparation for characterization of the Yucca Mountain area, which is under consideration as a site for a geologic repository in which high-level nuclear waste could be safely stored. Investigators from organizations that will conduct the site investigation have been afforded opportunity, through the prototype program, to test, evaluate, and develop instruments, equipment, and methods. The Exploratory Shaft Facility will be used to collect significant amounts of underground site characterization data. The prototype tests are conducted under similar conditions.

Los Alamos National Laboratory, 1990. "Role of Underground Testing to Determine Suitability of Yucca Mountain as a Potential Repository Site," from the International Conference for High-Level Radioactive Waste Management, Las Vegas, NV, April 8-12, 1990, LA-UR-90-13, Los Alamos, NM.

A brief description of the Exploratory Shaft based site characterization testing program for the Yucca Mountain Project of the permanent disposal of high level radioactive waste is briefly described in this paper. Details of the testing program are presented in the DOE-issued Site Characterization Plan. Overview of the current planning process and status of various activities is briefly described. This study will reevaluate the mining method, ESF location and any changes in the ESF testing program.

Los Alamos National Laboratory, 1990. "Simulation of Heat Transfer in the Unsaturated Zone," from the International Conference for High-Level Radioactive Waste Management, Las Vegas, NV, April 8-12, 1990, LA-UR-90-351, Los Alamos, NM.

Heat transfer can play an important role in fluid flow near the emplacement site of high-level nuclear waste. The effects on far-field flow can be important in understanding net moisture fluxes above the repository zone. The convection in the unsaturated zone at the Yucca Mountain site was responsible for this movement. If this is so, then the convection could provide a mechanism for drying the rock above the repository zone and thus provide a buffer for heavy rainfall events. In addition, the convection would increase the movement of gaseous radionuclides such as $^{14}CO_2$, tritiated water vapor, and iodine-129 (Weeks, 1987). Because of the complexity of the problem, numerical models were required to calculate gas flow and vapor transport at the site. Kipp previously modeled this problem using the code HST3D. This code represents the flow of a single-phase fluid with both heat- and mass-transfer effects included. Water density and partial pressure effects are accounted for by the virtual temperature method. In this paper, the problem was simulated using the code FEHMN, a finite-element heat- and mass-transfer code being developed for the Yucca Mountain Project. The work described in this paper was done in preparation of the upcoming problem to be formulated for the Performance Assessment Calculation Exercise.

Los Alamos National Laboratory, 1990. "Thermal Stability of Zeolitic Tuff from Yucca Mountain, Nevada," from the International Conference for High-Level Radioactive Waste Management, Las Vegas, NV, April 8-12, 1990, LA-UR-90-68, Los Alamos, NM.

Thermal models of the proposed repository at

Yucca Mountain, Nevada, suggest that rocks near the proposed host rock will experience elevated temperatures for at least 1000 yrs. The effects of elevated temperatures on zeolites clinoptilolite and mordenite were investigated using a combination of high-temperature X-ray powder diffraction, thermogravimetric and differential scanning calorimetric analysis, and long-term heating experiments.

Maiya, P. S., W. J. Shack, and T. F. Kassner, 1990. "Stress Corrosion Cracking of Candidate Materials for Nuclear Waste Containers," from Corrosion '90, Las Vegas, NV, April 23-27, 1990, CONF-900403-3, Argonne National Laboratory, IL.

Types 304L and 316L stainless steel (SS), Incoloy 825, Cu, Cu-30%Ni, and Cu-7%Al have been selected as candidate materials for the containment of high-level nuclear waste at the proposed Yucca Mountain Site in Nevada. The susceptibility of these materials to stress corrosion cracking has been investigated by slow-strain-rate tests (SSRTs) in water which simulates that from well J-13 (J-13 water) and is representative of the groundwater present at the Yucca Mountain site. The SSRTs were performed on specimens exposed to simulated J-13 water at 93°C and at a strain rate 10^{-7} per second under crevice conditions and at a strain rate of 10^{-8} per second under both crevice and noncrevice conditions. All the tests were interrupted after nominal elongation strains of 1 to 4%. Examination by scanning electron microscopy showed some crack initiation in virtually all specimens. Optical microscopy of metallographically prepared transverse sections of Type 304L SS suggests that the crack depths are small ($<10^{-5}$ m). Preliminary results suggest that a lower strain rate increases the severity of cracking of Types 304L and 316L SS, Incoloy 825, and Cu but has virtually no effect on Cu-30%Ni and Cu-7%Al. Differences in susceptibility to cracking were evaluated in terms of a stress ratio, which is defined as the ratio of the increase in stress after local yielding in the environment to the corresponding stress increase in an identical test in air, both computed at the same strain. On the basis of this stress ratio, the ranking of materials in order of increasing resistance to cracking is: Types 304L SS < 316L SS < Incoloy 825 Cu-30%Ni < Cu Cu-7%Al.

Majer, E. L., J. E. Peterson, L. R. Myer, K. Karasaki, T. M. Daley, and J. C. Long, 1989. "Vertical Seismic Profiling (VSP) and Cross Hole Tomographic Imaging for Fracture Characterization," from FOCUS' 89: Nuclear Waste Isolation in the Unsaturated Zone, Las Vegas, NV, September 18-21, 1989, LBL-27778, Lawrence Berkeley Laboratory, CA.

Experiments at various fractured rock sites have been conducted to determine the fundamental nature of the propagation of seismic waves in fractured media. These experiments have been utilizing high frequency (1000 to 10000 Hz.) signals in a cross-hole configuration at scales of several tens of meters. Three component sources and receivers are used to map fracture density and orientation. The goal of the experiments has been to relate the seismological parameters to the hydrological parameters, if possible, in order to provide a more accurate description of a starting model for hydrological characterization. The work is ultimately aimed at the characterization and monitoring of the Yucca Mountain site for the storage of nuclear waste. In addition to these controlled experiments, multicomponent VSP work has been carried out at several sites to determine fracture characteristics. The results to date indicate that both P-wave and S-wave can be used to map the location of fractures. In addition, fractures that are open and conductive are much more visible to seismic waves that non-conductive fractures. The results of these tests indicate direct use in an unsaturated environment.

Oak Ridge National Laboratory, 1990. "Characteristics of Potential Repository Wastes," from the International Conference for High-Level Radioactive Waste Management, Las Vegas, NV, April 8-12, 1990, CONF-900406-11, Oak Ridge, TN.

The Office of Civilian Radioactive Waste Management (OCRWM) is responsible for the spent fuels and other wastes that will be disposed of in a geologic repository. The two major sources of these materials are commercial

light-water reactor (LWR) spent fuel and immobilized high-level waste (HLW). Other wastes that may require long-term isolation include non-LWR spent fuels and miscellaneous sources such as activated metals. Detailed characterizations are required for all of these potential repository wastes. These characterizations include physical, chemical, and radiological properties. The latter must take into account decay as a function of time. This information has been extracted from primary data sources, evaluated, and assembled in a Characteristics Data Base which provides data in four formats: hard copy standard reports, menu-driven personal computer (PC) data bases, program-level PC data bases, and mainframe computer files. The Characteristics Data Base provides a standard set of self-consistent data to the various areas of responsibility including systems integration and waste stream analysis, storage, transportation, and geologic disposal. The data will be used for design studies, evaluation of alternatives, and system optimization by OCRWM and supporting contractors.

Oak Ridge National Laboratory, 1990. Integrated Data Base for 1989: Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics, Revision 5, DOE-RW-0006-Rev.5, Oak Ridge, TN.

The Integrated Data Base (IDB) Program has compiled current data on inventories and characteristics of commercial spent fuel and both commercial and US Government-owned radioactive wastes through December 31, 1988. These data are based on the most reliable information available from government sources, the open literature, technical reports, and direct contacts. The current projections of future waste and spent fuel to be generated through the year 2020 and characteristics of these materials are also presented. The information forecasted is consistent with the latest US Department of Energy/Energy Information Administration (DOE/EIA) projections of US commercial nuclear power growth and the expected defense-related and private industrial and institutional (I/I) activities. The radioactive materials considered, on a chapter-by-chapter basis, are spent fuel, high-level waste, transuranic waste, low-level waste, commercial uranium mill tailings, remedial action waste, commercial reactor and fuel cycle facility decommissioning waste, and mixed (hazardous and radioactive) low-level waste. For most of these categories, current and projected inventories are given through the year 2020, and the radioactivity and thermal power are calculated based on reported or estimated isotopic compositions. In addition, characteristics and current inventories are reported for miscellaneous, highly radioactive materials that may require geologic disposal.

Oak Ridge National Laboratory, 1990. "Investigation of Burnup Credit Allowance in the Criticality Safety Evaluation of Spent Fuel Casks," from the International Conference for High-Level Radioactive Waste Management, Las Vegas, NV, April 8-12, 1990, CONF-900406-12, Oak Ridge, TN.

This presentation discusses work in progress on criticality analysis verification for designs which take account of the burnup and age of transported fuel. The work includes verification of cross section data, correlation with experiments, proper extension of the methods into regimes not covered by experiments, establishing adequate reactivity margins, and complete documentation of the project. Recommendations for safe operational procedures are included, as well as a discussion of the economic and safety benefits of such designs.

Oak Ridge National Laboratory, 1990. Non-LWR and Special LWR Spent Fuels: Characteristics and Criticality Aspects of Packaging and Disposal, ORNL/TM-11016, Oak Ridge National Laboratory, TN.

Two important categories of potential repository wastes, non-LWR spent fuels and special LWR spent fuels, were evaluated regarding their future quantities and packaging requirements, including criticality aspects. Assuming that canisters similar to those planned for vitrified high-level waste and conventional LWR fuel assemblies prove to be acceptable for these fuels, it is estimated that about 1400 such canisters will be needed for the non-LWR and special LWR spent fuels on hand

and projected through the year 2020. Approximately half of these canisters are for HTGR spent fuel, a quarter are for TMI-2 spent fuel and core debris, and the balance are for fuels from a score of diverse sources. About two thirds of these spent fuels can be accommodated in extended vitrified HLW-size canisters and the remainder will fit into canisters proposed for use in a tuff repository. Since many of these fuels are of higher enrichment and/or lower burnup than standard LWR spent fuel, estimation of the number of fuel assemblies that could be safely placed in a canister required preliminary calculations of neutron multiplication factors to ensure non-criticality. These estimates showed that the canister configurations used would provide more than adequate volume for the neutron poisons needed for this purpose.

Osnes, J. D., J. L. Ratigan, M. C. Loken, and D. K. Parrish, 1989. Documentation of SPECTROM-55: A Finite Element Thermohydrogeological Analysis Program, DOE/CH/10378-4, RE/SPEC, Inc., Rapid City, SD.

SPECTROM-55 is a finite element computer program for analyses of coupled heat and fluid transfer through fully saturated porous media. The code is part of the SPECTROM (Special Purpose Engineering Codes for Thermal/ROck Mechanics) series of special purpose finite element programs, that address the many unique rock mechanics problems resulting from storage of radioactive waste in geologic formations. This document presents the theoretical basis for the mathematical model, the finite element formulation of the problem, and a description of the input data for the program along with details about program support and continuing documentation. The program is especially suited for analyses of the regional hydrogeology in the vicinity of a heat-generating nuclear waste repository. These applications typically involved forced and free convection in a ground-water flow system. The program provides transient or steady-state temperatures, pressures, and fluid velocities resulting from the application of a variety of initial and boundary conditions to bodies with complicated shapes. The boundary conditions include constant heat and fluid fluxes, convective heat transfer, constant temperature, and constant pressure. Initial temperatures and pressures can be specified. Composite systems of anisotropic materials, such as geologic strata, can be defined in either planar or axisymmetric configurations. Constant or varying volumetric heat generation, such as decaying heat generation from radioactive waste, can be specified.

Pacific Northwest Laboratory, 1989. "Measurement of Soluble Nuclide Dissolution Rates from Spent Fuel," from the Scientific Basis for Nuclear Waste Management Conference, Boston, MA, November 27-30, 1989, PNL-SA-17120, Richland, WA.

Gaining a better understanding of the potential release behavior of water-soluble radionuclides is the focus of new laboratory spent fuel dissolution studies being planned in support of the Yucca Mountain Project. Dissolution rates for several soluble nuclides have been measured from spent fuel specimens using static and semi-static methods. Flow-through tests are being developed as a potential supplemental method for determining the matrix component of soluble-nuclide dissolution. Advantages and disadvantages of both semi-static and flow-through methods are discussed. Tests with fuel specimens representing a range of potential fuel states that may occur in the repository, including oxidized fuel, are proposed. Preliminary results from flow-through tests with unirradiated UO_2 suggesting that matrix dissolution rates are very sensitive to water composition are also presented.

Pacific Northwest Laboratory, 1989. The AREST [Analytical REpository Source-Term] Code: User's Guide for the Analytical Repository Source-Term Model, PNL-6645, Richland, WA.

This document is a user's guide for the Analytical REpository Source-Term (AREST) code that has been developed by the Performance Assessment Scientific Support (PASS) program. These analyses will provide program guidance and help to identify technical design issues that require resolution.

Polzer, W. L., and H. R. Fuentes, 1989. "Experiences of Fitting Isotherms to Data from Batch Sorption Experiments for Radionuclides on Tuffs," from Migration '89: 2nd International Conference on Chemistry and Migration Behavior of Actinides and Fission Products in the Geosphere, Monterey, CA, November 6-10, 1989, LA-UR-89-3116, Los Alamos National Laboratory, NM.

Laboratory experiments have been performed on the sorption of radionuclides on tuff. This paper presents general observations on the results of curve-fitting of sorption data by isotherm equations and the effects of experimental variables on their regressional analysis. Observations are specific to the effectiveness and problems associated with fitting isotherms, the calculation and value of isotherm parameters, and the significance of experimental variables such as replication, particle size, mode of sorption, and mineralogy. These observations are important in the design of laboratory experiments to ensure that collected data are adequate for effectively characterizing sorption of radionuclides on tuffs or other materials.

Prindle, R. W., 1989. "A Sensitivity Analysis of Flow Through Layered, Fractured Tuff: Implications for Performance Allocation and Performance Assessment Modeling," from FOCUS '89: Nuclear Waste Isolation in the Unsaturated Zone, Las Vegas, NV, September 18-21, 1989, SAND-89-1915C, Sandia National Laboratories, Albuquerque, NM.

A sensitivity study of unsaturated flow through a system of layered, fractured tuffs has been completed. The study was defined and performed for the International Hydrologic Code Intercomparison Project (HYDROCOIN). The modeled system was highly constrained and simplified but was loosely based on conditions thought to exist at Yucca Mountain, Nevada. The paper covers a brief description of the system modeled; the mathematical model used and the analyses performed for the study; a summary of the major conclusions drawn regarding the important types of flow behavior that were observed, and a discussion of the implications of the different types of flow behavior for performance allocation and for performance assessment using simplified models.

Ramirez, A., J. Beatty, T. Buscheck, R. Carlson, W. Daily, V. LaTorre, K. Lee, D. Towse, D. Watwood, and D. Wilder, 1989. "Prototype Engineered Barrier System Field Tests: Progress Report," from FOCUS '89: Nuclear Waste Isolation in the Unsaturated Zone, Las Vegas, NV, September 18-21, 1989, UCRL-101615, Lawrence Livermore National Laboratory, CA.

This paper presents selected preliminary results obtained during the first 54 days of the Prototype Engineered Barrier System Field Tests (PEBSFT) that are being performed in G-Tunnel within the Nevada Test Site. The tests are precursor to in situ tests of the geohydrologic and geochemical environment in the near field (within a few meters) using heaters emplaced in welded tuff to simulate the thermal effects of waste packages. The PEBSFTs are being conducted to evaluate the applicability of measurement techniques, numerical models, and procedures for future investigations that will be conducted in the Exploratory Shaft at Yucca Mountain. The paper discusses the evolution of hydrothermal behavior during the prototype test, including rock temperatures, changes in rock moisture content, air permeability of fractures, gas pressures, and rock mass gas-phase humidity.

Reynolds Electrical and Engineering Co., Inc., 1990. "Horizontal Coring Using Air as the Circulating Fluid: Some Prototype Studies Conducted in G Tunnel at the Nevada Test Site for the Yucca Mountain Project," from the Energy-Sources Technology Conference and Exhibition, New Orleans, LA, January 14-18, 1990, CONF-900102-3, Las Vegas, NV.

Horizontal coring using air as the circulating fluid has been conducted in the G Tunnel Underground Facility (GTUF) at the Nevada Test Site. This work is part of the prototype investigations of hydrogeology for the Yucca Mountain Project. The work is being conducted to develop methods and procedures that will be used during the characterization of the Yucca Mountain, Nevada, site.

Sandia National Laboratories, 1989. "Concepts in Prototype Testing for In Situ Geomechanical Investigations at Yucca Mountain," from the International Conference for High-Level Radioactive Waste Management, Las Vegas, NV, April 8-12, 1990, SAND-89-2098C, Albuquerque, NM.

Geomechanical investigations comprise a significant portion of the scientific investigation program to be conducted at Yucca Mountain. The investigations will include a number of large-scale experiments that will be conducted in an exploratory shaft facility at the site. A program of prototype testing has been initiated to ensure the success of these expensive and complex experiments. The prototype testing program addresses three problems in rock mechanics: measurement of rock-mass strength, measurement of joint properties in situ, and measurement of rock-mass response to thermally-induced loading. Active areas of development in support of these tests include cutting deep, narrow slots in rock and fabricating high-pressure flatjacks.

Sandia National Laboratories, 1989. "Deposition of Airborne Particles from Fractured Spent Fuel or High-Level Waste," from the International Conference for High-Level Radioactive Waste Management, Las Vegas, NV, April 8-12, 1990, SAND-89-7019C, Sandia National Laboratories, Albuquerque, NM.

This paper describes a study to estimate the deposition of airborne particles either within a hot cell or outside the building as they are dispersed through the atmosphere, and the extent to which these depositions reduce the offsite dose at the site boundary.

Sandia National Laboratories, 1989. "Initiating Event Identification and Screening for Nuclear Waste Repository Preclosure Risk Assessment," from the International Conference for High-Level Radioactive Waste Management, Las Vegas, NV, April 8-12, 1990, SAND-89-2050C, Albuquerque, NM.

This paper describes a method to identify potential initiating events that might occur during the preclosure phase at a nuclear waste repository proposed for the Yucca Mountain area of Nevada. Initiating events of interest must be theoretically capable of causing radiological exposure hazards to either repository operations personnel or to the general public.

Sandia National Laboratories, 1989. Mineralogic and Chemical Data Supporting Heat Capacity Determination for Tuffaceous Rocks, SAND-88-0882, Albuquerque, NM.

Bulk chemical, x-ray diffraction, and petrologic data are presented for 20 samples of tuffaceous rocks from Yucca Mountain, Nevada. Uncertainties are presented for quantitative results (bulk chemistry and point-counting results) but have not been estimated for the semiquantitative x-ray diffraction data.

Sandia National Laboratories, 1989. "Modeling the Uncertainties in the Parameter Values of a Sparse Data Set using the Beta Probability Distribution," from the Conference on Indirect Methods for Estimating Hydraulic Properties, Riverside, CA, October 11-13, 1989, SAND-89-2377C, Albuquerque, NM.

The geological formations in the unsaturated zone at Yucca Mountain, Nevada, are being investigated as the proposed site of a repository for the disposal of high-level radioactive waste. The numerical and conceptual tools that will be used to assess the degree to which the site complies with specified regulatory criteria are currently under development. This paper reports the status of a probability model that has been implemented to address uncertainties in quantitative predictions of parameter values that are used as input to numerical simulation models of flow.

Sandia National Laboratories, 1989. "One-Dimensional Radionuclide Transport Under Time-Varying Conditions," from the International Conference for High-Level Radioactive Waste Management, Las Vegas, NV, April 8-12, 1990, SAND-89-1988C, Albuquerque, NM.

New analytical and numerical solutions are presented for one- dimensional radionuclide transport under time-varying fluid-flow conditions including radioactive decay. The analytical solution assumes that all radionuclides have identical retardation factors, and is limited to instantaneous releases. The numerical solution does not have these limitations, but is tested against the limiting case given for the analytical solution. Reasonable agreement between the two solutions was found. Examples are given for the transport of a three-member radionuclide chain transported over distances and flow rates comparable to those reported for Yucca Mountain, the proposed disposal site for high-level nuclear waste.

Sandia National Laboratories, 1989. "Preliminary Methodology for Design of Stable Drifts for the Yucca Mountain Project," from the International Conference for High-Level Radioactive Waste Management, Las Vegas, NV, April 8-12, 1990, SAND-89-2073C, Albuquerque, NM.

This paper defines a methodology and criteria by which the stability of underground repository drifts in tuff is determined and from which the ground support system is designed. Preconstruction evaluations of stability are required for planning and to support the license application process. The emphasis is on analytical numerical methods because, at this time, empirical data are generally not available for excavations in welded tuff at elevated temperatures or in seismic environments. Observational methods are only applicable during construction. The methodology suggests analytical techniques for the range of structural conditions of the rock currently expected at the Yucca Mountain site: systematically jointed rock masses, randomly jointed rock masses, and widely spaced discrete joints. The analyses must also load on the rock in the vicinity of excavations that result from in situ stresses, thermal expansion, and seismic events. Large-scale field experiments at the Exploratory Shaft Facility (ESF) and laboratory experiments on ESF samples define the controlling deformation mechanisms and allows evaluation of in situ properties. The methodology presented is expected to evolve.

Sandia National Laboratories, 1989. "Synthesis of Studies for the Potential of Fault Rupture at the Proposed Surface Facilities, Yucca Mountain, Nevada," from the International Conference for High-Level Radioactive Waste Management, Las Vegas, NV, April 8-12, 1990, SAND-89-2099C, Albuquerque, NM.

Published data for the Midway Valley area, suggest that since middle Miocene time, recognized regional faults have had average slip rates of less than 0.10 mm/yr. Slip rates in the last 8 Ma are estimated to be one-sixth of previous slip rates or less. The decrease in fault activity coincides with the waning of magmatism related to the Paintbrush tuff. Two important uncertainties are inherent in the slip rate estimates, the relative amount of strike-slip versus dip-slip displacement and the errors in precision of dating offset units. Reliable Quaternary slip rates and recurrence intervals are not yet available for the Midway Valley area. The apparent lack of fault scarps in alluvium, however, indicates that no important displacements have occurred in Holocene time, although several photolineaments have been identified.

Subramanian, C. V., 1989. "Cost-Benefit Assessment of the Seismic Design of the Tuff Repository Waste Handling Facilities," from the DOE Natural Phenomena Hazards Mitigation Conference, Knoxville, TN, October 3-5, 1989, SAND-89-0734C, Sandia National Laboratories, Albuquerque, NM.

This paper summarizes a cost-benefit assessment of the seismic design of the waste-handling facilities associated with the prospective high-level waste repository at Yucca Mountain, Nevada. It provides a very brief description of the methodology used and the costs and benefits of varying design levels for vibratory ground motions and surface fault displacements for structures,

components, and equipment that are important to safety in the waste-handling facilities.

Svalstad, D. K., 1989. Documentation of SPECTROM-41: A Finite Element Heat Transfer Analysis Program, DOE/CH/10378-1, RE/SPEC Inc., Rapid City, SD.

SPECTROM-41 is a finite element heat transfer computer program developed to analyze thermal problems related to nuclear waste disposal. The code is part of the SPECTROM (Special Purpose Engineering Codes for Thermal/ROck Mechanics) series of special purpose finite element programs to address the many unique formations. This document presents the theoretical basis for the mathematical model, the finite element formulation of the program, and a description of the input data for the program, along with details about program support and continuing documentation. The principal component model used in the programs based on Fourier's law of conductance. Numerous program options provide the capability of considering various boundary conditions, material stratification and anisotropy, and time-dependent heat generation that are characteristic of problems involving the disposal of nuclear waste in geologic formation. Numerous verification problems are included in the documentation in addition to highlights of past and ongoing verification and validation efforts. A typical repository problem is solved using SPECTROM-41 to demonstrate the use of the program in addressing problems related to the disposal of nuclear waste.

Thompson, A. F., and R. B. Knapp, 1989. "Reactive Geochemical Transport Problems in Nuclear Waste Analyses," from the Joint International Waste Management Conference, Kyoto, Japan, October 23-28, 1989, URCL-99552-Rev.1, Lawrence Livermore National Laboratory, CA.

This paper reviews the generic formulation of reactive geochemical transport problems that may be associated with the design of a nuclear waste repository. A summary of the relevant physical and chemical transport phenomena is provided as a basis for developing suitable numerical models of these processes. Particular emphasis is devoted to numerical and computational aspects of simulating the movement of several reactive chemical components within a porous medium using particle method. In addition, avenues for future theoretical and applied research are discussed in light of the various uncertainties that presently exist in solving these problems.

Thompson, J. L., 1989. "Radionuclide Migration Studies at the Nevada Test Site," from the International Chemical Congress of Pacific Basin Society Symposium on Polymer Rheology and Processing (PACIFICHEM '89), Honolulu, HI, December 17-22, 1989, LA-UR-89-3701, Los Alamos National Laboratory, NM.

The United States government routinely tests nuclear devices at the Nevada Test Site (NTS) in southern Nevada. For many years, the DOE has sponsored a research program on radionuclide movement in the geologic media at this location. Goals of this research program are to measure the extent of movement of radionuclides away from underground explosion sites and to determine the mechanisms by which such movement occurs. This program has acquired significance in another aspect of nuclear waste management because of the Yucca Mountain Project. Yucca Mountain, partially on the NTS, is being intensely studied as the possible site for a mined repository for high level nuclear waste. This paper summarizes some of the significant findings made under this research program at the NTS and identifies reports in which the details of the research may be found.

Triay, I. R., A. Meijer, M. R. Cisneros, G. G. Miller, A. J. Mitchell, M. A. Ott, D. E. Hobart, P. D. Palmer, R. E. Perrin, and R. D. Aguilar, 1989. "Sorption of Americium in Tuff and Pure Minerals Using Synthetic and Natural Groundwaters," from Migration '89: 2nd International Conference on Chemistry and Migration Behavior of Actinides and Fission Products in the Geosphere, Monterey, CA, November 6-10, 1989, LA-UR-89-3733, Los Alamos National Laboratory, NM.

The distribution of americium between selected

solid and liquid phases has been studied using initial americium-214 solutions with a molarity smaller than 1×10^{-11}. The synthetic and natural groundwaters used have pH values in the 7 to 8 range and a total alkalinity of approximately 1 mN which is mainly due to bicarbonate. Mass spectrometric isotope dilution was utilized to determine the amount of americium in the solution phase initially and after equilibrium was attained. Using this sensitive technique, 7×10^8 atoms of americium-241 were accurately measured. Our results indicate that the percent of americium lost to the walls of the container in the absence of geologic material varies from 35 to 84%. The americium sorption coefficient determined is on the order of 10^3 ml/g for clinoptilolite, 10^4 ml/g for tuff consisting mainly of alkali feldspar and cristobalite, and 10^5 ml/g for romanechite.

Triay, I. R., R. S. Rundberg, A. J. Mitchell, M. A. Ott, D. E. Hobart, P. D. Palmer, T. W. Newton, and J. L. Thompson, 1989. "Size Determinations of Plutonium Colloids Using Autocorrelation Photon Spectroscopy," from Migration '89; 2nd International Conference on Chemistry and Migration Behavior of Actinides and Fission Products in the Geosphere, Monterey, CA, November 6-10, 1989, LA-UR-89-3702, Los Alamos National Laboratory, NM.

Autocorrelation Photon Spectroscopy (APS) is a light-scattering technique utilized to determine the size distribution of colloidal suspensions. The capabilities of the APS methodology have been assessed by analyzing colloids of known sizes. Plutonium (IV) colloid samples were prepared by a variety of methods including dilution, peptization, and alpha-induced auto-oxidation of plutonium (III). The size of these plutonium colloids, analyzed using APS, varied from 1 to 370 nanometers.

Zimmerman, R. W., and G. S. Bodvarsson, 1989. "Semi-Analytical Solutions for Flow Problems in Unsaturated Porous Media," from the American Society of Mechanical Engineers Winter Meeting, San Francisco, CA, December 10-15, 1989, LBL-27578, Lawrence Berkeley Laboratory, CA.

Semi-analytical solutions are developed for two unsaturated flow problems that are relevant to characterizing the hydrological behavior of Yucca Mountain, Nevada. The "integral" or "boundary-layer" approach is used to find a closed-form approximate solution for absorption of water from a saturated fracture into an unsaturated semi-infinite formation. This solution is then programmed into a numerical code as a source/sink term for fracture elements, and used to study the problem of flow along a fracture with transverse leakage to the rock matrix.

Zwahlen, E. D., T. H. Pigford, P. L. Chambre, and W. W. Lee, 1989. "Gas Flow in and out of a Nuclear Waste Container," from the American Nuclear Society Winter Meeting, San Francisco, CA, November 26-30, 1989, LBL-27225, Lawrence Berkeley Laboratory, CA.

The flow of gases out of and into a high-level-waste container in the unsaturated tuff of Yucca Mountain has been analyzed for the first 300 years after emplacement. Containers are expected to fail eventually by localized cracks and penetrations. Even though the penetrations may be small, argon gas initially in the hot container can leak out. As the waste package cools, the pressure inside the container can become less than atmospheric, and air can leak in. C-14 released from the hot fuel-cladding surface can leak out of penetrations, and air inleakage can mobilize additional C-14 and other volatile radioactive species as it oxidizes the fuel cladding and the spent fuel.

DOE F 1325.28-
(10-89)

United States Government | Department of Energy

memorandum

ES - _____

Date: **SECRETARIAL ACTION REQUESTED BY:**

Orig. Office: RW-22:Switzer/Mozumder:586-4262

Transmittal: ACTION: Issuance of the "Progress Report on the Scientific Investigation Program for the Nevada Yucca Mountain Site"

To: The Secretary

Through: Under Secretary

Issue: Approve issuance of the attached progress report, required under section 113(b)(3) of the Nuclear Waste Policy Act of 1982, as amended (NWPA).

Timing: The NWPA requires that the Secretary report to the Nuclear Regulatory Commission and to the Governor and legislature of the State of Nevada not less than once every 6 months on the nature and extent of the Department's scientific investigation activities at the Yucca Mountain, Nevada, site and the information developed from these activities.

Issuance of the progress report was scheduled for July. The last progress report was issued in February.

Discussion: The report, covering the period from October 1, 1989, through March 31, 1990, presents summaries of the status of scientific investigation activities at the Yucca Mountain, Nevada site and cites documents that provide more detailed information. This report provides highlights of work in progress and work completed during the reporting period. Future reports are intended to discuss any major changes to DOE's scientific investigation program as information about the site is obtained and evaluated, more detailed designs of the repository and the waste package are developed, and new results from performance assessments are obtained. They would also discuss any major changes to the scientific investigation program made in response to external concerns.

The progress report indicates that the scientific investigation program activities which the Department has been able to conduct have progressed satisfactorily.

Recommendation: That the Secretary: (1) approve issuance of the statutorily required document titled "Progress Report on the Scientific

Investigation Program for the Nevada Yucca Mountain Site," (2) approve the two attached transmittal letters at tabs D and E, and (3) grant auto-pen authorization for ES to complete the 30 transmittal letters. Attached to the letters at tabs D and E are the lists of addressees (9 and 21 respectively) to be used with the letters. The two letters are identical, except that the letter at tab E is being sent pursuant to the NWPA (as stated in letter.)

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

4 Attachments

APPROVED: _____

DISAPPROVED: _____

DATE: _____

CONCURRENCE: EH Brush GC Wakefield CP Knox-Brown

RECORD OF CONCURRENCE

Please indicate, by signature below, your concurrence on the Progress Report on the Scientific Investigation Program for the Nevada Yucca Mountain Site for the period October 1, 1989, to March 31, 1990, and the associated transmittal letters.

Jacqueline Knox-Brown, CP-1

Peter N. Brush, EH-1

Stephen Wakefield, GC-1

The Secretary of Energy
Washington, DC 20585

The Honorable J. Bennett Johnston
Chairman, Committee on Energy and
Natural Resources
United States Senate
Washington, D.C. 20510

Dear Mr. Chairman:

In accordance with section 113(b)(3) of the Nuclear Waste Policy Act of 1982, as amended, (NWPA) the Department has prepared the second of a series of reports on the progress of scientific investigations at Yucca Mountain. The Department will continue to issue progress reports covering six month periods, as specified in the NWPA, as amended. The document, entitled "Progress Report on the Scientific Investigation Program for the Nevada Yucca Mountain Site," covers the period from October 1, 1989, through March 31, 1990, and is being sent to you under separate cover.

Sincerely,

James D. Watkins
Admiral, U.S. Navy (Retired)

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

ADDRESSEES - LIST 2 (Tab "D")

The Honorable Harry Reid
United States Senate

The Honorable Barbara Vucanovich
U.S. House of Representatives

The Honorable James H. Bilbray
U.S. House of Representatives

The Honorable Richard H. Bryan
United States Senate

The Honorable Morris K. Udall
Chairman, Committee on Interior and Insular Affairs
U.S. House of Representatives

The Honorable Don Young
Ranking Minority Member
Committee on Interior and Insular Affairs
U.S. House of Representatives

The Honorable J. Bennett Johnston
Chairman, Committee on Energy and Natural Resources
United States Senate

The Honorable James A. McClure
Ranking Minority Member
Committee on Energy and Natural Resources
United States Senate

The Honorable John D. Dingell
Chairman, Committee on Energy and Commerce
U.S. House of Representatives

The Honorable Norman F. Lent
Ranking Minority Member
Committee on Energy and Commerce
U.S. House of Representatives

The Honorable Philip R. Sharp
Chairman, Subcommittee on Energy and Power
Committee on Energy and Commerce
U.S. House of Representatives

The Honorable Carlos J. Moorhead
Ranking Minority Member
Subcommittee on Energy and Power
Committee on Energy and Commerce
U.S. House of Representatives

The Honorable Tom Bevill
Chairman, Subcommittee on Energy and Water Development
Committee on Appropriations
U.S. House of Representatives

The Honorable John T. Myers
Ranking Minority Member
Subcommittee on Energy and Water Development
Committee on Appropriations
U.S. House of Representatives

The Honorable Quentin N. Burdick
Chairman, Committee on Environment and Public Works
United States Senate

The Honorable John H. Chafee
Ranking Minority Member
Committee on Environment and Public Works
United States Senate

The Honorable Donald B. Rice
Secretary of the Air Force

The Honorable Samuel K. Skinner
Secretary of Transportation

The Honorable William K. Reilly
Administrator, Environmental Protection Agency

The Honorable Manuel Lujan, Jr.
Secretary of the Interior

Dr. Don U. Deere
Chairman
U.S. Nuclear Waste Technical Review Board

The Honorable James V. Hansen
Ranking Minority Member
Subcommittee on Energy and the Environment
Committee on Interior and Insular Affairs
U. S. House of Represenatives

The Honorable Mark O. Hatfield
Ranking Minority Member
Committee on Appropriations
U.S. Senate

The Honorable Bob Graham
Chairman, Subcommittee on Nuclear Regulation
Committee on Environment and Public Works
U.S. Senate

The Honorable Alan K. Simpson
Ranking Minority Member
Subcommittee on Nuclear Regulation
Committee on Environment and Public Works
U.S. Senate

Mr. William McCollam, Jr.
President
Edison Electric Institute

Mr. Ed Davis
President
American Nuclear Energy Council

Mr. Paul Rodgers
Administrative Director & General Counsel
National Association of Regulatory
Utility Commissioners

Mr. James Johnson
Acting Director, Washington Office
Electric Power Research Institute

Mr. Harold B. Finger
President & Chief Executive Office
U.S. Council on Energy Awareness

Mr. Robert C. Dickonson
Nevada Nuclear Waste Study Committee

The Secretary of Energy
Washington, DC 20585

The Honorable Keith Whipple
Chairman
Lincoln County Commission
P.O. Box 90
Pioche, Nevada 89043

Dear Mr. Chairman:

In accordance with section 113(b)(3) of the Nuclear Waste Policy Act of 1982, as amended, (NWPA) the Department has prepared the second report of a series of reports on the progress of scientific investigations at Yucca Mountain. The Department will continue to issue progress reports covering six month periods, as specified in the NWPA, as amended. The document, entitled "Progress Report on the Scientific Investigation Program for the Nevada Yucca Mountain Site," covers the period from October 1, 1989, through March 31, 1990, and is being sent to you pursuant to the NWPA. Your copy will arrive under separate cover.

Sincerely,

James D. Watkins
Admiral, U.S. Navy (Retired)

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

ADDRESSEES - LIST 1 (Tab "E")
(Recipients Pursuant to the NWPA)

The Honorable Kenneth M. Carr
Chairman, U.S. Nuclear Regulatory Commission

The Honorable Bob Miller
Governor of Nevada

The Honorable Bruce Woodbury
Chairman, Clark County Commission

The Honorable Bob Revert
Chairman, Nye County Commission

The Honorable Keith Whipple
Chairman, Lincoln County Commission

The Honorable Thomas J. Hickey
Chairman, Nevada Legislative Committee
on High Level Radioactive Waste

The Honorable Grant Sawyer
Chairman, Commission on Nuclear Projects

The Honorable Lawrence E. Jacobsen
President Pro-Tem of the Senate

The Honorable Joseph E. Dini, Jr.
Speaker of the Assembly