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Nuclear Waste Policy Act
(Section 113)

Site Characterization Progress Report: Yucca Mountain, Nevada

April 1, 1992 — September 30, 1992

Number 7

December 1992

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

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NOTE TO READERS:

In accordance with section 113(b)(3) of the Nuclear Waste Policy Act of 1982, as amended (NWPA), the Department has prepared the seventh in a series of reports on the progress of site characterization at the Yucca Mountain candidate site. The document is entitled "Site Characterization Progress Report: Yucca Mountain, Nevada" and covers the period from April 1, 1992 through September 30, 1992.

The Civilian Radioactive Waste Management Program made significant progress during the reporting period at the Yucca Mountain Site Characterization Project. Several important advances were made in the surface-based testing program including: initiation of borehole drilling utilizing the new, state-of-the-art LM-300 drill rig which employs dry drilling and coring techniques; neutron access borehole drilling to evaluate infiltration processes; excavations to aid geologic mapping; and trenching in Midway Valley to study Quaternary faulting.

A Floodplain Assessment and Statement of Findings was published in the Federal Register which concluded there would be no significant impact nor cumulative impacts on floodplains resulting from Exploratory Studies Facility activities.

The National Academy of Sciences' National Research Council released its report entitled "Ground Water at Yucca Mountain: How High Can It Rise?" which concluded that none of the evidence cited as proof of groundwater upwelling in and around Yucca Mountain could be reasonably attributed to that process and that significant water table excursions to the repository design level are not shown by the geologic record.

The June 29, 1992, earthquake near Yucca Mountain provided scientists with a wealth of information relevant to understanding the neotectonics of the area and the geometry of faults at depth. Early findings suggest that accelerations recorded were well within proposed design limits for the surface waste handling facilities.

Nevada State agencies continued the timely and professional processing and issuance of requisite permits including air quality, underground injection control and supplemental water appropriations.

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

John W. Bartlett

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

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PROGRESS REPORT #7

EXECUTIVE SUMMARY

In accordance with the requirements of Section 113(b)(3) of the Nuclear Waste Policy Act (NWPA) and 10 CFR 60.18(g), the U.S. Department of Energy (DOE) has prepared this report on the progress of site characterization activities at Yucca Mountain, Nevada, for the period April 1, 1992, through September 30, 1992. This report is the seventh in a series of reports that are issued at intervals of approximately six months during site characterization. Also included in this report are activities such as public outreach and international programs that are not officially part of site characterization. Information on these activities is provided to fully integrate all technical aspects of the Yucca Mountain studies.

A 5.6 Richter magnitude earthquake occurred near Yucca Mountain on the morning of June 29, 1992. The epicenter was located approximately 20 km (12 mi) from the potential repository block. The Yucca Mountain Site Characterization Project Office's (YMPO) Field Operations Center sustained minor damage from surface ground motion. Project personnel worked around the clock until July 14, to deploy portable seismographs to record aftershocks and process incoming data from the Southern Great Basin Seismic Network (SGBSN). Rapid response enabled U.S. Geological Survey (USGS) and University of Nevada at Reno (UNR) scientists to gather additional information relevant to understanding the neotectonics of the area and the geometry of faults at depth. A white paper titled "The Little Skull Mountain Earthquake of June 29, 1992" was prepared by USGS/UNR Seismic Laboratory (UNRSL) staff and contained basic parameters of the earthquake and a description of its effects in the immediate area. The white paper was provided to the U.S. Nuclear Regulatory Commission (NRC), the Nuclear Waste Technical Review Board (NWTRB), and the State of Nevada.

The Office of Civilian Radioactive Waste Management (OCRWM) forwarded the Floodplain Assessment and Statement of Findings for the Exploratory Studies Facility (ESF)-based activities and the cumulative impacts of the ESF-based and surface-based activities for publication in the Federal Register. The conclusion of the findings was that there would be no significant impact on floodplains as a result of ESF activities, and no cumulative impacts.

A Free Use Permit for extraction of sand and gravel from Fortymile Wash to be used in the construction of roads, drill pads, and ESF pads was granted by the U.S. Bureau of Land Management (BLM) on May 20, 1992. In addition, an Air Registration Certificate for the gravel screen operation located in Fortymile Wash was granted by the State of Nevada on June 8, 1992.

The Nevada Department of Conservation and Natural Resources issued a permit modification for the underground injection control permit. YMPO submitted four

water appropriation applications affecting the use of ground water from Wells J-13, J-12, and VH-1 which have been approved by the Nevada State Engineer.

The National Academy of Sciences' National Research Council (NAS/NRC) Panel on Coupled Hydrologic/Tectonic/Hydrothermal Systems at Yucca Mountain released its report entitled "Ground Water at Yucca Mountain: How High Can It Rise?" (Raleigh et al., 1992). The 17-member panel, convened by the Council, examined the hypothesis that significant ground-water upwellings as the result of seismic activity (i.e., seismic pumping) had occurred in the past and could occur in the future. The panel concluded that none of the evidence cited as proof of ground-water upwelling in and around Yucca Mountain could be reasonably attributed to that process and that significant water table excursions to the design level of the repository are not shown by the geologic record.

The surface-based testing program advanced significantly with the beginning of core drilling with the new LM-300 drill rig. The LM-300 utilizes dry drilling and coring techniques to avoid contaminating core samples and in situ rocks and ground water with drilling fluids. UE-25UZ#16, the first borehole to be drilled with the LM-300, was spudded (start of actual drilling) on May 27, 1992, and has been cored to 673 feet and reamed to a depth of 639 feet. This borehole is expected to reach its final depth just below the water table by March 1993. Borehole UE-25UZ#16 will be used to help characterize the unsaturated zone (UZ) as well as provide samples and access for other studies.

Phase I of the neutron access drilling on the northeastern edge of the potential repository block was completed with neutron boreholes USW UZN-38, USW UZN-64, USW UZN-27, and USW UZN-53. Phase II, which includes an additional 12 boreholes, was begun with the completion of UE-25UZN#63, USW UZN-31, USW UZN-33, and USW UZN-34. The 24 boreholes of Phases I and II complement an existing suite of 74 boreholes which are being used to evaluate present day infiltration processes and net infiltration rates.

Surface-based excavations continued to provide samples and exposures to aid geologic mapping. Through June 1992, 28 soil test pits for surficial geologic mapping and four trenches (MWV-T5, MWV-T6, MWV-T14D, and MWV-T4) to study Quaternary faulting were dug in Midway Valley. Interim results of Quaternary fault studies were presented during an NRC site visit September 17 and 18, 1992. In August 1992, four natural bedrock surfaces were cleared at Busted Butte to expose Quaternary faults. Two trenches in Crater Flat (CF1 and CF8) were deepened and cleared to map Quaternary faulting and a third (SC1) was excavated across the Solitario Canyon fault. Bedrock excavation was begun in September 1992 at Fran Ridge Test Pit No. 1 for facilitating bedrock fracture network mapping.

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On May 7, 1992, DOE conducted the first Director's Forum which focused on policy issues related to the Early Site Suitability Evaluation (ESSE). The Director's Forum was an opportunity for representatives of affected governments and Indian Tribes, interested parties, and the public to discuss policy, strategy, and plans for site evaluation, and the relationship of the ESSE report to the site evaluation process with DOE representatives. At the Director's Forum, DOE reiterated that the ESSE study is a contractor study and DOE has not determined whether OCRWM will implement the study's recommendations. OCRWM is now considering the written comments received from the NRC, the State of Nevada, and the counties of Clark, Esmeralda, and Lincoln, Nevada, as well as the substance of the discussions at the Forum, in order to evaluate ESSE and to formulate policy decisions on site evaluation.

Public outreach continues to be an integral component of DOE's effort in introducing site characterization and nuclear waste disposal concepts to the public. Numerous tours of Yucca Mountain were conducted for the public and other interested parties. Workshops and presentations on programmatic and technical aspects of the Yucca Mountain Site Characterization Project (YMP) were provided by YMP staff members at the Yucca Mountain Information Office (YMIO). In addition, the YMPO coordinated the schedule for an exhibit of a 25-ton transport container which was viewed by approximately 800 people at the YMIO in Las Vegas, Nevada, and other locations in the Las Vegas area. YMP Public Update Meetings were held in Nevada with participation by the State of Nevada. Substantive interactions with the NRC, and oversight organizations, such as the NWTRB and the NRC's Advisory Committee on Nuclear Waste (ACNW), continued.

The OCRWM international program continued to work in cooperation with a number of countries and international organizations to share advances in technology, science, and public education in nuclear waste disposal. Cooperative testing efforts with Switzerland and Canada involving borehole logging technology development, studies of fractured rock hydrology, and radionuclide transport and retardation continued. Technical work scopes for cooperative studies with Sweden were developed and are in the final stages of review and approval. Natural analog studies of sites in Canada continued as a significant component of the international program, and prospective sites in Africa, Australia, and New Zealand are being considered for future studies. Final reports for the International Stripa Project were completed, and arrangements have been completed for a symposium, presenting the results from the ten-year collaborative international effort, to take place in Sweden in October 1992.

PROGRESS REPORT #7

1.0 INTRODUCTION

1.1 PURPOSE AND SCOPE

In accordance with the requirements of Section 113(b)(3) of the NWPA and 10 CFR 60.18(g), DOE has prepared this report on the progress of site characterization activities at Yucca Mountain, Nevada, for the period April 1, 1992, through September 30, 1992. This report is the seventh in a series of reports that are issued at intervals of approximately six months during site characterization.

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

DOE's plans for site characterization are described in the Site Characterization Plan (SCP) for the Yucca Mountain site (DOE, 1988). More detailed information on plans for site characterization is presented in Study Plans for the various site characterization studies and their component activities. The SCP has been accepted by the NRC, State of Nevada, affected units of local government, other interested parties, and the public. DOE continues to respond to all written inquiries received on the site characterization program. Changes to the statutory SCP are documented in the Yucca Mountain technical baseline documents.

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

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

The PR consists of two main sections: (1) an introductory section, and (2) a section on the status of site characterization activities, which follows the format of SCP Chapter 8. Section 3 (Schedule) contains the current summary schedule for the repository program. In addition, Section 4 (Epilogue) provides a brief summary of some key events that occurred after the close of the reporting period on September 30, 1992. A list of acronyms is also provided at the back of this report.

The documents cited in the text are available for inspection at DOE public reading rooms in Washington, D.C., and Nevada. They can also be obtained through DOE's Office of Scientific and Technical Information (OSTI) at Oak Ridge, Tennessee.

1.2 BACKGROUND INFORMATION

The Yucca Mountain site has not been selected for a repository. Rather, it has been designated by the U.S. Congress as the only site to be characterized. In accordance with the requirements of Section 113 of the NWPA, DOE is conducting a program of detailed investigations and suitability evaluations at the Yucca Mountain site to determine whether it is suitable for development as a high-level radioactive nuclear waste repository. The plans, activities, and results of this program will be reviewed by the State of Nevada, the NRC, the NWTRB, and other external organizations.

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

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

Surface-based characterization studies at Yucca Mountain have been in progress since May 1986, when the site was approved for characterization. Initially, these studies consisted of non-surface-disturbing testing in existing exploratory boreholes and wells; analyses of, and experiments with, rock and water samples; geophysical surveys; meteorological, hydrologic

and seismic monitoring; and geologic mapping. Expanded surface-based activities, as detailed in Section 2.2 of this report, began in January 1992.

According to the current program schedule (see Section 3.0), all site characterization activities are to be completed by the end of the year 2001. During site characterization, a performance confirmation program, as required by 10 CFR 60.140, will be initiated and, as part of this program, selected surface-based and underground tests will be continued beyond the site characterization phase until permanent closure, if the site is found to be suitable. Appropriate new tests and monitoring would also be initiated and continued while DOE is building the repository and during waste emplacement until such time as there is adequate confidence that the potential repository is performing as expected and the NRC issues a license amendment to permanently close the repository.

1.2.1 Site Characterization

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

A 5.6 Richter magnitude earthquake occurred near Yucca Mountain on the morning of June 29, 1992. The epicenter was located approximately 20 km (12 mi) from the potential repository block. YMPO's Field Operations Center sustained minor damage from surface ground motion. Project personnel worked around the clock until July 14, to deploy portable seismographs to record aftershocks and process incoming data from the SGBSN. Rapid response enabled USGS and UNR scientists to gather additional information relevant to understanding the neotectonics of the area and the geometry of faults at depth. A white paper titled "The Little Skull Mountain Earthquake of June 29, 1992" was prepared by USGS/UNRSL staff and contained basic parameters of the earthquake and a description of its effects in the immediate area. The white paper was provided to the NRC, the NWTRB, and the State of Nevada. Although it was among the largest earthquakes known to have occurred in southern Nevada, the accelerations (1 g) recorded were well within proposed design limits (0.4-0.6 g) for the surface waste-handling facilities.

At DOE's request, the NAS/NRC established the Panel on Coupled Hydrologic/Tectonic/Hydrothermal Systems at Yucca Mountain to evaluate (1) if the water table had risen in the geologically recent past to the level of the proposed repository, and (2) if the water table is likely to rise in the manner described in a DOE staff scientist's report within the 10,000 year period covered by the regulations. The NAS/NRC panel released its report entitled "Ground Water at Yucca Mountain: How High Can It Rise?" (Raleigh et al., 1992) in April 1992. The 17-member panel, convened by the Council, examined the theory purporting that significant ground-water upwellings as the result of seismic activity (i.e.,

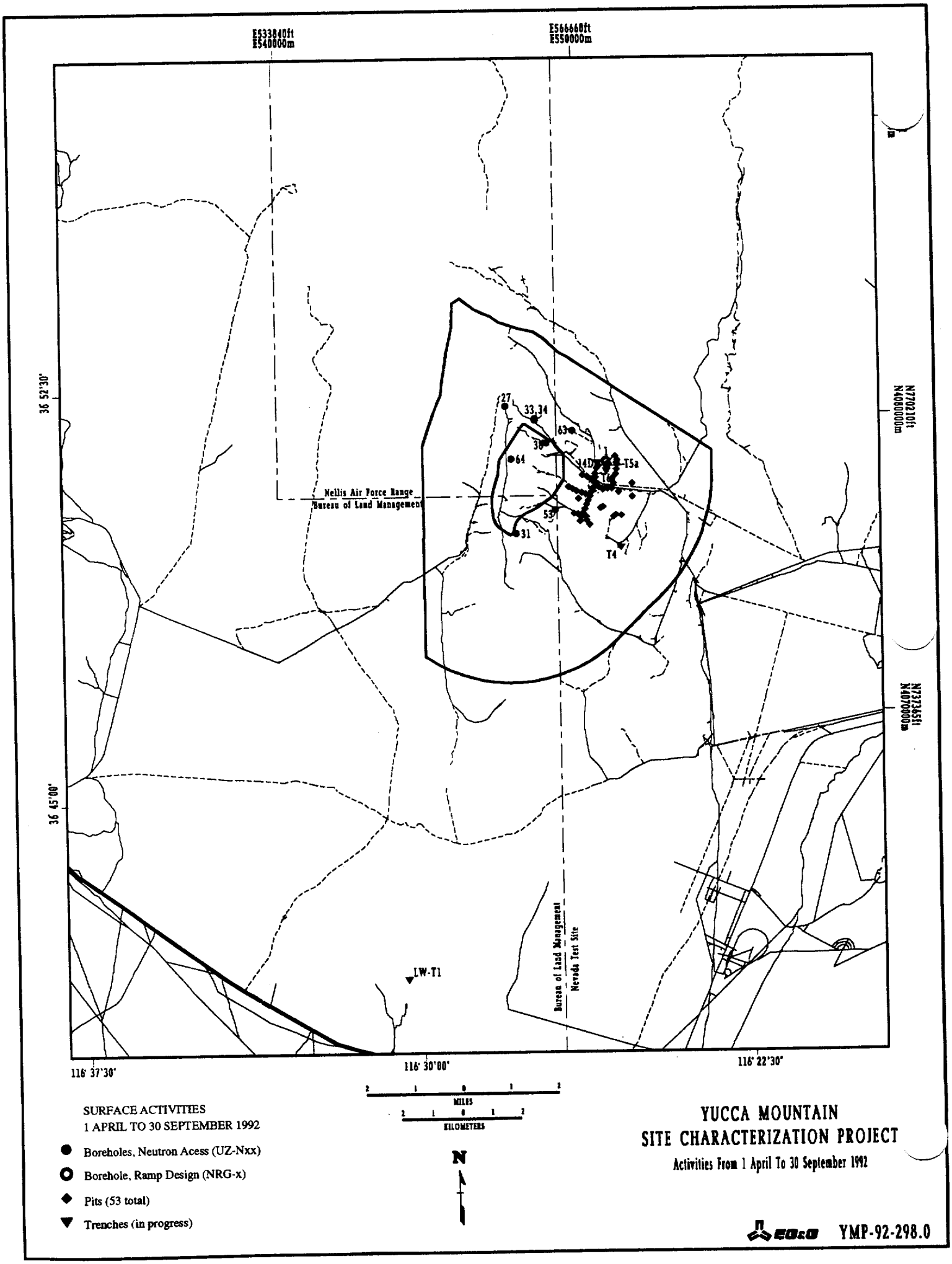
seismic pumping) had occurred in the past and could occur in the future. Ground-water upwellings to the level of the proposed repository could affect the suitability of the site. The panel concluded that, (1) geologic evidence does not support the conclusion that ground water has risen to the level of the potential repository, or even close to it, (2) the evidence convincingly shows that mineral deposits, purported (Szymanski, 1989) to be evidence for an upwelling phenomenon, in fact indicate that they were formed by soil-forming processes operative in desert climates, and (3) no credible geologic mechanism was/is capable of rapidly raising the water table to reach the potential repository level.

During the reporting period, OCRWM forwarded the Floodplain Assessment and Statement of Findings for the ESF-based activities and the cumulative impacts of the ESF-based activities and the surface-based activities for publication in the Federal Register. The release of the document for publication was in accordance with Executive Order 11988, "Flood Plain Management" and 10 CFR 1022 "Compliance with Floodplains/Wetlands Environmental Review Requirements." The conclusion of the findings was that there would be no significant impact on floodplains as a result of ESF activities, and no cumulative impacts.

A Free Use Permit for extraction of sand and gravel from Fortymile Wash was granted by the BLM on May 20, 1992. The permit allows DOE to excavate 351,693 cu m (460,000 cubic yards) of borrow material for use in the construction of roads, drill pads, and ESF pads. In addition, an Air Registration Certificate for the gravel screen operation located in Fortymile Wash was granted by the State of Nevada on June 8, 1992.

The Nevada Department of Conservation and Natural Resources issued a permit modification for the underground injection control permit. The modified permit authorizes DOE to inject water and various tracers, including gas, into 53 wells located at the Yucca Mountain site. Also, the YMPO submitted four water appropriation applications which have been approved by the Nevada State Engineer. These permits will increase the ground-water appropriations from Well J-13, to modify the place of use for water appropriated for Well J-13, to use Well J-12 as a backup for Well J-13, and change the place of use of ground water appropriated from Well VH-1. The YMPO also requested a time extension for drilling hole UE-25UZ#16.

Figure 1.1. Site Characterization activities undertaken during the reporting period in the Yucca Mountain area including the Lathrop Wells volcanic center. "Circular" areas enclosed by black lines on Yucca Mountain define the following: large area = boundary of the accessible environment; small area = potential repository block. Large area is the approximate location shown in Figure 1.2.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116 30'00"
116 22'30"
27
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64
14D
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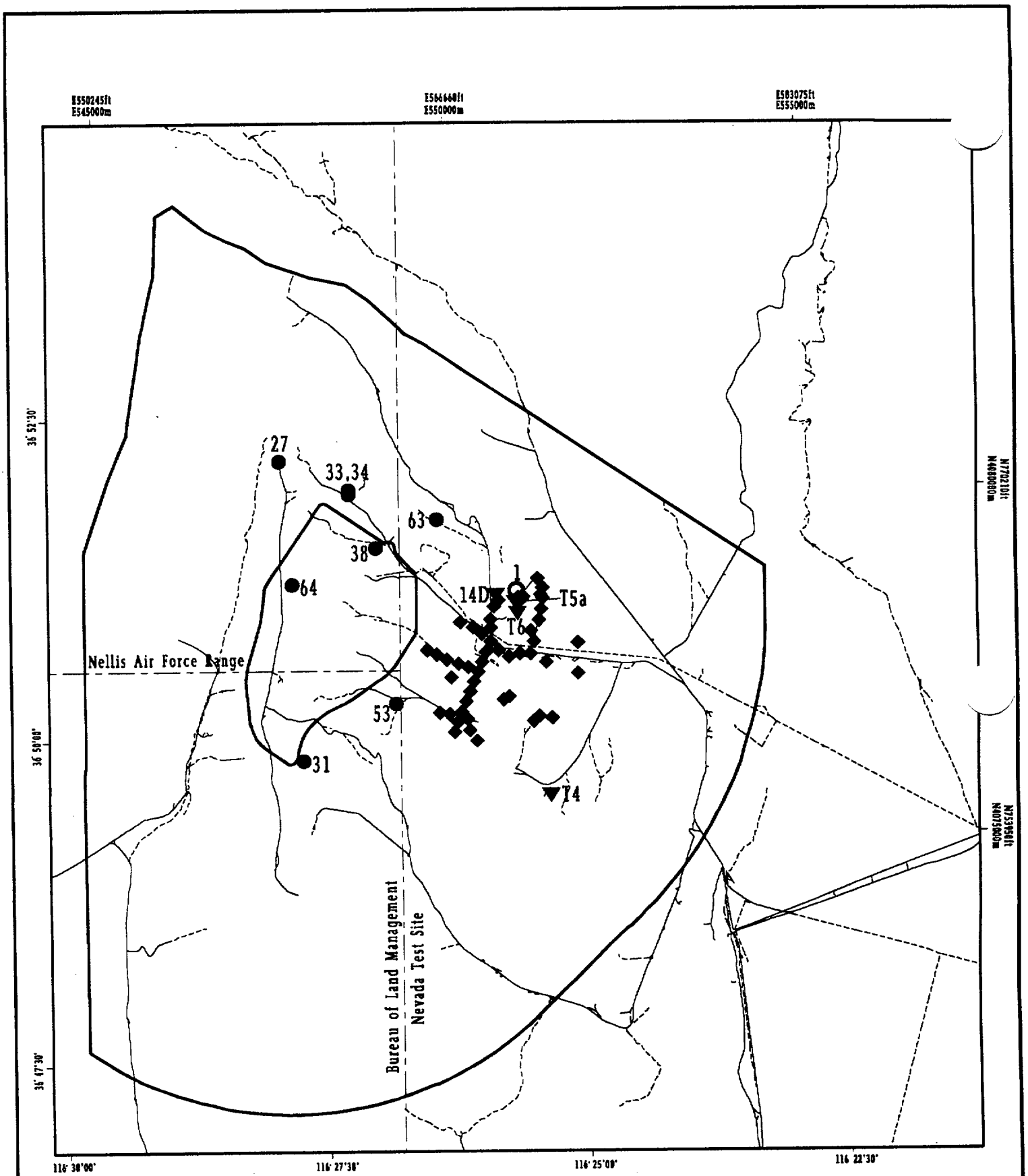
53
31
T4
LW-T1
Nellis Air Force Range
Bureau of Land Management
Bureau of Land Management
Nevada Test Site
MILES
KILOMETERS
N
SURFACE ACTIVITIES
1 APRIL TO 30 SEPTEMBER 1992
Boreholes, Neutron Acess (UZ-Nxx)
Borehole, Ramp Design (NRG-x)
Pits (53 total)
Trenches (in progress)
YUCCA MOUNTAIN
SITE CHARACTERIZATION PROJECT
Activities From 1 April To 30 September 1992
EG&G
YMP-92-298.0

Figure 1.2. Site Characterization activities undertaken during the reporting period in the area of the Yucca Mountain site accessible environment. Conceptual Controlled Area Boundary = boundary of the accessible environment; Conceptual Perimeter Drift Boundary = potential repository block.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116° 25'00"
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27
33,34
63
38
64
1
14D
T5a
T6
Nellis Air Force Range
53
31
T4
Bureau of Land Management
Nevada Test Site
MILES
KILOMETERS
N
SURFACE ACTIVITIES
1 APRIL TO 30 SEPTEMBER 1992
Boreholes, Neutron Acess (UZ-Nxx)
Borehole, Ramp Design (NRG-x)
Pits (53 total)
Trenches (in progress)
Contour Interval 200 Feet
YUCCA MOUNTAIN
SITE CHARACTERIZATION PROJECT
Activities From 1 April To 30 September 1992
EG&G
YMP-92-297.0

PROGRESS REPORT #7

YMPO continued to make progress in activities related to the ESF Title II design. An independent technical review of the 50-percent-complete Design Package 1A (the first of ten design packages which includes the north portal, north portal site preparation, and surface facilities), was completed on April 16, 1992. Comments arising during the review were submitted to DOE management and were resolved. Subsequently, a 90-percent-complete Design Package 1A was released for management and independent technical review resulting in the submission of additional comments. As of September 30, 1992, only nine of these comments were unresolved. Portions of the design are currently undergoing design verification. The completion of design verification activities and subsequent submittal to DOE for approval and construction is expected in the early portion of the next reporting period.

A request for proposal (RFP) to select an ESF construction contractor was released by DOE at the end of March 1992. Technical, management, and cost proposals were submitted by several bidders during the reporting period, and the proposals are currently being evaluated by the Source Evaluation Board (SEB). It is anticipated that the SEB will recommend an ESF construction contractor early in calendar year 1993.

The surface-based testing program advanced significantly with the beginning of core drilling with the new LM-300 drill rig. The LM-300 utilizes dry drilling and coring techniques to avoid contaminating the rocks and ground water with drilling fluids. The first borehole to be drilled with the LM-300, UE-25UZ#16, was spudded (start of actual drilling) on May 27, 1992. As of September 30, 1992, UE-25UZ#16 had been cored to 205 m (673 ft) and reamed to a depth of 195 m (639 ft). This borehole is expected to reach its final depth just below the water table by March 1993. Borehole UE-25UZ#16 will be used to help characterize the UZ as well as to provide samples and access for other studies. Other drill rigs, including the CME-850, were used to complete Phase I and begin Phase II drilling of neutron access boreholes, which are being used to help determine present-day surface-water infiltration rates and processes. Boreholes USW UZN-38, USW UZN-64, USW UZN-27, and USW UZN-53 completed the suite of 12 boreholes for Phase I. Phase II, which includes an additional 12 boreholes, was begun with the completion of UE-25UZN#63, USW UZN-31, USW UZN-33, and USW UZN-34. The 24 boreholes of Phases I and II complement an existing suite of 74 boreholes.

Surface-based excavations continued to provide samples and exposures to aid geologic mapping. Through June 1992, 28 soil test pits for surficial geologic mapping and four trenches (MWV-T5, MWV-T6, MWV-T14D, and MWV-T4) to study Quaternary faulting were dug in Midway Valley. Interim results of Quaternary fault studies were presented during an NRC site visit September 17 and 18, 1992. In August 1992, four natural bedrock surfaces were cleared at Busted Butte to expose Quaternary faults. Two trenches in Crater Flat (CF1 and CF8) were deepened and cleared to map Quaternary faulting and a third (SC1)

was excavated across the Solitario Canyon fault. Bedrock excavation was begun in September 1992, at Fran Ridge Test Pit No. 1, for facilitating bedrock fracture network mapping. A major box trench was completed by expanding and deepening trench 14D to look for hidden splays of the Bow Ridge fault and to check for possible strike-slip movement.

Construction of a large trench at the Lathrop Wells volcanic center was started on September 8, 1992. The purpose of the trench is to expose stratigraphic relationships including a buried lava flow, pyroclastic units, and possibly a soil. The exposures will be studied to help further define the geochronology of the Lathrop Wells volcanic center. The trench and the quarry at the Lathrop Wells volcanic center were included on a field trip conducted by YMPO in conjunction with an NWTRB Structural Geology & Geoengineering Panel meeting convened to discuss progress since March 1991 on the issue of volcanism.

YMPO directed the Civilian Radioactive Waste Management System Management and Operating (CRWMS M&O) Contractor to study the systems implications of thermal loading options for the potential repository. The focus of the study was to identify the information that will aid the decision-making process when site characterization data are available. A workshop on Repository Thermal Design Strategy was held August 20-21, 1992, in Las Vegas, to define a method for establishing repository thermal characteristics in the Advanced Conceptual Design (ACD). As an outcome of the workshop, a Thermal Loading Task Force was established to prepare an action plan to prioritize research needs to allow an early decision on the thermal load of the repository. Task teams were designated to address specific issues (radionuclide transport, corrosion, PA, operational issues, and thermal/mechanical effects) and to identify information needs necessary for either acceptance or elimination of specific thermal scenarios. A preliminary draft report of the Thermal Loading Task Force was prepared and distributed to the task teams for review. A final report is expected to be submitted to YMPO early in fiscal year (FY) 1993.

The initial Total System Performance Assessment (TSPA) analyses were completed and documented by SNL and the Pacific Northwest Laboratory (PNL) during the reporting period. The SNL analysis entitled "TSPA 1991: An Initial Total-System Performance Assessment for Yucca Mountain" (Barnard et al., 1992) was published. The PNL report "Preliminary Total-System Analysis of a Potential High-Level Nuclear Waste Repository at Yucca Mountain" (Eslinger et al.) is in final YMP program review. Both initial TSPA reports provide sections recommending areas of future work and topics that should be addressed in future TSPA analysis.

According to the SNL TSPA, the estimate of gaseous releases of carbon-14 (C-14) exceeds the Environmental Protection Agency (EPA) limit (as outlined in 40 CFR 191) when one particular model is used to compute the rate at which radionuclides are mobilized from the waste packages. All other categories modeled by the TSPA (human intrusion, igneous intrusion, and gaseous and aqueous flow and transport) do not exceed the EPA limits. It

should be recognized that these results reflect considerable uncertainties and conservatism. However, the SNL TSPA demonstrates the capability to obtain "abstracted" representations of complex features, events, and processes (FEPs) and to allow estimations of the behavior of a total repository system.

1.2.2 Programmatic developments in support of site characterization

Preferential pathways for ground-water flow and radionuclide transport in both the saturated zone (SZ) and UZ represent key targets for the site characterization program at Yucca Mountain. A joint meeting of the Geochemistry Integration Team (GIT) and Hydrology Integration Team (HIT) was held on June 9-11, 1992, to address the subject of "Preferential Pathways: Definition and Detection." Sixty participants from YMPO and participant organizations attended the meeting and considered questions relevant to preferential pathways in the shallow and deep UZ, SZ, and all zones under postclosure conditions. The participants developed a series of recommendations for focusing site characterization efforts to detect preferential pathways. These recommendations will be forwarded to YMPO for consideration. The workshop was very effective in promoting communication among the participants, and in focusing more closely on characterization needs for preferential pathways. Both the GIT and HIT anticipate sponsoring additional workshops that will focus on specific site characterization issues and will continue to foster integration among the YMP participants.

The EPA is currently proposing to repromulgate 40 CFR 191, the EPA standard for management and disposal of high-level and transuranic waste. In a December 20, 1991, meeting between high-level EPA and DOE management, DOE offered to provide technical assistance to EPA in developing a technical basis for repromulgation. This assistance was provided to the EPA in the report "Technical Assistance to the U.S. Environmental Protection Agency on 40 CFR Part 191" (DOE, 1992b) on August 10, 1992. Among other recommendations, the report proposed that scenarios for human intrusions be considered in a more qualitative manner and that a repository's releases be expressed as cumulative curies <u>or</u> collective doses for 10,000 years. Unlike the current curie limits, the collective doses would be more amenable to site-specific applications while providing the same level of protection as the curie limits. The report also recommended that EPA either relax its release limits for C-14 (as they would apply to C-14 dioxide), regulate C-14 under a more equitable regulation, or not regulate it at all. In addition, DOE provided example regulatory language illustrating how the proposed revision might be incorporated into the standard. Technical and regulatory justification for the proposed revision and details of the technical analysis that support the proposed revision were also provided. The proposed rule is expected to be published in the <u>Federal Register</u> during 1993. The EPA Science Advisory Board (SAB) reviewed the issue of potential release of gaseous C-14 from a potential repository located in a UZ. The SAB report is expected to be completed by the fall of 1992, with a final report to be issued early

in 1993. In addition, the NAS/NRC's Board on Radioactive Waste Management (BRWM) held a workshop on September 23-24, 1992, to evaluate the technical information and analyses provided by the DOE to support the proposed revision in the standard. The BRWM is expected to issue its report in late 1992.

On May 7, 1992, DOE conducted the first Director's Forum which focused on policy issues related to ESSE. The purpose of the ESSE study, which was conducted by a team of experts from many of DOE's participants and contractors, was to provide an early assessment of the suitability of the Yucca Mountain site using DOE's General Siting Guidelines as promulgated in 10 CFR 960. A review by an independent Peer Review Panel of the ESSE draft report containing the analyses, conclusions, and recommendations of the ESSE team was completed in November, 1991. The final ESSE report (Younker et al., 1992) and report of the Peer Review Panel (Albrecht et al., 1992) was submitted to DOE and released for public review and comment on February 21, 1992. The Director's Forum was an opportunity for representatives of affected governments and Indian Tribes, interested parties, and the public to discuss policy, strategy, and plans for site evaluation, and the relationship of the ESSE report to the site evaluation process with DOE representatives. At the Director's Forum, DOE reiterated that the ESSE study was a contractor document and DOE has not determined whether OCRWM will implement the study's recommendations. The Public Comment period on the ESSE report was extended to July 15, 1992. Written comments have been received from the NRC, the State of Nevada, and Clark, Esmeralda, and Lincoln Counties, Nevada. OCRWM is now considering the written comments, as well as the substance of the discussions at the Forum to evaluate ESSE and to formulate policy decisions on site evaluation.

The OCRWM international program continued to work in cooperation with a number of countries and international organizations to exchange information of mutual interest, develop consensus on common issues, and develop and conduct cooperative activities of mutual benefit. During the reporting period, the technical tasks in the five-year cooperative testing agreements established between the OCRWM program and the waste management programs in Canada and Switzerland were implemented. The technical tasks in the Canadian agreement involve field and laboratory testing, instrumentation development and testing, engineered barrier performance, PA, and natural analog studies. Some of the testing under the Canadian agreement makes use of unique facilities, including the borehole calibration laboratory and the Canadian Underground Research Laboratory in Manitoba. The cooperative agreement with Switzerland involves fracture flow and two-phase flow hydrological studies, geophysical technique development, and laboratory radionuclide retardation studies. Most of the cooperative testing under the Swiss agreement is being performed in the Grimsel Pass underground facility in Switzerland.

The international program has also developed technical tasks for a five-year cooperative testing program with Sweden, to make use of the underground Hard Rock Laboratory being

developed in Sweden. Technical work scopes for cooperative studies have been developed and the agreement is in the final stages of review and approval. It is anticipated that the agreement will be signed and implemented in FY 1993.

Examination of a number of potential sites for natural analog studies, notably in Africa (the Oklo mine in Gabon), Australia (the Alligator River Project), and New Zealand continued. Criteria to guide the evaluation of prospective natural analog studies have been developed so that analog studies can be evaluated in relation to their application to repository performance.

Final reports for the International Stripa Project have been completed, and a final symposium dealing with the results from this ten-year collaborative international effort will take place in Sweden in October 1992.

There were substantive interactions with the NRC, including informal technical exchanges on various topics such as the "three-bucket approach" to demonstrate compliance with 40 CFR Part 191, renegotiation of the 1986 Level-of-Detail Agreement for Study Plans, preparation of ESF design review, and a site visit to the Midway Valley trenches to discuss Quaternary faulting. The "three-bucket approach" is an NRC staff proposal to separate possible scenarios for repository performance into three categories based on their probability of occurrence.

In addition, DOE and the NRC held an informal technical exchange on the content of a Topical Report that DOE is preparing on the subject of erosion rates and processes at Yucca Mountain as part of the Issues Resolution effort. During the technical exchange, the NRC agreed to provide technical comments on Topical Reports, but noted that any resolution prior to licensing was at the NRC staff level and was based on what was known at the time. Such informal resolution is not binding on the Commission itself, however. DOE expects to issue the Topical Report on Erosion late in January 1993.

Interactions between OCRWM and the NWTRB were held for discussions on assorted topics such as ESSE, TSPA, surfaced-based testing and drilling program, seismic activity at Little Skull Mountain, role of the CRWMS/M&O, natural and archeological analogs, engineered barrier system (EBS), waste acceptance, and volcanism.

In August 1992, the Office of External Relations (OER) of OCRWM completed a draft OCRWM American Indian Policy Implementation Plan Outline. The plan was developed in support of the Secretary's Policy of ensuring that tribal rights and interests are identified and considered in pertinent decision-making. The OCRWM American Indian Policy Implementation Plan will have an overview section on OCRWM Program coordination, and three separate sections, corresponding to each of the three Radioactive Waste Program Elements: Monitored Retrievable Storage (MRS), Disposal (Repository), and Transportation.

Work is currently under way on all three sections, with the YMPO having submitted a draft for the Disposal Element section to OER for review and incorporation. Along with the development of the Implementation Plan, consultation with respective Tribes associated with the YMPO continued as well (see PR Section 2.1.11).

Public outreach continues to be instrumental in introducing site characterization and nuclear waste disposal concepts to the public. Fifty-two tours of Yucca Mountain were conducted for 2,700 members of the public and other interested parties such as the Assistant Secretary for Nuclear Energy, members of the United Kingdom Radioactive Waste Management Advisory Committee Study Team, representatives from the French Utilities, NBC Nightly News, members of Edison Electric Institute (EEI), and attendees to the International High-Level Radioactive Waste Management (IHLRWM) Conference. Numerous programmatic and technical workshops and presentations were provided by YMP staff members at the YMIO. YMP Public Update Meetings were held in Pahrump, Henderson, and Carson City, Nevada, with participation by the State of Nevada.. These meetings were attended by a total of approximately 325 people. The meetings were structured to allow the public to have more of an opportunity to communicate with YMP staff.

2.0 STATUS OF SITE CHARACTERIZATION

2.1 PREPARATORY ACTIVITIES

2.1.1 Quality Assurance program

The OCRWM Office of Quality Assurance (OQA), Yucca Mountain Quality Assurance Division (YMQAD) has implemented a comprehensive audit program. During FY 1992, a minimum of three audits per participant and three audits of the YMPO were performed. Collectively, the three audits covered all applicable quality assurance (QA) program elements of the audited organization.

During the reporting period, YMQAD conducted 11 audits. The audits were conducted of Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL), Raytheon Services Nevada (RSN), Reynolds Electrical and Engineering Company, Inc. (REECo), Sandia National Laboratories (SNL), Technical and Management Support Services (T&MSS) (2), USGS (2), and YMPO (2). The audits evaluated the QA programs for compliance to OCRWM requirements and effectiveness of QA program implementation. It was determined by the respective audit teams that the participants and YMPO are implementing effective QA programs.

YMQAD conducted 24 surveillances. The surveillances were conducted to evaluate specific site characterization related activities and as follow-up to verify corrective actions taken to close open deficiencies. It was determined that the participants are implementing effective QA programs and that corrective actions have been taken to close open items.

Resolution work continues on the comment and review phase of the Quality Assurance Requirements Document (QARD).

Reorganization of the YMQAD was effectively implemented in the areas of QA Audits, QA Surveillances, QA Programs, Engineering, and QA Field and Test activities. The new organization structure allows for focused oversight on all ongoing site characterization activities.

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

2.1.2 Exploratory Studies Facility (ESF) Design and Construction

The ESF Design Requirements (ESFDR) document contains functional requirements, performance criteria, constraints, and assumptions for all systems and subsystems within the scope of the ESF. The latest revision to this document was effective July 22, 1992.

The ESF Title I Design Summary Report (YMP/CC-0019) provides an overview and record of preliminary engineering (including design drawings) and YMP management planning, reflecting completed Title I design for the ESF. Revision 0 was not controlled by the YMP Change Control Board (CCB). However, revision 1 became CCB-controlled on May 6, 1992. This revision reflects the change in name from Exploratory Shaft Facility to Exploratory Studies Facility and the change in ESF configuration based on the ESF Alternatives Study (ESFAS) (Dennis, 1991).

A phased approach to ESF Title II design has been adopted by the program. Design activities continued on Package 1A during the reporting period. Design Package 1A consists of site preparation, utilities, and the Tunnel Boring Machine (TBM) launching chamber at the north portal of the ESF. Ninety percent management and technical reviews were successfully completed during July and August 1992. Design verification was started late in the reporting period, with completion anticipated early in FY 1993.

RSN performed a study to determine the required diameter of the north ramp opening. The ramp sizing study was completed on September 30, 1992, and the report will be reviewed during October and released early in FY 1993.

The M&O ESF Design team continued readiness preparations during the reporting period. The ESF Design Transition Plan was approved and released and the ESF Design Readiness Review was held during the week of September 14-18, 1992. Transition of the responsibility for ESF Design from RSN to the M&O is scheduled for October 1, 1992.

The ESF Construction Management (CM) Plan was approved and issued and the ESF CM team underwent readiness review during the week of September 14-18, 1992. The CM team also participated in the overall YMPO Construction Readiness Review for the start of ESF construction. This review is a prerequisite to the Energy Systems Acquisition Advisory Board (ESAAB) approval for the start of construction. During the period, the CM team worked on the ESF Operations Plan, the ESF Maintenance Plan, and the Job Package required for construction of Design Package 1A.

Site preparation for the ESF is scheduled to begin on November 30, 1992. This activity will consist of construction of a portion of Design Package 1A. The north portal pad, access road, and TBM launch chamber will be developed, as will a portion of the topsoil stockpile

and mined rock storage area. It is planned that design and construction of the Nevada Test Site (NTS) power system upgrades and a 138-kV power system will be accelerated in FY 1993.

2.1.3 OCRWM initiatives in surface-based and underground testing

2.1.3.1 Early Site Suitability Evaluation (ESSE)

The ESSE report is a contractor evaluation of the technical suitability of Yucca Mountain, Nevada, as a potential site for a mined geologic repository for the permanent disposal of high-level radioactive waste (HLRW). The report was reviewed by an external peer review panel, modified on the basis of their comments, and issued in January 1992 (Younker et al., 1992). On February 21, 1992, OCRWM released the report for public review and comment. On April 7-8, 1992, the DOE provided the NWTRB with a briefing that contained an introduction and overview of the ESSE process and results.

On May 7, 1992, an OCRWM Director's Forum was conducted in Chicago, Illinois. At the meeting, a site evaluation policy, strategy, and plans were presented to the interested parties. Also presented at the meeting was an overview of the ESSE that included the objective of the ESSE task, the approach for evaluating the proposed site against the siting guidelines of 10 CFR 960, the peer review structure, and a summary of the guideline evaluations.

On July 15, 1992, the public comment period for the ESSE was closed. Comments were submitted by the NRC, the State of Nevada, and Lincoln, Clark, and Esmeralda Counties, Nevada. Some of the comment topics included the evaluation methodology, regulatory guidelines, emergency procedures, transportation issues, the issue resolution process, the off-site impact of operations, the region's population density, and the site's environmental quality, socioeconomics, tectonics, natural resources, rock characteristics, and hydrology. The comments were reviewed and members of the ESSE core team were assigned responsibility for preparing responses to the comments. A DOE response will be provided to those submitting comments and to other affected units of government during 1993.

2.1.3.2 Integrated Test Evaluation (ITE)

The ITE was formally initiated in March of 1992. This effort focused on providing a decision framework to prioritize the site testing program based on several different criteria. The criteria used in evaluating the effectiveness of tests included ability to provide or determine the following: (1) site suitability; (2) regulatory compliance; and (3) scientific confidence. Costs of the tests were also included in the decision framework, but are not a

criterion for conducting the tests. In the ITE, tests were evaluated at the level of Study Plans, which were defined in the SCP. An executive summary, the decision framework, the initial ITE application of the model, and the ITE team recommendations were provided to YMPO to assist in test-planning and budget allocation decisions. The decision framework and its initial application were developed by a team of 11 members, representing six participant organizations. Team members were selected for their technical expertise and their broad program understanding. The ITE data base can be updated and the method can be used to reevaluate test priorities as site characterization progresses and DOE priorities change.

The ITE decision framework is based, in part, on the results and recommendations of previous studies, including the ESSE (Younker et al., 1992), the Calico Hills Risk/Benefit Analysis (CHRBA) (DOE, 1991), the ESFAS (Dennis, 1991), the Test Prioritization Task (TPT) (Mattson et al., 1991), and various TSPAs. Although each of these previous studies considered specific aspects of the site characterization program, none provided an integrated approach that evaluated tests with respect to the multiple reasons for testing, which in some cases are nontechnical.

Likewise, the 1992 ITE did not consider all the possible criteria for evaluating the priorities of tests. For example, tests that are primarily useful for building constituent confidence or that provide information for engineering design were not considered in the ITE analysis. However, the ITE provides the most comprehensive approach developed to date for prioritizing the site characterization program.

2.1.4 Permits

2.1.4.1 Compliance with federal environmental requirements

YMPO continues to work with the Federal agencies regarding necessary permits and clearance for all site characterization activities. This includes a floodplain assessment for the ESF and a free use permit for the excavation of sand and gravel. Consultations continue with Native American tribes and bands, as specified in the Programmatic Agreement with the Advisory Council on Historic Preservation.

Reports on water levels and spring-flow measurements continue to be sent to the Nevada State Engineer and the National Park Service on a quarterly basis, as stipulated in the water appropriation permit.

2.1.4.2 Compliance with state environmental requirements

During the reporting period the State of Nevada has issued to YMPO additional permits for water appropriation, air quality permits to construct, and approval to inject tracers in boreholes. The three water appropriation permits allow for the beneficial use of water not to exceed 1.0 cubic feet per second(102 m^3/h), and not to exceed 430.19 acre-feet annually. Air quality permits to construct were issued for four air compressors, a portable gravel screen, and a cone screen plant. The underground injection control permit, used for the C-well hydrologic tests, was modified to include approval to inject tracers in 50 additional boreholes.

YMPO has submitted reports for air quality monitoring in compliance with the permit for land disturbance and tracer use. The YMPO will continue to work closely with the State of Nevada regulatory agencies to satisfy permit conditions in a timely manner.

2.1.5 Land Acquisition

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

Twenty-three participant requests to initiate site characterization activity were processed during the reporting period. Nineteen of these requests have been completed and access authorization has been granted. The remaining four have been partially completed. These four requests are awaiting the results of the following actions: additional information from the requesters for soil test pits at Providence Mountain, California, and a pump test and water sampling program; a right-of-way application to the Stateline Resource Area Office of the BLM for trench excavations at Bare Mountain, Nevada; and a right-of-way application to the same office for a seismic reflection program. Additionally, four requests from the last reporting period are awaiting the results of the following actions: two rights-of-way applications to the Barstow Resource Area BLM office for surface water monitoring stations; two rights-of-way applications to the Barstow Resource Area BLM office for seismic stations; five rights-of-way applications to the Stateline Resource Area BLM office for seismic stations; and five rights-of-way applications to the Tonopah Resource Area BLM office for seismic stations.

2.1.6 Interactions with the NRC and oversight organizations

2.1.6.1 NRC Interactions

During the reporting period, YMPO participated in 13 interactions with the NRC, as listed below .

April 28-29, 1992	Technical exchange in Albuquerque, New Mexico, on technical and regulatory issues related to scenario development and screening, and construction of complementary cumulative distribution functions (CCDF)
April 30, 1992	Meeting in Rockville, Maryland, to discuss items of interest regarding QA
May 19, 1992	Management meeting in Rockville, Maryland, to negotiate and schedule DOE-NRC interactions through December 1992
May 27, 1992	Technical exchange in Rockville, Maryland, on DOE's annotated outline for a topical report on erosion at Yucca Mountain.
June 2, 1992	Management meeting in Rockville, Maryland, to renegotiate revisions to the "Procedural Agreement Between the Nuclear Regulatory Commission and the U.S. Department of Energy Identifying Guiding Principles for Interface During Geologic Repository Site Characterization"
June 3, 1992	Technical exchange in Rockville, Maryland, on the DOE's Mined Geologic Disposal System (MGDS) Annotated Outline for a license application and the NRC's Draft Regulatory Guide D-3003, "Format and Content for the License Application for the High-Level Waste Repository"
June 24, 1992	OCRWM Director's Briefing to the NRC on the status of implementation of the annotated outline and issue resolution initiatives.
July 16, 1992	Meeting in Rockville, Maryland, to discuss items of interest regarding QA.

July 22, 199	Technical exchange in Bethesda, Maryland, to discuss the use of the NRC's "three-bucket" approach for implementing the requirements of 40 CFR 191
July 23, 1992	Management meeting in Rockville, Maryland, to discuss the renegotiation of the May 7-8, 1986, Agreement on the Format and Content of Yucca Mountain Study Plans
August 25, 1992	Technical Exchange in Las Vegas, Nevada, and Vienna, Virginia, using the video-conference method to discuss NRC comments on Study Plan 8.3.1.8.1.1.
September 17, 1992	Meeting in Rockville, Maryland, to discuss items of interest regarding QA
Sept. 17-18, 1992	Site visit at Yucca Mountain to observe ongoing site characterization activities in the Midway Valley area.

In addition to the above interactions, the NRC Commissioner toured Yucca Mountain and the NTS on August 21, 1992.

Also during the reporting period, YMPO either attended or participated in five interactions with the ACNW in Bethesda, Maryland. These interactions included:

April 22-24, 1992	ACNW 42nd Meeting to discuss the use of a systems analysis ranking system for assessing performance.
May 28-29, 1992	ACNW 43rd meeting to discuss changes to 10 CFR 72, design basis accident dose limits for HLRW, revised hazard ranking system, and DOE reports on the ESF alternatives study.
June 17, 1992	ACNW Working Group Meeting to discuss the NRC Staff review of the ESSE.
July 29-30, 1992	ACNW 45th Meeting to discuss, review, and comment on the NRC Staff Technical Position on Repository Design for Thermal Loading of a Geologic Repository, and Systems Analysis Approach to Reviewing the Overall High-Level Waste Program.

Sept. 22-25, 1992	ACNW 46th Meeting to discuss C-14 release limits, and the proposed guide on 10 CFR 20 As Low As Reasonably Achievable (ALARA) criteria.

2.1.6.2 NWTRB Interactions

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

April 7-8, 1992	Full Board Meeting in Dallas, Texas, on ESSE and TSPA
May 11, 1992	EBS Panel meeting in Hanford, Washington on defense high-level waste management activities at Hanford
May 12, 1992	Tour of Hanford site facilities
May 13, 1992	EBS Panel meeting in Idaho Falls, Idaho, on defense high-level waste activities at Idaho National Energy Laboratory (INEL)
May 14, 1992	Tour of INEL
July 7-8, 1992	Full Board Meeting in Denver, Colorado, on DOE's strategy for determining suitability of Yucca Mountain and the M&O's role and scope of current and planned activities in Vienna, Virginia and Las Vegas, Nevada
Sept. 14-15, 1992	Structural Geology and Geoengineering Panel meeting in Las Vegas, Nevada, to update volcanism studies
Sept. 16, 1992	Field trip to the Yucca Mountain area (Crater Flat) to observe volcanism investigations.

2.1.7 Resolution of NRC Open Items

The NRC evaluated DOE responses to the Site Characterization Analysis (SCA) (NRC, 1989) in a letter dated July 31, 1991. Of the 198 objections, comments, and questions in the SCA, the NRC closed 59 in their evaluation and established the remaining 139 as open items. The DOE is aware of these open items and continues to work toward their resolution. Open items will be addressed by DOE as site characterization and other programmatic

developments provide information such that these concerns can be resolved. DOE will supply the NRC with documentation to support the basis for resolving SCA open items.

During this reporting period, documentation has been supplied to the NRC to resolve the following open items: comments 42 and 43 (letter dated July 23, 1992); comments 100, 104, 106, 108, 110, 112, and 113 (letter dated August 31, 1992); and question 31 (letter dated September 16, 1992).

In total, DOE has supplied documentation to resolve Objection 1, along with 20 comments and three questions. Table 2-1 lists the status of NRC open items. A list of possible ways of addressing each remaining open item is also provided. Comment numbers not listed are closed. The NRC had not yet responded to the documentation supplied by DOE on the subject open items as of September 30, 1992.

2.1.7.1 Comments on SCP Study Plans

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

SCA numbers not listed are considered by the NRC to be closed. Asterisks (*) show open items that DOE considers closed and that require concurrence by the NRC.

#KEY TO POSSIBLE/PROPOSED METHOD OF RESOLUTION:

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

PR = Site Characterization Progress Reports

TABLE 2.1 STATUS OF SCA OPEN ITEMS

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

TABLE 2.1 STATUS OF SCA OPEN ITEMS

SCA OPEN ITEM		SUMMARY OF OPEN ITEM	RESOLUTION STATUS # (see codes, page 2-12)
COMMENT	24	Standard solubility approaches are not adequate for thermodynamic properties of zeolites	1, 5
	25	Waste package degradation products and interactions between radionuclides on sorption	5
	31	Some parameters for speciation, kinetics, and matrix diffusion are not planned	5
	32	Integration of geophysics and discussion is not included	5
	33	Engineering rock characteristics are not integrated into three-dimensional models	5
	*34	Integration of drilling program	-
	*35	Adequacy of lithological, structural, and drifting activities to characterize the site	-
	36	Adequacy of location of perimeter drift and the concentration of faults	2, 11
	*42	Adequacy of evaluation of escarpment retreat	-
	*43	Adequacy of numerical goals in erosion, postclosure tectonics, and preclosure tectonics performance assessment tables	-
	45	Volcanic rate calculations independent of underlying volcanic-tectonic processes	1, 5
	47	Relationship of postclosure tectonics to the waste package and EBS requirements	5
	48	Use of fault slip rates on the repository facilities are not conservative	1, 5
	49	Investigations on basaltic volcanism will fail to meet overall system performance	5, 9, 10
	51	Adequacy of geophysics to determine deep and shallow crustal features	5, geophysics White Paper

TABLE 2.1 STATUS OF SCA OPEN ITEMS

SCA OPEN ITEM		SUMMARY OF OPEN ITEM	RESOLUTION STATUS # (see codes, page 2-12)
COMMENT	52	Use of geophysics in evaluating basaltic volcanism	5
	53	Adequacy of natural resource assessment; consideration of ore deposition models	5
	55	Adequacy of geostatistical approach to geomechanical and thermal properties	1, 4, 5
	56	Validation of models for mechanical and thermal properties	5, 9
	*57	Design verification does not consider alternate methods of excavation . .	-
	59	Preclosure tectonics activities to be performed and timing of activities	4
	60	Adequacy of preclosure design and performance goals and characterization parameters	1, 5, 9
	61	Assumption that future faulting will follow previous faulting	5
	62	Use of standoff distances in preclosure tectonics for surface facilities	5
	63	Use of pre-existing and unavailable information for the preclosure tectonics program and the surface facilities	5, 9
	64	Adequacy of study of faults for design and performance	2, 6
	66	Release via a single event (10,000 year cumulative slip earthquake) .	5
	68	Adequacy of treatment on detachment faulting affects	5
	69	Synthesis of data on the northwest trending of faulting	2, 5
	71	Adequacy of technologies in assessing faulting for construction, operation, and closure	2, 3, 4, 5
	*72	Adequacy of seal program	-
	73	Adequacy of required backfill hydraulic conductivity	1, 10
	74	Adequacy of seal testing	1, 2, 5

TABLE 2.1 STATUS OF SCA OPEN ITEMS

SCA OPEN ITEM		SUMMARY OF OPEN ITEM	RESOLUTION STATUS # (see codes, page 2-12)
COMMENT	75	Definition of and inconsistent use of "geologic setting"	6
	77	Adequacy of consideration of retrieval operations	2
	79	Adequacy of waste package corrosion tests for the repository	1, 5, 11
	80	Performance goals consistent with interpretation and intent of "substantially complete containment"	6
	81	Adequacy of program in stress corrosion cracking behavior of waste package	1, 5
	82	Adequacy of waste package performance at licensing	1, 2, 5, 11
	84	Adequacy of issue resolution strategy for the EBS and waste package	1, 5, 6, 10
	85	Accounting of temporal changes in state of stress due to corrosion of container	5, 10
	86	Adequacy of degradation models of copper-based alloys	5
	87	Adequacy of effect of the contact of dissimilar metals causing corrosion	5
	88	Assumption of reduced uncertainties because of the unsaturated zone	1, 5, 10
	89	Effect of introduction of materials that affect performance of waste package and glass	1, 5, 8, 10, 11
	90	Consideration of varying oxygen fugacity on corrosion of waste package	1, 5, 10
	91	Consideration of alternate canisters for reduction of C-14 releases	10
	95	Adequacy of logic to screen and develop release scenarios	1, 5, 10
	96	Adequacy of the use of K_d for modeling heterogeneous medium	5
	98	Appropriateness of weighting CCDFs by expert judgment	10
	99	Quantification of all release modes	10

TABLE 2.1 STATUS OF SCA OPEN ITEMS

SCA OPEN ITEM		SUMMARY OF OPEN ITEM	RESOLUTION STATUS # (see codes, page 2-12)
COMMENT	*100	Adequacy of consideration of faulty release scenarios	-
	101	Adequacy of SCP equation 8.3.5.13.21	10
	102	Adequacy of Ross sequences in comparison to the hydrologic flow model	10
	103	Ross sequences addressing anticipated conditions and not scenarios	10
	*104	Ross sequences address spent fuel and not a vitrified waste form	-
	105	Rationale for elimination of scenarios	1, 5, 6, 10
	*106	Missing coupling term for calculation of liquid phase radionuclide transport	-
	*108	Appropriate use of expected partial performance measure	-
	109	Adequacy of treatment of coupling time between matrix and fracture flow in hypothesis testing tables	10
	*110	Adequacy of dealing with human intrusion in the CCDF	-
	*112	Adequate discussion of state variables as constants or random variables	-
	*113	Consistency of definition of CCDF and the unit step function	-
	115	Adequacy of expanding of CCDF in terms of scenario classes	10
	116	Individual exposures via potable water may need to be expanded	6
	117	Individual exposure rates of C-14 may need to consider advective and diffusive flow rates	1, 5, 10
	118	Conduct of long-term in situ laboratory waste package activities	1, 2, 5, 10, 11
	119	Adequacy of performance confirmation testing (10 CFR 60)	1, 2, 5, 10, 11
	120	Model and computer code validation studies	10
	121	Adequacy of seismic design of ESF	5, 6, 11

TABLE 2.1 STATUS OF SCA OPEN ITEMS

SCA OPEN ITEM		SUMMARY OF OPEN ITEM	RESOLUTION STATUS # (see codes, page 2-12)
COMMENT	122	Demonstration and acceptability of the dry coring method	PRs
	123	Assessment of effects of ventilation on the ESF	2, 5, 8, 11
	*127	Design Acceptability Analysis	-
	*128	Design Acceptability Analysis	-
	*130	Design Acceptability Analysis	-
	*132	Design Acceptability Analysis	-
QUESTION	*1	Integration of mapping efforts	5
	3	Area of repository development	2, PRs
	5	Adequacy of vertical boreholes for evaluation of faults and fractures	2
	8	Rock properties: level of detail and uncertainty in 3D model	10
	9	Systematic drilling program: adequacy of sampling same specimens for rock properties	5
	12	Rationale for exclusion of lunar crater basaltic field as analogue	5
	14	Natural resources: adequacy of evaluation of previous mining and drilling leases on the site	5
	15	Resource exploration and mineral resource potential	5
	17	Rock properties: activities to investigate effects on thermal and mechanical properties	5, 11
	20	Discussion on vertical or horizontal emplacement	PRs
	21	Parameters for radiation shielding properties of the host rock	5
	22	Parameters related to repository construction and operation	5, 10
	23	Computer code verification and validation	7
	25	Heterogeneous air flow characteristics for seal program	5
	*28	ESF penetration of Calico Hills and impact on Issue 4.4	-
	30	Water quality as related to waste package design	5

TABLE 2.1 STATUS OF SCA OPEN ITEMS

SCA OPEN ITEM		SUMMARY OF OPEN ITEM	RESOLUTION STATUS # (see codes, page 2-12)
QUESTION	*31	Integrity of spent fuel cladding	-
	32	Container "similarity" for borosilicate glass waste vs. spent fuel .	5
	33	Emplacement hole drainage concerns	1, 5, 10
	34	Meaning of undetected defective closures	10
	35	Acceptance criteria for helium leak tests	6, 10
	36	Contact of canisters with corrosive elements during shipping and handling	1, 5
	37	Basis for 10 cm of free fall for canister and contents	5
	38	Basis for 1 mm of thinning of canister due to impact or handling	1, 5, 10
	39	Definition of "unusual process history" of canister	1, 5, 10
	40	Basis for factor of 2 on borehole liner in comparison to container material	1, 5, 10
	41	Consideration of 10 CFR 60.132 (a) in resolution of 2.4	1, 5
	42	Assumption of stability of vertical emplacement hole	5
	44	Basis for assumed numbers of breached assemblies or canisters	5
	45	Investigation of particulate source terms, retention factors, and plate-out of waste package during accident conditions	1, 5
	46	Basis for stricter containment of long-half-life isotopes	6
	47	Assumption on breaches of waste containers	6
	49	Effects of low-temperature oxidation on containers	1, 5, 10
	51	Design and research criteria for accepting waste from INEL and Hanford	5, 9
	53	Specification of cooling rate of the glass waste	Waste Acceptance Committee and Materials Steering Committee

TABLE 2.1 STATUS OF SCA OPEN ITEMS

SCA OPEN ITEM		SUMMARY OF OPEN ITEM	RESOLUTION STATUS # (see codes, page 2-12)
QUESTION	55	Interference at the ESF by water storage tanks, septic field, and waste water lagoon	8, 11
	56	Basis for 5 cm of fault displacement in waste package environment . . .	-
	57	Effects of drilling multipurpose boreholes	8
	58	Flexibility of ESF to accommodate in situ testing of waste package	11
	59	Basis for length of in situ thermal tests	2, 9, 11
	*61	Accommodation of design changes during ESF construction	-
	62	Basis for 152.4 m (500 ft) of separation of ESF from waste emplacement and 30 m of separation from ESF and waste emplacement	11

2.1.8 Site Characterization Program Baseline (SCPB)

The SCPB identifies DOE's baselined site characterization program and provides a means to demonstrate traceability of changes in the site characterization studies. All revisions to the SCPB are controlled in accordance with approved procedures.

During this reporting period, four revisions of the SCPB were issued:

Revision 5 (July 15, 1992) - Activity 8.3.1.17.4.3.1 contained incorrect references to integration of geophysical activities; the reference was corrected to read 8.3.1.4.1.2.

Revision 6 (July 15, 1992) - Section 8.4 of the SCPB was updated to be consistent with the current ESF concept.

Revision 7 (July 15, 1992) - Activity 8.3.1.4.2.1.6 (Integration of geophysical activities) was deleted. The scope was redundant with 8.3.1.4.1.2.

Revision 8 (September 24, 1992) - This revision reorganized the waste package near-field environment program (Section 8.3.4.2.4) to separate the tests addressing the effects of man-made materials from testing in the near-field environment. This resulted in a new study: Characterize the effects of man-made materials on water chemistry in the post-emplacement environment.

Revision 9 (In preparation, due October 2, 1992) - This revision limits text that is controlled simultaneously and separately in the SCPB and Study Plans or other requirements documents. Revision 9 is included during this reporting period because it occurred so close to the end of the reporting period, and because it is a major revision of the document. It will be discussed in more detail in PR 8 (October 1, 1992 through March 31, 1993).

2.1.9 Performance Assessment (PA)

TSPA provides a systematic approach that identifies and models the FEPs that affect the safety and environmental acceptability of a waste repository. Specifically, the final TSPA for the license application will apply appropriate models and experimental results to systematically evaluate the effects of the FEPs on the long-term performance of the entire system.

New TSPA analyses for Yucca Mountain were completed and documented by SNL and PNL during the reporting period. The SNL analysis entitled "TSPA 1991: An Initial Total-System Performance Assessment for Yucca Mountain" (Barnard et al., 1992) was published. The PNL report "Preliminary Total-System Analysis of a Potential High-Level Nuclear Waste Repository at Yucca Mountain" (Eslinger et al.) is in final YMP program review. Both TSPA reports provide sections recommending areas of future work and topics that should be addressed in future TSPA analysis.

In preparing these TSPAs, both SNL and PNL utilized the same SNL-assembled data base and covered the same major assessment elements, including waste release, ground-water flow, gas flow, human intrusion, and basaltic volcanism. The modeling approach used and the associated data emphasis involved in the analyses were considerably different, yet both modeling approaches represent only two of the many alternative conceptual models that could be used to assess the performance of a potential Yucca Mountain repository. Additional hypothesis testing and sensitivity results are needed to evaluate whether or not the most representative alternative conceptual site models were used.

The PNL analysis generally used more detailed, multidimensional, process-coupled models in comparison with the SNL analysis. The SNL analysis used less detailed, abstracted models that adopt simpler expressions for the phenomena they describe and allow easier generation of multiple realizations. Typical examples include: PNL analyzed two-dimensional, steady-state, partially saturated water flow and transport in vertical sections with tilted lateral strata, while SNL considered downward, one-dimensional steady flow and transport in several vertical columns intersecting horizontal strata. In analysis of nonisothermal gas flow and C-14 transport, PNL used a multidimensional model involving coupled water and air flow under nonisothermal conditions, while SNL considered a constant temporal thermal field and pressure-induced flow of only the air phase to evaluate the transport by advection.

The PNL analysis was not as conservative, in terms of the range of parameter values used, as the SNL analysis. Consequently, the PNL analysis suggested no system "failures" in terms of unallowable releases via the aqueous, gaseous, or direct pathways. The SNL analysis included ranges of parameter values deliberately chosen to "fail" the system. This was done to allow the determination of system sensitivities to help select some input parameter ranges.

2.1.10 Transition to the CRWMS M&O Contractor

Significant progress was made in transitioning activities from T&MSS to the M&O Contractor. Early in the reporting period, the Plans and Procedures organization was transferred to the M&O; all local records centers in Las Vegas were consolidated into one;

remaining support responsibilities for regulatory and licensing activities not previously transferred were transitioned; and responsibility for coordination of Study Plans was assumed by the M&O.

In June 1992, the M&O contractor became responsible for operation of the microfilm center and for production of project-level activity reports, and in August 1992, the central records facility and document center were transitioned.

Plans were completed for the transfer, effective October 1, 1992, of the following:

- ESF design
- Site facilities design
- Support for YMPO Project Control Branch
- Operational responsibility for the Planning and Control System (PACS)
- Support for Technical Data Management
- Development of project-level software

2.1.11 Public Outreach

Institutional and External Affairs (IEA) staff coordinated six open house tours of the Yucca Mountain area, which were attended by approximately 1,190 guests. Additionally, 57 special group tours were also held, with a total of 1,450 participants. These special tours consisted of tours for private groups, VIPs, media, and educational tours for schools.

IEA staff coordinated YMP public update meetings, which were held in Pahrump, Henderson, and Carson City, Nevada, with a total of over 325 people in attendance in the three locations.

IEA staff prepared briefing packages, handled logistics, and accompanied YMP staff to approximately 111 speaking engagements. These presentations were made to technical groups, as well as students and the general public.

An open house was held in April 1992, for the new YMIO in Pahrump, Nevada. Many members from the Pahrump community were invited, and Barbara Raper, Nye County Commissioner, was invited to speak.

IEA staff, as part of the public education effort to provide Nevada residents with information about nuclear waste transportation, coordinated a schedule for the transportation

container exhibit. The container was on display at 22 different locations during this report period. Approximately 3,560 people viewed the container.

A total of approximately 7,800 visitors toured the YMIOs in Las Vegas, Beatty, and Pahrump, Nevada. Significant events at the offices included two live remote broadcasts on KFM-102 radio from the Las Vegas YMIO during the transportation container event and participation in the Pahrump Harvest Festival via the transportation container exhibit.

The YMP exhibit was set up and staffed for 25 events, including six Public Open Houses. These exhibits ranged from public to technical and educational. Exhibits were also shown at the three Public Update Meetings in May 1992. A total audience of approximately 9,100 was provided with information about the YMP.

Various events were developed, coordinated, and implemented by the YMPO Educational Program. Among the events were a Boy Scout Geology Merit Badge Workshop, a Boy Scout Atomic Energy Merit Badge Workshop, two Girl Scout Geology Merit Badge Workshops, three Yucca Mountain Lecture Series presentations, and school field trips and tours to the Las Vegas YMIO and to Yucca Mountain.

Two recent field trips for Native American Tribal members were hosted by the YMPO; one for adults and tribal leaders in May 1992, and one for youth in August 1992. The youth tour was developed in response to adult tribal members' recommendations on the May tour that a similar field trip be designed for tribal youth. Through these informal field trip exchanges and other related efforts, OCRWM is gaining additional insights into the Indian Peoples' perspectives of the program.

YMP volunteers participated in the REECo Partners in Education Workshop, giving presentations on geology, transportation of spent fuel, and native American culture. LLNL and YMP conducted an intensive, hands-on, two-week short course for Nye County teachers, kindergarten through eighth, including instruction in physics, chemistry, biology, and electricity and magnetism.

IEA staff assisted in the coordination of a University of Nevada Las Vegas (UNLV) Teacher Workshop on curriculum for high-level waste education programs. YMP, LLNL, the Clark County School District, and other corporate sponsors provided a two-week Lessons in Science Education Workshop for kindergarten through eighth grade Clark County School District teachers, with 18 teachers attending.

Interactions continued with the Nevada League of Cities, Nevada Association of County Organizations, educational and business communities, and other key groups. IEA staff participated in the Nevada League of Cities 33rd Annual Conference, held in

Winnemucca, Nevada, in August 1992. The County Representative program has proved to be quite successful and relations with the affected counties has continued to be proactive.

YMP and CRWMS M&O staff met with the UNLV Dean of Education to discuss an Education Plan for university activities. CRWMS M&O staff began planning for presentations on nuclear power to be used in public schools and also met with Nevada Senator Tom Hickey to discuss a proposal for a working group, hosted by UNLV, on math/science education restructuring and other interactions with Nevada educational institutions.

Other accomplishments included: Six panel forums were conducted during this reporting period. YMP and T&MSS staff also participated in Town Forums held in Eureka, Carlin, and Crescent Valley, Nevada. Eight new fact sheets and one, four-color folder were printed. Eighteen new fact sheets have been developed and are being readied for the approval process. One hundred eighty biographies were drafted, revised to reflect recent organizational changes and 140 are ready for use. A video data base with approximately 300 entries is in place with key word search capability for accessing the topic descriptions. A number of videos have been combined. The script for the ESF video was finished and the computer graphics subcontract RFP was written, issued, received, and evaluated. A number of papers for the YMP manager's presentations to technical/professional conferences were developed and submitted. The YMP Educational Plan was approved by YMPO. Goals of the plan are to provide information about the YMP to K-12 teachers and students and to help build a future technical work force for the U.S.

2.2 SITE PROGRAMS

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

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

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

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

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

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

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

- Human Interference - evaluates the known and potential natural resources in the site area, and the potential for future human intrusion into the site area in search of such resources (SCP Section 8.3.1.9).

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

- Offsite Installations and Operations - determines the presence of offsite industrial, transportation, and military installations and operations in the Yucca Mountain vicinity, and the potential impacts of these installations and operations on the site area (SCP Section 8.3.1.13).

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

- Thermal and Mechanical Rock Properties - determines rock thermal and mechanical properties from laboratory and in situ investigations, and characterizes thermal and mechanical stress conditions at the site (SCP Section 8.3.1.15).

- o Preclosure Hydrology - characterizes the potential for flooding, and determines location of an adequate water supply for repository construction and operation and preclosure hydrologic conditions in the UZ at Yucca Mountain (SCP Section 8.3.1.16).

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

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

2.2.1 Geohydrology (SCP Section 8.3.1.2)

2.2.1.1 Study 8.3.1.2.1.1 - Characterization of the meteorology for regional hydrology

The NRC accepted Study Plan 8.3.1.2.1.1 on October 21, 1991.

Responses to ten comments by the State of Nevada on the Study Plan were returned to the State of Nevada on July 13, 1992.

Activity 8.3.1.2.1.1.1 - Precipitation and meteorological monitoring. Rainfall in the Yucca Mountain region was scarce during the reporting period compared to the winter months of 1992. An El Niño (weather pattern) event appears to have been the prime influence affecting weather patterns. It also appears to have been the reason for the extremely wet winter and the dry spring and summer at Yucca Mountain. There were seven rainfall events that occurred at Yucca Mountain during the reporting period. These events were recorded by the precipitation gauge network and the data were archived. All events were isolated showers and affected locations on and around the mountain to different degrees.

The collection gauge network was expanded to 120 gauges. National Weather Service standard eight-inch-diameter metal gauges were installed at four of five weather stations to provide a backup to the automated tipping-bucket rain gauges. Automated weather data acquisition continued via the weather stations and tipping-bucket precipitation gauges. Data were downloaded via radio (installed at all weather stations plus two precipitation gauge sites) and were archived. The collection of regional precipitation and available evaporation pan data continued. These data were received in report format from the National Climate Data Center (NCDC).

Lightning strike data continued to be collected and archived for the 1992 thunderstorm season in the southwest U.S. One thunderstorm occurred directly over Yucca Mountain on August 11, 1992. Work was begun to attempt to correlate 1991 and 1992 Yucca Mountain

and NTS precipitation data with lightning strike data. A statistical relationship was attempted, using a nearest neighbor technique. This met with limited success as the best correlation failed to exceed 50 percent. Another approach, to study only those instances when a storm occurred directly over a particular rain gauge, was planned.

Daily weather patterns were monitored and categorized according to the five major weather types of North America. National Weather Service charts and maps, received each day, were the source of the data. Satellite data, from the Geostationary Operational Environmental Satellite (GOES), provided additional information on synoptic-scale storm genesis and movement and were added in the weather typing study. GOES data were routinely downloaded and archived.

Time-lapse video tape continued to be used to document weather that directly affects Yucca Mountain. A new video surveillance system was installed at the Hydrologic Research Facility (HRF). The growth, downburst, and precipitation pattern from the August 11, 1992 thunderstorm at Yucca Mountain was recorded. Winds were measured at over 65 miles per hour by a weather station on the crest. The maximum rainfall recorded at Yucca Mountain was 19 millimeters.

Forecast: In FY 1993, data collected from five weather stations during FY 1992 will be reduced and a geostatistical analysis of the precipitation data will be performed. Additional tipping-bucket and collector-type rain gauges will be installed to increase the spatial coverage of the present system. Data collection will continue, using the weather stations and rain gauges. GOES data will be received, archived, and analyzed to determine the origin, movement, and intensity of precipitation events affecting Yucca Mountain. Reports will be prepared on the meteorological data collected from the various types of monitoring stations during FY 1992. A series of annual interpretive and data reports will be issued in conjunction with this study.

2.2.1.2 Study 8.3.1.2.1.2 - Characterization of runoff and streamflow

The NRC submitted two comments and three questions on August 14, 1992 in a Phase II review of the Study Plan. The USGS is preparing responses to these comments and questions.

Activity 8.3.1.2.1.2.1 - Surface-water runoff monitoring. Monitoring activities continued at 10 continuous-recording stream gauges, 13 peak-flow sites, and 21 storage-type precipitation gauges. An additional continuous-recording gauge was installed during September 1992 on Pagany Wash at Yucca Mountain. This site represents the first continuous-recording gauge to be installed as part of the planned Yucca Mountain surface-water network. Testing continued on the ALERT telemetry systems installed at selected

gauges within the Upper Fortymile Wash and regional surface-water networks. Surveying levels were run at selected network sites to check staff plate settings and newly installed peak-flow indicators against established reference marks. Review of the records for the report on surface-water and precipitation data collected during water years 1983-85 was completed and the report is in final USGS review prior to submittal to DOE. Compilation of the 1986-92 surface-water and precipitation records continued. Intermittent precipitation during the reporting period resulted in minor to moderate runoff at several of the regional surface-water sites. Indirect measurements of streamflow were made and documented for inclusion into a planned data report.

Activity 8.3.1.2.1.2.2 - Transport of debris by severe runoff. Field reconnaissance of erosional and depositional features related to severe runoff was conducted at a number of localities. Aerial photographs, Landsat image data, and digital terrain models were evaluated in terms of their availability and suitability to this study. Sites affected by severe runoff due to historic weather events are being selected from field and aerial reconnaissance for subsequent site-specific analysis to determine relationships between transport processes and those terrain factors that control the location and geographic extent of debris flows. Reconnaissance activities have focused on examining sites of the 1969, 1984, and 1990 severe runoff events. Areas currently under investigation are: the Amargosa River; Fortymile Wash; Las Vegas Wash and its major tributaries; and sites of known debris flows at Copper Canyon, Ophir Creek, Potosi Mountain, and Jake's Ridge.

Field investigations of recent debris movement by severe runoff were conducted in central and northern Nevada. Fine-grained sand and gravel were transported and deposited on many streets in Hawthorne, Nevada, as a result of severe flooding on July 11, 1992. Moderately heavy debris, consisting of boulders up to two feet in diameter in a sand and gravel matrix, was deposited across Interstate 80 east of Reno, Nevada, during an intense storm on July 14, 1992. Debris flows also occurred from the same storm in Gray Creek, a tributary of the Truckee River, north of Reno. Data collected from these events will provide further insight into the processes of debris movement by severe runoff.

Forecast: In FY 1993, runoff monitoring will continue at approximately 12 continuous-recording stream gauges, 13 peak-flow sites, and 21 storage-type precipitation gauges (SCP Activity 8.3.1.2.1.2.1). Three additional continuous-recording gauges will be installed in washes on the eastern slope of Yucca Mountain to support the UZ natural infiltration activity (SCP Activity 8.3.1.2.2.1.2). Other runoff gauges may be installed near Yucca Mountain, either in upper Fortymile Wash to support the Fortymile Wash Recharge Study (SCP Activity 8.3.1.2.1.3.3), or on the Amargosa River to support regional hydrologic studies. Reports documenting historical runoff data in the vicinity of Yucca Mountain for 1983-85, 1986-89, and 1990-91 will be completed. Investigation of the transport of debris by

severe runoff (SCP Activity 8.3.1.2.1.2.2) will be suspended during FY 1993 pending identification of any need for additional debris-flow data to support design of surface facilities (see SCP Activity 8.3.1.16.1.1.1).

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

The NRC Phase I review of Study Plan 8.3.1.2.1.3 was completed October 4, 1991, with no comments.

Activity 8.3.1.2.1.3.1 - Assessment of the regional hydrogeologic data needs in the saturated zone. This activity was evaluated during the completion of the Study Plan, in which prioritization of project data needs was largely completed. It was determined that as new project data become available, data needs may change based on previously unrecognized hydrologic conditions. The current data uncertainty was used to prioritize data collection needs, as documented in the Study Plan.

Activity 8.3.1.2.1.3.2 - Regional potentiometric-level distribution and hydrogeologic framework studies. Data from mining-company boreholes constructed in the Amargosa Desert continued to be assembled and processed. Cuttings collected from mining company boreholes were correlated with rock outcrops in the field. Meetings were held with mining company representatives and others to discuss processing of the field and borehole data as a USGS Open-File Report. Preparation of a cross section of hydrostratigraphic units within the Amargosa Desert began, using a cluster of data from mining company exploration boreholes.

A borehole data package for mining company boreholes in the Amargosa Desert was finalized and prepared for technical review as a USGS Open-File Report. A new format for producing combined geophysical and lithologic logs was written, and the 60 existing logs were recompiled into 44 logs and replotted. These logs incorporated standardized lithologic patterns.

A galvanized-steel one-inch-diameter pipe and sucker rod were installed to a depth of 125 m (410 ft) in a two-inch piezometer west of Stateline, Nevada, for the purpose of obtaining hydrochemical samples. The piezometer was pumped at a rate of about 22 L per minute for a combined total period of about two hours; however, each pumping cycle lasted only 15 minutes because the piezometer dried out. An additional well on the west side of Franklin Lake playa was tested using a small-diameter pump jack. This well was pumped to dryness in about one hour at a rate of about 22 L per minute. Hydrochemical sampling was conducted in the well. After sampling, the well was plugged per agreement with the California State Lands commission. A report on that activity was also prepared.

Activity 8.3.1.2.1.3.3 - Fortymile Wash recharge study. Ground-water responses to recharge and seismic events, precipitation events, and soil-moisture conditions were documented during the reporting period. An abstract entitled "Runoff, Infiltration, and Recharge near Yucca Mountain, Nevada, 1992" (Savard) was submitted to the American Geophysical Union (AGU) for presentation at the 1992 Fall meeting's special session, "Semiarid Runoff Studies: Experimental and Model Linkage."

The Merced River, California discharge-derivative streamflow time series (1916-90) was analyzed using nonlinear dynamics methods, chaos theory (Savard, 1992) and presented at the 1992 Spring AGU meeting special session, "Predictability of Climatic and Hydrologic Systems: Insights from Nonlinear Dynamics." The main conclusion from the study was that current methodology to analyze for low-dimensional chaos appears to be inadequate for natural hydrologic systems which appear to exhibit high-dimensional behavior.

A report describing infiltration estimates based on channel geometry data and precipitation data for Fortymile Wash, Topopah Wash, and the Amargosa River was drafted. A companion report describing the methodology using data collected in the Mid-East has been drafted and is being readied for internal review.

Prototype infiltration tests were conducted in wash sediments similar to future testing locations in Fortymile Wash. A system for rapid delivery of water to the infiltration tank with minor disturbance to the sediments was tested satisfactorily. The electronic system to monitor water levels in the tanks needs more development. However, the manual method of measuring water levels has been successful and will be used as a backup and check to the automated method.

Activity 8.3.1.2.1.3.4 - Evapotranspiration studies. Equipment configuration of a Bowen ratio station for obtaining estimates of Evapotranspiration Studies (ET) was designed and programmed into a datalogger. The system employed dew-cell hygrometers, thermistors, a net radiometer, and soil heat flux plates connected to a datalogger.

Wells from several sites on Franklin Lake playa were sampled to determine strontium-87/strontium-86 ($^{87}Sr/^{86}Sr$) ratios, which may be useful for identifying sources of water in the playa. A paper entitled "Does Localized Recharge Occur at a Discharge Area With the Ground-Water Flow System of Yucca Mountain, Nevada" (Czarnecki et al., 1992a) was published. A poster and paper entitled "A Hint of Recharge at Franklin Lake Playa" (Czarnecki et al., 1992b) was also presented at the 7th International Conference on Water-Rock Interaction and has since been published.

Forecast: Work planned for FY 1993 includes interpretation of data from two deep oil exploration boreholes in the Amargosa Desert and additional data collection from deep boreholes as opportunities develop. A data report on regional ground water levels will be

completed. Tests will be completed on prototype water-sampling equipment for small-diameter wells; water samples will be obtained whenever opportunities develop. A Bowen-ratio ET station may be deployed at Franklin Lake playa. Potential recharge events in Fortymile Wash (like that which may have occurred in 1992) will be analyzed and documented. Documentation will include analysis of precipitation and streamflow data, soil-moisture data from three boreholes, and water-level data from three wells in Fortymile Wash. Artificial-infiltration methods will be developed for the Fortymile Wash activity.

2.2.1.4 Study 8.3.1.2.1.4 - Regional hydrologic system synthesis and modeling

The NRC completed their Phase I review of Study Plan 8.3.1.2.1.4 on May 6, 1992, and provided one comment regarding the relationship between this Study Plan and SCA open items. The DOE responded to the NRC on July 23, 1992.

Activity 8.3.1.2.1.4.1 - Conceptualization of regional hydrologic flow models. A joint meeting entitled "Fast Pathways: Definition and Detection" was sponsored by the HITF and the GIT and held June 9-11, 1992, in Denver, Colorado. A presentation on the subregional ground-water flow system, with emphasis on uncertainty regarding flow coming into Yucca Mountain, was presented. This analysis was done by examining extant hydrologic and hydrochemical data. A proposal was presented to perform hydraulic and hydrochemical tests in borehole USW G-2 at a meeting of the HITF held at SNL July 28, 1992.

Activity 8.3.1.2.1.4.2 - Subregional two-dimensional areal hydrologic modeling. A ground-water computer code, MODFE, was successfully verified, using benchmark ground-water flow problems. A software package, GRID BUILDER, was successfully used to generate finite-element meshes comprising triangular elements of the subregional ground-water flow system. A digitized outline of a new model domain that included Yucca Mountain, and digitized coordinates of wells within that domain, were successfully included in the construction of the new finite-element mesh. The digitized well locations were used with the program to relocate nodes within the mesh to coincide with the exact well locations. Scoping calculations were made regarding the potential precipitation of calcite resulting from elevated SZ temperatures following waste emplacement.

Activity 8.3.1.2.1.4.3 - Subregional two-dimensional cross-sectional hydrologic modeling. No progress during the reporting period; this is an out-year activity.

Activity 8.3.1.2.1.4.4. - Regional three-dimensional hydrologic modeling. Presently existing ARC/INFO interfaces were tested and USGS staff developed an interface with IDRISI Geographic Information System (GIS) software. Modifications were made to Intergraph's ERMA/MODFLOW Interface so that three-dimensional modeling can be conducted in a timely manner. Because of ERMA's completely integrated nature, it was

selected for use in three-dimensional modeling of the regional study area and preliminary testing and code modifications were conducted to ensure compatibility.

Memory requirements and/or code constraints were tested because of the three-dimensional regional model complexity. The model was also tested with the extremely large grid arrays required for this activity. Grid dimensions included 200 x 240 x 10 cells, which translates to 1-km ground resolution. Grid creation and boundary definition of the model was conducted on the ERMA system when the model test was completed. Numerous software packages were tested that will be used to visualize modeling results including the three-dimensional hydrogeologic framework model and the simulated regional potentiometric surface.

Forecast: No activity is planned for FY 1993.

2.2.1.5 Study 8.3.1.2.2.1 - Characterization of unsaturated-zone infiltration

Proposed revisions to the Study Plan were transmitted to YMPO April 24, 1992. On September 16, 1992, the DOE provided NRC references cited in the Study Plan that were requested in their Phase I acceptance letter of May 31, 1991.

Activity 8.3.1.2.2.1.1. - Characterization of hydrologic properties of surficial materials. Laboratory measurements have been completed on transects of surface outcrop samples collected in early 1992 to determine bulk density, porosity, grain density, saturated hydraulic conductivity and sorptivity. Technical data information forms have been submitted for seven of the transects and an outline has been prepared for a data report. A series of transects were run to characterize horizontal and vertical variability in the nonwelded shardy base of the Tiva Canyon flow unit. This unit has a defined deterministic trend with depth for porosity which then relates to all the other properties. However, there is very little difference in porosity with horizontal distance over the 1.3-km transect. Results of this study will be presented in a paper, "Influence of Deterministic Geologic Trends on Spatial Variability of Hydrologic Properties in Volcanic Tuffs," (Rautman et al.) at the 1993 IHLRWM Conference. Another paper, "Deterministic Geologic Processes and Stochastic Modeling" (Rautman and Flint, 1992), was presented at the 1992 IHLRWM Conference.

Compilation and analysis of existing soils data were conducted to address where additional information is needed for planning full-scale field sampling for characterizing soils. Initial sampling has been done in conjunction with studies characterizing two watersheds for rainfall-runoff and net infiltration models. Pagany Wash, a fault-controlled wash to the north, and Split Wash, an erosional wash over the potential repository zone, were chosen as representatives and will be studied in depth. Field surveys of the surficial materials have been done on a 15.24 x 15.24-m (50 x 50-foot) grid which will be used to assess the

sampling density necessary to adequately evaluate the spatial heterogeneity of the surface materials. Preliminary sampling has been done and analyzed for particle size-distribution and geostatistical spatial analysis.

Information about alluvium/bedrock contacts was compiled from the existing borehole data. Mapping the depth to bedrock is necessary for characterizing the hydrologic properties of the surficial materials.

New geophysical logging tools were successfully field tested in USW UZN-55 and USW UZN-54 in WT-2 Wash. Gamma-gamma logging and neutron logging were performed and data were collected indicating that all electronic instrumentation is in working condition. Data and calibrations will be checked against known borehole conditions and measured core densities and water contents.

Activity 8.3.1.2.2.1.2 - Evaluation of natural infiltration. The small-scale deterministic model was continued as a study to evaluate mechanisms of net infiltration occurring on a small watershed. The model is a two-dimensional model spanning five boreholes in lower Pagany Wash. Simulations were run using the TOUGH computer code. To define the upper layer boundary conditions it was necessary to incorporate ET data as well as meteorology data. Moisture profiles using neutron holes UE-25UZN#4 through UE-25UZN#8 have been analyzed and mass balances have been done as a check of all the data. An abstract entitled "The Influence of Seasonal Climatic Variability on Shallow Infiltration at Yucca Mountain" (Hevesi and Flint), was written for the 1993 IHLRWM Conference. The elevations and the boundaries defining the alluvial washes, channel segments, sideslopes and ridgetops of Pagany Wash and Split Wash have been digitized. Programs have also been developed to perform slope and aspect calculations for use in energy balance calculations.

Large-scale net infiltration processes were evaluated, using one-dimensional simulations of USW UZN-55. This exercise has been extended to an INTRAVAL test case to provide data to simulate a saturation profile from UE-25UZ#16 that has not been completed or analyzed yet. A predicted lithologic profile will be provided for UE-25UZ#16. The same data were used to predict the saturation profiles in US UZN-55 with the use of published paleoclimate estimates as inputs to simulate 300,000-year cycles in net infiltration. This work will be presented at the 1993 IHLRWM Conference in a paper entitled "The Influence of Long Term Climate Changes on Net Infiltration at Yucca Mountain" (Flint et al.).

Because of the high amounts of precipitation during the past winter, there has been higher soil water content available for ET. Most of the moisture profiles have returned to their original pre-winter water contents. Boreholes with alluvium appeared to have shallow moisture penetration and subsequent water loss to ET. Boreholes with little alluvial cover indicated deeper moisture penetration. Mass balance calculations were attempted, but slight errors in the calibration equation make analysis difficult. Detailed analysis reinforced the

need for a flexible data base for the neutron moisture logs. PARADOX is being utilized to input all the neutron log data collected during the last eight years, along with any other information on the boreholes.

There are currently two evaporation pans operational in Jackass Flats to measure potential evaporation: one is an automated pan that collects data daily, using a datalogger, and the other is manually operated. They will serve as checks for each other until the manual evaporation pan is relocated to a field site in one of the washes on the mountain and is automated.

A preliminary field calibration has been developed from USW UZN-55 core data. The equation is polynomial and has been tested with some success. However, some boreholes show negative water content, which could be formation voids behind the casing or could be errors in the equation due to additional bound water in the core samples. The data from USW UZN-54 and USW UZN-27 will also be included in the final equation. In addition, samples from USW UZN-55 have been dried at 800 °C to drive off all bound hydrogen to calculate final volumetric water contents. Once core from all three boreholes has been dried, the field equation will be finalized and incorporated into the neutron log data base.

All neutron holes have been logged on a monthly basis. New boreholes are logged every six months to total depth and monthly to 19 meters. Additional boreholes have been drilled during the reporting period (see figures 1.1 and 1.2). Boreholes USW UZN-27 [62 m (203 ft) deep] and USW UZN-64 [18 m (60 ft) deep] were drilled on the ridge, USW UZ N-38 [18 m (60 ft) deep] was drilled in Wren Wash, UE-25UZN#63 was drilled in Pagany Wash, USW UZN-53 [79 m (260 ft) deep] was drilled on the ridge south of USW UZN-54 in WT-2 Wash, USW UZN-33 and USW UZN-34 were drilled in Drill Hole Wash in a channel-terrace location, and USW UZN-31 and USW UZN-32 (in progress at end of reporting period) were drilled in upper Split Wash in the middle of the potential repository block. These last two holes will provide an analog to USW UZN-54 and USW UZN-55 in a more northern location, penetrating through the Tiva Canyon welded unit and through the Topopah Spring caprock, yet still in a channel-sideslope setting.

ET data from the Bowen ratio station that is set up at the mouth of Pagany Wash next to UE-25UZN#14 was collected and organized for analysis. Preliminary analyses indicated some errors, mostly due to ice building up on the chilled mirror, but, in general, the data were very reasonable. A modified Priestley-Taylor equation, using estimates of soil water content from the top meter of the neutron logs, compared very well with the Bowen ratio estimates of ET. These data were useful in estimating upper boundary fluctuations in the two-dimensional Pagany Wash model and were scaled down to provide annual ET cycles for input to the simulations.

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Activity 8.3.1.2.2.1.3 - Evaluation of artificial infiltration. Various types of infiltrometers were tested under various field conditions and on different geohydrological surfaces. Development of a prototype double-ring infiltrometer capable of accurately controlling water levels to ±1 mm was completed. The system has been calibrated in the laboratory and has been tested once in the field.

In conjunction with the infiltrometer tests, several different soil/unconsolidated sediment sampling schemes and sampling devices have been evaluated. Optimal sample size, sample containers, and techniques for taking whole soil samples, coarse fragment samples, fine (2 mm or less) soil samples, and unconsolidated material samples have been investigated.

Five sets of probes for the time-domain reflectrometry unit (TDR) were installed in the field and were monitored under in-situ moisture conditions. Two sets of the probes were also monitored as 30 L of water infiltrated into an area around the probes. Gravimetric moisture samples were taken from the infiltration area to calibrate the TDR moisture reading with the actual mass and volumetric wetness.

A prototype ponding study site has been located. Layout of field instrumentation, radio telemetry equipment, suction lysimeter equipment, and various pre- and post-infiltration event-sampling schemes have been evaluated. This prototype ponding study will be conducted at the UE-25N#85 neutron access borehole.

Forecast: Work planned for FY 1993 includes field sampling of unconsolidated surficial materials and laboratory measurements of physical and hydrologic properties. Bedrock outcrop samples also will be collected for laboratory determination of physical and hydrologic properties. This information will be used to develop a preliminary infiltration/runoff surficial units map to describe the upper boundary for net infiltration at Yucca Mountain. Neutron-access borehole logging will continue to monitor natural infiltration, which will contribute to the understanding of processes governing shallow infiltration at Yucca Mountain. Water balance studies will be conducted to provide input for watershed modeling and to provide information on shallow infiltration. A small scale watershed model will be developed, using information from the neutron logging, water balance, surficial mapping, and artificial infiltration studies. Prototype ponding and small- and large-plot rainfall-simulation experiments will begin for the evaluation of artificial infiltration if adequate resources are available. The design and applicability of field infiltrometers will be evaluated to determine their usefulness for studies at Yucca Mountain, and the accuracy and precision of each instrument will be determined. Following evaluation of these instruments, infiltrometer studies will be conducted to collect site-characterization data.

2.2.1.6 Study 8.3.1.2.2.2 - Water movement test

Revision 0 of Study Plan 8.3.1.2.2.2 was sent to the NRC on February 9, 1989. The NRC deferred their Phase I review until DOE has evaluated the need to revise the plan for consistency with current ESF design.

YMPO sent the comments on revision 1 of the Study Plan to the principal investigator on May 12, 1992; these comments are currently being addressed.

Activity 8.3.1.2.2.2.1 - Chloride and chlorine-36 measurements of percolation at Yucca Mountain. Chlorine-36 and chloride/bromide analyses were performed on (1) cuttings from neutron-access boreholes USW UZN-37, USW UZN-54, and USW UZN-55; (2) soil samples from Midway Valley; and (3) water samples from the Yucca Mountain vicinity. Preliminary results were presented at the Joint Geochemistry/Hydrology Integration Team meeting June 9-11, 1992, in Denver, Colorado. Ream-bit cuttings continued to be collected from additional neutron-access boreholes and from UE-25UZ#16.

Forecast: Complete resolution of YMPO review comments on Study Plan, "Water Movement Test," is planned by November 1992. This Study Plan is critical for the accelerated ESF initiative in FY 1993. Chlorine-36, chloride and bromide data generated during FY 1992 will be reviewed during FY 1993 for acceptability in preparation for their submission to YMP. Technical procedures for using the shatterbox, for conducting step-leaching, and for using ion chromatography to measure chloride and bromide will be completed during FY 1993. In addition, existing technical procedures will be revised as necessary and a test planning package (TPP) and job package for sample collection from the ESF will be prepared. Soil and borehole cuttings samples will continue to be processed for chlorine/bromide and chlorine 36/chloride ratios.

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

The NRC accepted the Study Plan on March 23, 1992, and requested specific references cited in the Study Plan.

Activity 8.3.1.2.2.3.1. - Matrix hydrologic properties testing. Analysis of rock matrix hydrologic properties has continued, using samples from the new neutron access boreholes. Measurement of volumetric water content, bulk density, grain density and porosity-to-water have been made. Some of the samples were baked (>800 °C) to remove all water. This latter step was performed on cores from neutron-access boreholes that were being used to calibrate neutron moisture meters. Over 600 core samples from 12 neutron-access boreholes have been run as of September 1992. Thermocouple psychrometer measurements of water

potential have been performed on approximately 100 samples from one borehole. An abstract entitled "The Effect of High Temperature on the Hydrologic Properties of the Volcanic Tuffs at Yucca Mountain" (Flint and Nash) was submitted for the 1993 IHLRWM Conference.

A low-pressure permeameter with four coreholders, a pressure transducer, and electronic balances to measure outflow on multiple samples has been operational in the lab for several months. Water flow and pressure head data from the apparatus are logged electronically, although air permeability flow rates must be collected manually. Permeabilities on nominal 2.5-cm (1-in.) diameter by 5.1-cm (2-in.) long cylindrical samples can be measured across a range of approximately 1 microdarcy to >1 darcy. Matrix permeability measurements have been completed on several hundred rock samples collected from surface outcrop transects and traverses on Yucca Mountain. These include samples from the vitric and zeolitic parts of the Calico Hills (CH) nonwelded unit, lower nonlithophysal Topopah Spring, fault breccia, samples from a horizontal traverse of the shardy base of the Tiva Canyon welded unit, and a composite group of plugs from several transects representing all of the various microunits in the UZ.

Several core samples have been injected with an epoxy mixed with florescent dye for pore structure analysis. Thin sections have been made and photographed using a petrographic microscope. Image analysis software, a video camera and an image-digitizing board have been obtained for the petrographic microscope, which will allow more detailed, quantitative analysis of the pore morphology of tuffs in the UZ at Yucca Mountain.

Prototype testing was completed on the helium pycnometer, which measures grain density and volume using a Boyle's Law gas expansion method. A chilled-mirror psychrometer is being used to provide water activity data (from which water potential can be calculated) by employing a Peltier-cooled mirror to detect the dewpoint and an infrared sensor to measure temperature. The advantage of this instrument over a thermocouple psychrometer is that it is automatic, fast, and can measure water potentials as low as -400 megapascal (MPa) Experiments were performed with this psychrometer to determine the effect of particle size on the measurement of water activity. The results showed that the largest possible sample size that would fit into the chamber produced the most accurate data. Five different welded and nonwelded tuff samples were analyzed across a variety of water saturations, and moisture characteristic curves were fit to the data, using the Brooks and Corey function and the van Genuchten equation. This technique may allow for rapid determination of water characteristic curves and may be the preferred method for most rock samples.

Simple, gravimetric imbibition measurements have been completed on several hundred small plugs from the transect samples. Researchers from Lawrence Berkeley Laboratory (LBL), in conjunction with the USGS, derived a new formulation for water characteristic and permeability functions which match the laboratory imbibition data better than previous calculations.

Activity 8.3.1.2.2.3.2 - Site vertical borehole studies. HRF borehole monitoring continued throughout the reporting period. Sensors are maintaining stability and have performed exceptionally well since monitoring was initiated on October 20, 1991. Each primary sensor has experienced over 1,700 duty cycles as of September 30, 1992. Alternate, backup sensors are read periodically to corroborate the primary sensor's reading. Water potentials, which are measured by thermocouple psychrometers, have equilibrated with seasonal temperature changes at the ground surface. The sensitivity of the psychrometers (better than ±0.05 bars) is sufficient to detect the influence of very small temperature changes at depth on relative humidity. Theoretically, seasonal temperature transducers should influence the psychrometric measurement, i.e. as temperatures increase, the relative humidity should decrease, resulting in an increase in water potential (a more negative reading). Psychrometers located at 6.1, 9.1, and 12.2 m (20, 30, and 40 ft) below the ground surface are responding in a manner that mimics propagation of the annual temperature wave at depth. At 3 m (10 ft) below the ground surface, the system response has been dominated by infiltration from winter precipitation in early 1992. Infiltration down to depths below 3 m has not yet been detected with sensors in the HRF boreholes. Water potentials in the shallowest instrument stations (3 m deep) have decayed to their pre-winter precipitation levels, suggesting that most of the winter infiltration has evaporated.

Pressure transducer data from the HRF boreholes indicate that barometric pumping is an active vapor/air exchange mechanism down to depths of at least 12.2. m (40 ft). The record indicates that pressure changes caused by diurnal temperature changes at the land surface, cyclic storm fronts, and seasonal pressure patterns across Southern Nevada are the primary mechanisms for inducing convective air flow in the shallow ground penetrated by these boreholes. Convective mixing and exchange of dry atmospheric air with moist, nearly vapor-saturated pore gases at depth has contributed significantly to the decay of the infiltration pulse that was observed in the shallowest instrument stations earlier in the year.

The equilibrium history of each instrument station clearly reflects the dynamics of the energy systems involved. The shallowest stations reached equilibrium much earlier than the deeper stations. At Yucca Mountain, downhole instrument stations with little or no communication to external energy influences will take longer to equilibrate than those that can communicate readily with their outside environment (i.e., stations located in fractures and faults that provide a permeable flow path to the land surface).

In June 1992, an unsuccessful attempt was made to convert the local PC-based data acquisition system at the HRF boreholes to the Integrated Data Acquisition System (IDAS). The IDAS is the primary data collection, processing, and archiving component of the UZ borehole instrumentation and monitoring program. In July and August 1992, modifications were made to the IDAS code, and a successful restart of IDAS was implemented in September 1992. The HRF boreholes will be utilized as a test bed facility for developing and

testing the interactive component of IDAS. A draft integration test plan for the entire IDAS program was written during the reporting period.

The deep UZ Denver data base has been designed and most of the coding is complete. This data base system is designed to handle data transfers from IDAS and to provide a working data base for preparation of yearly borehole-monitoring data reports. Data that will be resident on this system represents about 10 percent of all the data and information that will be collected and archived by IDAS.

The first insulated instrument shelter (IIS) was completed in September 1992. Acquisition of the environmentally controlled shelter was a major procurement milestone over FY 1992. These shelters are equipped with uninterruptible power supplies, battery back-up systems, heating, ventilating, and air conditioning (HVAC) systems, and electronic keyed entry systems. Environmental monitoring of the shelter and physical access monitoring are integral aspects of the IDAS' data collection functions at the UZ borehole monitoring sites. Additional shelters will be procured in FY 1993.

Preliminary (bench) testing of a data telemetry system that operates in a 970-990 MHz bandwidth was conducted. This system is being evaluated as a possible replacement to the 23-GHz GEMLink system that could not provide the multi-drop communications capabilities needed to operate more than two field sites at a time. Field testing of this equipment is scheduled for mid-October 1992.

Simulated tests of the gas sampling apparatus were conducted at the HRF, using a dual-pressure humidity generator to simulate a nearly vapor-saturated borehole environment. This microcomputer-controlled system is designed to withdraw nearly vapor-saturated gases from deep boreholes without condensing water vapor in the sampling tubes. Tests have indicated that the system can run unattended for extended periods of time and maintain a stable flow of source gas mixed with a dry carrier gas. When the system is deployed in the field, continuous sampling, for periods of up to two weeks, is anticipated.

Drilling continued on the UE-25UZ#16 borehole. Total depth (cored and reamed) as of September 30, 1992, was 244 m (800 ft). Borehole deviation [approximately 3.65 m (12 ft) offset at 244 m] may be a problem for the planned installation of geophones in this borehole. Corrective action to reduce the rate of deviation is being attempted. Current estimated completion date for UE-25UZ#16 is March 1993.

Seismic cross-borehole system testing (cross-hole tomography) continues at the Colorado School of Mines (CSM) Bergen Park Seismic Observatory and the CSM Experimental Mine. Drilling of all four boreholes at the Bergen Park facility has been completed.

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The HRF calibration laboratory has been expanded to calibrate instruments for Surface-Based Air-Permeability Testing. The laboratory is capable of calibrating four-wire pressure transducers [1.05-5.27 kg/cm^2 (15-75 psi)], four-wire thermistors (10 to 45 °C), and is in the process of installing a mass-flow calibration system that will calibrate mass-flow controllers [1 standard cubic centimeter (sccm) to 1,500 standard liters per minute (slpm)]. The support trailer office, reel, winch cover, and boom construction in support of the air-permeability testing has been completed. The control panel, mass flow controllers housing, and hose bundle are presently under construction. The 31.11-cm (12.25-in.) packer assembly is 65 percent complete.

A report entitled "Characterization of Liquid-Water Percolation in Tuffs in the Unsaturated Zone, Yucca Mountain, Nye County, Nevada" (Kume and Rousseau, 1992) was published.

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

Forecast: During FY 1993, rock-core samples from deep UZ boreholes and outcrop samples from Yucca Mountain will be tested in the laboratory for matrix hydrologic properties. Samples will be analyzed for porosity, bulk density, grain density, water saturation, and water potential. Permeability tests will be run on selected core samples. Initial work will begin on a three-dimensional matrix-hydrologic-properties model, using rock physical properties. This activity will define the geohydrologic units in the UZ for use in hydrologic models. A number of activities associated with UE-25UZ#16 will be completed including drilling, borehole geophysical logging, hydrochemical sampling, air-permeability testing, instrumentation with a geophone string, and zero-offset and preliminary variable-offset vertical seismic profiling. The in-situ instrumentation will consist of thermistors, pressure transducers, and psychrometers to measure temperature, moisture potential, and moisture content. All of these instruments will be calibrated at the HRF calibration laboratory prior to emplacement. The hardware and software components of the IDAS will be tested before deployment to field sites. Data communication equipment will be tested under field conditions and additional instrument shelters for deep UZ boreholes will be procured. The prototype IDAS will be evaluated through interactive testing at the HRF boreholes. When in-situ monitoring instruments are emplaced in UZ borehole, the IDAS will be deployed in the field. As additional UZ boreholes are drilled in accordance with the YMP drilling schedule, the same sequence of activities will commence at each new borehole.

2.2.1.8 Study 8.3.1.2.2.4 - Characterization of Yucca Mountain percolation in the unsaturated zone--Exploratory Studies Facility study

Revision 0 of Study Plan 8.3.1.2.2.4 was sent to the NRC on February 9 1991. The NRC has deferred their review of this Study Plan (Activities 4, 5, 7, 8, and 9) until DOE has evaluated the need to revise the plan for consistency with the current ESF design.

Activity 8.3.1.2.2.4.1 - Intact-fracture test in the Exploratory Studies Facility. Laboratory procedures continued to be developed and tested for the determination of fluid-flow and chemical transport properties in discrete fractures. Staff provided support for prototype testing of the percolation test in the ESF. Support included recalibration of all the thermocouple psychrometers instrumenting the block and comparisons to duplicate psychrometers that were calibrated and placed in the block; modifications to the programs for thermocouple psychrometer data collection; preparation of water (adjustment of constituents and tracers) for the test; calibration of pressure transducer tensiometers, and numerous other tasks.

Development of the Moire projection method for fracture profile characterization continued. The high-resolution imaging equipment has been installed, but equipment problems have delayed completion of integrating the USGS equipment into the prototype experimental set-up. The technique utilizing transform analyses for replicating the topographical surfaces will be employed.

Two technical papers concerning the Moire projection technique for fracture topography have completed technical review and are in YMPO review: "Implementation and Use of an Automated Projection Moire Experimental Set-Up" (Cardenas-Garcia et al.), and, "Projection Moire as a Tool for the Automated Determinations of Surface Topography" (Cardenas-Garcia et al.).

Activity 8.3.1.2.2.4.2 - Percolation tests in the Exploratory Studies Facility. The prototype ponding test on a large, fractured, welded-tuff block from the Tiva Canyon columnar unit continued. The block dimensions are 54.3 cm long x 47.5 cm wide x 80.6 cm high. Following testing with two slugs of water during the previous reporting period, a continuous water supply tagged with boron (B) was maintained along the top block surface to maintain a constant and positive water pressure. The initial applied pressure was +10 cm of water, and was later increased to +12 cm. The initial water flow rate into the block was about 100 cubic cm of water per day. However, it gradually decreased to zero within six weeks. The fracture network appeared to be interconnected when it was tested with air prior to starting the test, and accordingly, water flow should have continued under positive pressure. The mineralogy of the fracture coating indicated that less than 1 percent is composed of swelling clays. To date, 15 out of the 18 thermocouple psychrometers are indicating water potentials greater than -80 bars. Five psychrometers are indicating water

saturations close to 1.0, and they will be replaced with tensiometers to obtain more accurate water potential values. This prototype test was scheduled to end in September 1992; however, the completion date will be delayed until causes of water flow cessation are known. A talk entitled "Laboratory Study of Water Infiltration into a Block of Welded Tuff" (Thamir), was prepared and presented at the USGS UZ Interest Group meeting.

Activity 8.3.1.2.2.4.3 - Bulk-permeability test in the Exploratory Studies Facility. Preparation of the Bulk Permeability Tests section of the Study Plan 8.3.1.2.2.4 began.

Activity 8.3.1.2.2.4.4 - Radial borehole tests in the Exploratory Studies Facility. All data from the Apache Leap Tuff Site prototype testing have been reduced and analyzed. All raw and reduced data, along with associated field notes were submitted to the local records center in July 1992. The analysis, results and conclusions will be presented in an Open File Report scheduled for completion in 1993.

The prototype testing identified strengths and weaknesses of the equipment and methods proposed for use in the ESF and surface based air-permeability testing. The measurement and data storage equipment operated adequately. The downhole equipment performed as follows: (1) the pressure transducers had sensitivities of 0.0035 kg/cm^2 (0.05 psi) while operated in voltage mode, (2) the thermistors were stable and had sensitivities of greater than 0.05 °C, and (3) the thermocouple psychrometers were able to monitor the changing relative humidities associated with injection of dry air. The surface-based equipment power sources and data loggers operated without failure, while some minor problems with moisture condensation in the mass flow controllers were identified and solved. The packer system, and its assembly and control system, were found to be difficult to use and prone to failure; therefore, the possibility of using the SEAMIST borehole liner system, in place of packers, is being investigated.

Activities 8.3.1.2.2.4.5 through 8.3.1.2.2.4.10. No progress during the reporting period; these are out-year activities.

Forecast: The accelerated schedule for starting ESF construction requires that preparations for certain construction-phase tests commence early in FY 1993. A design for a confining vessel to apply hydrostatic load to core samples will be completed for the intact fracture test. Subsequently, the confining vessel will be fabricated and tested. Development of the Moire-projection system for characterization of rock-fracture profiles will be completed and reports will be prepared. A report containing results of the large-block ponding test and small-sample imbibition experiments also will be prepared to document the prototype percolation test. Borehole liners, capable of sealing and testing boreholes in the ESF, will be designed for use in a variety of ESF tests, including radial boreholes, bulk permeability, and perched water. A long-term pressure, temperature, and relative humidity monitoring system will be designed for use in the radial boreholes/bulk permeability test. Preparations for the

excavation effects test will begin with the procurement of equipment for fracture-air-permeability, rock stress, and fracture-deformation measurements. Equipment and technical procedures will be prepared for the perched-water test in the event that perched water is encountered during ESF construction. Hydrochemistry testing in the ESF will commence as soon as access to underground openings is available, and will consist of collecting samples from short boreholes for gaseous and aqueous geochemical analysis. As boreholes become available, in situ gas and water sampling will be conducted also.

2.2.1.9 Study 8.3.1.2.2.5 - Diffusion tests in the Exploratory Studies Facility

The Study Plan was approved by DOE on April 22, 1992, and was sent to the NRC on June 8, 1992.

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

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

Study Plan 8.3.1.2.2.6 received NRC acceptance on October 7, 1991. A minor comment in NRC's acceptance letter was responded to on July 23, 1992. Sixteen comments on the Study Plan were received from the State of Nevada on April 27, 1992. DOE responded to the State of Nevada's comments on July 27, 1992, and the Study Plan is currently being revised.

Activity 8.3.1.2.2.6.1 - Gaseous-phase circulation study. Deficiencies identified by a USGS internal QA audit resulted in the issuance of a USGS Corrective Action Report (CAR). Backlogged chemical and gas-flow data collected in support of this study between May 1989 and August 1989 were examined for qualification under the QA program. It was determined that additional data would be collected. The propeller anemometer flow data, temperature data, and relative humidity data were analyzed to attempt to condition the flow data from borehole USW UZ-6s. Conditioning the data allows for the flow direction, in or out of the borehole, to be determined. Two reports were presented at the Unsaturated-Zone Flow and Transport Through Fractured Rock--Related to High Level Radioactive Waste Disposal conference sponsored by the NRC at the University of Arizona. These reports, "Does the Wind Blow Through Yucca Mountain," (Weeks), and "The Carbon Dioxide and Carbon Isotopes of Gases from Borehole UZ-6 at Yucca Mountain," (Thorstenson) are awaiting the resolution of the CAR before publication.

Forecast: Gas samples and gas-flow data will be collected from boreholes USW UZ-6, USW UZ-6s, and selected neutron-access boreholes during FY 1993. The collected data will be analyzed to determine the mechanisms controlling gaseous-phase movement through Yucca Mountain. Flow interference tests will be planned to determine the near-field air conductivities, storativity, and anisotropy of the units above the repository horizon.

2.2.1.11 Study 8.3.1.2.2.7 - Hydrochemical characterization of the unsaturated zone

The NRC accepted Study Plan 8.3.1.2.2.7 on May 1 1992. In their Phase I acceptance letter, the NRC asked for specific references cited in the Study Plan. DOE is preparing to send these references.

Activity 8.3.1.2.2.7.1 - Gaseous-phase chemical investigations. Gaseous-phase isotopic and chemical composition data from test borehole USW UZ-1 was compiled and an interpretive report is in draft form. An extended summary entitled, "Carbon-Isotopic Data from Test Hole USW UZ-1, Yucca Mountain, Nevada," (Yang et al.) was submitted for presentation at the 1993 IHLRWM Conference.

The packer to be used at UE-25UZ#16 and future 31.75-cm (12.5-in.) boreholes to monitor trace gas removal and to collect gas samples from segregated depth intervals underwent several design changes. These included the addition of heat tape to prevent condensation, and a redesign of the packer bladder attachment system. The packers were leak tested in a smooth walled 30.8-cm (12 1/8-in.) pipe to 2.1 kg/cm^2 (30 psi), for 72 hours. A winch and boom system to insert and remove packers was designed for mounting on a flatbed truck and underwent engineering review.

Batch-type testing of the adsorption of tracer gases on Yucca Mountain volcanic tuffs and borehole stemming material is in progress. Initial adsorption testing of one tracer gas, sulphur hexafluoride (SF_6), has been completed on the stemming material and volcanic tuffs from the Pah Canyon Member, the Topopah Spring Member from UE-25UZ#4, and the bedded tuff between the Pah Canyon and Topopah Spring Members.

Research of gas tracers other than chlorofluorocarbons (CFCs) is ongoing. A position paper on tracer use has been compiled. This paper considers the tracers' effects on global warming and ozone depletion issues, as well as the scientific adequacy of each gas for tracer use and the amount of trace gas to be used. The paper contains a table of important physical properties of each potential trace gas.

Monitoring the injection of trace gas into the drilling air at UE-25UZ#16 continued. The calculated and measured concentrations of tracer gas in the drilling air were in good

agreement. The mass flow controller can be rapidly adjusted to match changes in the flow volume of drilling air. Three sample collection ports were installed on the uphole drilling line to check air leakage and an automated tracer injection system was installed and is undergoing testing.

Activity 8.3.1.2.2.7.2 Aqueous-phase chemical investigations. The MI-442 potassium (K) microelectrode and the MI-4 reference probe were calibrated. The electrode will be used in the UZ hydrochemistry lab for measuring K ion concentrations in pore water. Pore-water distilled from several core segments from borehole USW UZN-55 did not indicate any high-level tritium concentrations. Plans are under way to analyze core samples from UE-25UZ#16.

An abstract entitled "Preliminary Isotopic Data on Unsaturated-Zone Flows at Yucca Mountain, Nevada" (Yang) and another abstract entitled "Preliminary Results of Pore-Water Extraction from Unsaturated Tuff by Compression" (Peters et al., 1992) were submitted to the AGU fall 1992 meeting. A paper entitled "Preliminary Isotopic Data on Unsaturated-Zone Flows at Yucca Mountain, Nevada" (Yang, 1992) was submitted to the Water Resources Research Journal.

Pore water extraction tests were conducted on welded and nonwelded tuff cores to determine: (1) the relative efficiency of recovering pore water by continuous loading (rather than stepped loading) from 0 to 120 ksi; (2) if pore water could be extracted efficiently from chips as well as from core; and, (3) if pore-water chemistry results were similar for all methods. The time required for continuous loading compression was about one third of the stepped loading method and pore-water recovery volumes were similar. Preliminary analyses of pore-water chemistry data appear to show very little difference between extraction by continuous versus stepped methods and extraction of water from chips versus core. Pore-water chemical changes due to the compression process are possible because of temperature and pressure changes. However, temperatures inside the compression cell and of extracted water changed little during compression. Although the rock core is being subjected to 120 ksi during compression, the amount of pressure acting on the gas and water in the rock probably is much less because the extraction routes are open to the air. Therefore, the effects of pressure and temperature are seen as minor. A second load frame and data acquisition system was set up for one-dimensional compression testing. A second high-pressure one-dimensional compression cell is nearly completed. This second system will be utilized to do production compression testing.

A draft report entitled "Pore-Water Extraction from Unsaturated Tuff by Triaxial and One-Dimensional Compression Methods, Nevada Test Site" (Mower et al.) is in USGS review. Two papers were published during the period; "Flow and Transport through Unsaturated Rock--Data from Two Test Holes, Yucca Mountain, Nevada" (Yang, 1992) and "A Preliminary Study of the Chemistry of Pore Water Extracted from Tuff by One-Dimensional Compression" (Peters et al., 1992).

Core-sealing tests on 86 core pieces sealed by eight different methods were completed, with weight loss monitored monthly. A report describing the tests, results, and interpretation is in draft form. An extended summary entitled "Investigating the Effects of Core Sealing Methods on the Preservation of Pore Water in Cores" (Striffler and Peters) was submitted for presentation at the 1993 IHLRWM Conference.

Forecast: During FY 1993, in situ gas sampling of UZ borehole USW UZ-1 will continue. Gas and water-vapor samples also will be collected from discrete intervals with borehole UE-25UZ#16 prior to air-permeability testing. Gas and water-vapor samples will be analyzed for chemical and isotopic content and reports will be prepared. Tracer gas injection will be monitored at UE-25UZ#16 and other UZ boreholes that are drilled. An automated gas-injection system, currently under development, will be tested. A report documenting the results of prototype testing of gaseous tracers will be prepared. Core samples collected from UZ boreholes will be transported to USGS in Denver, Colorado for water extraction by compression and distillation methods. The extracted water will be analyzed for cations, anions, and isotopic content. Reports will be prepared on: (1) results of experimentation with sealing methods for rock cores, (2) development of the one-dimensional compression method for pore-water extraction, and (3) effects of high pressure on the chemistry of extracted pore water. In addition, a method for collecting liquid water from fractures in boreholes will be developed and tested.

2.2.1.12 Study 8.3.1.2.2.8 Fluid flow in unsaturated, fractured rock

Study Plan 8.3.1.2.2.8 was revised per YMPO review comments and was approved by DOE August 12, 1992. Revision 0 was submitted to the NRC on September 1, 1992.

Activity 8.3.1.2.2.8.1 - Development of conceptual and numerical models of fluid flow in unsaturated, fractured rock. Fracture network simulations examined the variability in pressure head and flux distribution in variably saturated fractures as a function of boundary pressure head. Relative permeability to air and water, water saturation, and pressure head that reflect the microscopic variation of aperture within hypothetical fractures were first developed by the variable aperture model VSFRAC. The network simulations were performed, using the TOUGH code. Details of this work are described in, "Numerical Investigation of Steady Liquid Water Flow in a Variably Saturated Fracture Network," (Kwicklis and Healy), a paper presented at the PA Flow and Transport Modeling Workshop.

A technique was developed to estimate downward liquid water flux, using data from boreholes UE-25UZ#4 & UE-25UZ#5. The data was used to develop water potential and water saturation profiles. These profiles were used along with effective hydraulic conductivity/

saturation relations and local hydraulic head gradients to estimate downward liquid water flux. The water saturation and water potential profiles will be used to help calibrate numerical models for the nonwelded tuffs above the Topopah Springs unit.

A presentation entitled "Numerical Investigations and Physical Experiments of Flow in Unsaturated, Fractured Rock" (Kwicklis et al.) was made to the joint GIT/HITF workshop on "Preferential Pathways--Definition and Detection" held in Denver, Colorado. The presentation summarized recent modeling efforts as well as experimental work of the Percolation Test Activity (8.3.1.2.2.4.2).

A paper entitled "Semi-Analytical Treatment of Fracture/Matrix Flow in a Dual-Porosity Simulator for Unsaturated Fractured Rock Masses" (Zimmerman and Bodvarsson, 1992) was presented at the 1992 IHLRWM Conference.

A method to determine the hydraulic conductivity function, based on measurements of sorptivity and water retention curves, has been developed by LBL. The method is being applied to data on various welded and nonwelded tuffs. This method will help provide the needed input for site-scale modeling purposes, while limiting the need for prohibitively time-consuming measurements. The lubrication theory model for fracture permeability that was developed at LBL was tested and the permeabilities predicted from the aperture distributions agreed with the measured values to within an average error of 16 percent.

Activity 8.3.1.2.2.8.2 - Validation of conceptual and numerical models of fluid flow through unsaturated, fractured rock. No progress during the reporting period; this is an out-year activity.

Forecast: During FY 1993, the large-block prototype percolation experiment that was conducted during the past year will be simulated with numerical models to evaluate the predictability of water and solute movement in variably saturated fractured tuff. Scoping and bounding calculations will be made, as required, to assist laboratory and field investigators in the design and interpretation of surface-based and ESF tests. Laboratory experiments on imbibition into variably saturated, fractured, and unfractured cores will be simulated as part of the model validation aspect of this study. An existing finite-element, fracture-network model will be adapted to simulate flow and transport for unsaturated conditions. Numerical experiments will be performed to examine the variability in matrix potential and the possible concentration of flow in networks of fractures at fluxes less than the flux at full saturation. Reports will be completed on: (1) a new dual-porosity code for simulating unsaturated flow in fractured tuffs using analytical expressions for fracture/matrix interaction, and (2) the determination of capillary pressure curves for Yucca Mountain tuffs based on inversion of linear sorptivity-saturation data.

2.2.1.13 Study 8.3.1.2.2.9 - Site unsaturated-zone modeling and synthesis

The principal investigator is preparing responses to the review comments on Study Plan 8.3.1.2.2.9.

Activity 8.3.1.2.2.9.1 - Conceptualization of the unsaturated-zone hydrogeologic system. A meeting of UZ modelers was held in Las Vegas, Nevada to review the current strategy to test faults from within the ESF and elsewhere, to present recent modeling work and to review recently acquired data. A field trip to the NTS was conducted to provide UZ modelers and other interested parties with a first-hand look at the stratigraphic section within the UZ at Yucca Mountain, with particular emphasis on fracture and fault characteristics. During the field trip, it was pointed out by geologists that fracture intensities exhibit considerable vertical variability from one subunit to the next.

Activity 8.3.1.2.2.9.2 - Selection, development and testing of hydrologic-modeling computer codes. LBL, in collaboration with USGS, conducted a literature review of unsaturated flow codes. The main purpose of this work was to obtain an understanding of the capabilities of existing numerical codes for unsaturated flow and to investigate their applicability and effectiveness for UZ modeling. Modifications of the computer code TOUGH2 that involve further decoupling of the code so that it can be efficiently used to model three-dimensional moisture flow without effects of gases or temperature were started. A new fully decoupled TOUGH2 code is much needed for the complex three-dimensional simulations of Yucca Mountain.

LBL staff attended the UZ modeler's meeting in Las Vegas, Nevada. The latest results and data were discussed with the USGS and SNL representatives. The results of simulation studies of the steep water level gradient at Yucca Mountain and a two-dimensional cross-section study were presented.

Activity 8.3.1.2.2.9.3 - Simulation of the natural hydrogeologic system. A paper entitled "Design of a Three-Dimensional Model for the Unsaturated Zone at Yucca Mountain, Nevada" (Wittwer et al., 1992) was presented at the 1992 IHLRWM Conference. Another paper by Wittwer et al., that includes results of the first, two-dimensional simulations was accepted for publication in the special issue of Radioactive Waste and the Nuclear Fuel Cycle.

Various meetings were held between USGS and LBL representatives to discuss and exchange the latest results on laboratory measurements and field work. This new information allows the adaptation and improvement of the input parameters for the simulations, as well as to refine the spatial distribution of the sublayers within the hydrogeological units. Data from several sources were used to develop a complete set of rock property data for the 17 sublayers of gridblocks, which represent the vertical lithological variation within the four main hydrogeological units.

A total of four, two-dimensional, vertical cross sections were chosen for numerical simulations. The cross sections cut through the main fault zones, and include as many wells as possible. Various types of rock properties (homogeneous, isotropic, heterogenous - four and 17 layers) and boundary conditions (no-flow, constant infiltration rates) were used to perform the simulations with the integrated finite-difference numerical code TOUGH2. These results were used to control the accuracy of the three-dimensional grid, as well as to evaluate the effect of permeability and porosity contrasts at the boundaries between hydrogeological units and sublayers.

Large-scale three-dimensional simulations with 8000 grid-blocks were successfully run on the IBM RISC machine to test the ability of the hardware and software to handle the kinds of large problems that will be produced by the site-scale model. Programs were developed to adapt the input and output of TOUGH2 simulations to the format used by the graphic package Tecplot, which allows a quick visualization of the input data, as well as the numerical results.

Activities 8.3.1.2.2.9.4 and 8.3.1.2.2.9.5. No progress during the reporting period; these are out-year activities.

Forecast: During FY 1993, evaluation of Yucca Mountain hydrologic, geologic, and geochemical data pertinent to characterizing UZ flow at the site scale will continue. Periodic technical workshops will be held involving modelers and field investigators in the hydrology and geology programs to evaluate implications of collected data for the overall moisture-flow system within the UZ at Yucca Mountain. Two-dimensional, cross-sectional, numerical models will be used to test evolving hypotheses of site-scale flow and to identify possible parameter ranges. Estimated parameter values will be evaluated against existing data sets to assess model validity. A literature review will be conducted of available numerical codes for simulation of unsaturated fluid flow. Codes will be evaluated, a subset of available codes will be acquired and tested, and a report on the code evaluation will be prepared. Testing of the decoupled TOUGH hydrologic-simulator code will be completed and a report describing performance of the code prepared. Development of the preliminary three-dimensional, site-scale, moisture-flow model using the TOUGH code will continue. New geologic and hydrologic data will be incorporated into the model as it becomes available. Reports describing the initial construction of the model and the effects of the model grid on calculated moisture distribution will be prepared. Data on spatial and temporal distribution of infiltration at Yucca Mountain will be incorporated into the model, and the model's sensitivity to infiltration will be tested. Work will begin to integrate the simulation of gaseous-phase flow in the UZ at Yucca Mountain into the site-scale, moisture-flow model. This will be accomplished through compilation and analysis of available gas-flow data, recoupling of the numerical simulators for moisture and gas flow in the TOUGH code, and evaluation of the coupled effects of gas and moisture flow using sub-models.

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

On September 14, 1992, the DOE responded to a variety of concerns expressed in NRC's December 6, 1991, Phase I acceptance letter. These concerns ranged from availability of technical procedures, potential for test-to-test interference, test start dates and duration information, and relationships between this study and performance modeling.

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

Activity 8.3.1.2.3.1.2 - Site potentiometric-level evaluation. Monitoring of water levels in the SZ at Yucca Mountain continued. Monthly water-level measurements were made in 15 wells, and quarterly measurements were made in four wells. Hourly water-level data were collected from 20 zones in 12 wells, and continuous data were obtained in various wells (maximum of two at any one time). All hourly water-level data are now being collected in real time, using data-collection platforms. This type of setup allows for monitoring of the network at any time, via computers and modems, to check on possible water-level excursions or for problems with the data recording equipment. Data loggers and transducers were installed in three wells in order to investigate potential recharge from precipitation and runoff in the Forty Mile Wash area. Forty-seven transducer calibrations and four barometer calibrations were performed. Water levels remained essentially stable during the April-September 1992 period.

Four zones in two wells were monitored continuously to detect water-level fluctuations caused by earthquakes and underground nuclear testing. Several major earthquakes struck California and Nevada during this reporting period, and water-level fluctuations were recorded. Water-level fluctuations in excess of 52.5 cm were recorded for an earthquake in northern California on April 25, 1992, but the fluctuations dampened to less than 1 cm after about 76 minutes. A report summarizing these results, "Earthquake-Induced Water-Level Fluctuations at Yucca Mountain, Nevada, April 1992" (O'Brien, 1992,) was published. Water-level fluctuations for earthquakes in southern California and southern Nevada on June 28-29, 1992, appear to be larger than those for the April earthquakes, but the data are still being analyzed. Slight water-level fluctuations have been observed for earthquakes as far away from Yucca Mountain as central Asia, as well as for several underground nuclear explosions (UNE). Water-level data for the April 1992 and June 1992 earthquakes were provided to the State of Nevada, upon their request

A study of precision and accuracy of water-level data from 1988-90 was completed. Mean precision and accuracy values were calculated; however, accuracy values for these data are somewhat tentative, because of incomplete information on borehole deviation for some

wells. A report entitled "Precision and Accuracy of Manual Water-Level Measurements Taken in the Yucca Mountain Area, Nye County, Nevada, 1988-90" (Boucher) has been written and submitted for USGS approval.

A report entitled "Water Levels in Continuously Monitored Wells in the Yucca Mountain Area, Nevada, 1985-88" (Luckey et al.) was approved and is awaiting publication. The draft report on 1989 continuous water-level data, has been revised in response to USGS reviewer comments. Work was begun on the water-level data report for the 1990-91 period.

Activity 8.3.1.2.3.1.3 - Analysis of single- and multiple-well hydraulic-stress tests. Work continued on a report entitled "Intraborehole Flow and Stress Test" (Patterson). The report will present results from three of the old hydraulic tests and will summarize the remaining tests. Appropriate data were also selected from these previously conducted C-hole aquifer tests and analyzed with dual-porosity techniques in a draft report (Geldon). Work continued on preparation of a report entitled "Strain-Related Water-Level and Fluid-Pressure Responses in Selected Wells, Yucca Mountain" (Galloway et al.).

Monitoring of strain-related hydraulic responses (to atmospheric loading, earth tides, earthquakes, and UNEs) in the H-holes continued. The magnitude 7.4 earthquake of June 28, 1992, epicenter in Joshua Tree, California, and the smaller earthquake of June 29, 1992, epicenter near the community of Amargosa Valley, Nevada, caused transient water-level and confined-pressure changes in wells USW H-5 and USW H-6. All these data are now being analyzed.

Activity 8.3.1.2.3.1.4 - Multiple-well interference testing. The contract for purchase of the additional packers needed to complete the third, three-zone packer string and to convert the three, three-zone packer strings to three, five-zone packer strings was awarded after review and evaluation. The three, three-zone packer strings have been completed and are ready for testing at the Raymond Quarry site in California (U.S. site of the DOE/Atomic Energy of Canada Limited (AECL) International Agreement). Other components of the multiple-zone packer system have been purchased, tested, and incorporated into the system.

LBL completed a seismic tomograph along a vertical cross section between wells UE-25c#2 and UE-25c#3. The tomograph results will assist in designing the upcoming cross-hole hydraulic and tracer tests at the C-hole complex.

Activity 8.3.1.2.3.1.5 - Testing of the C-hole site with conservative tracers. Meetings were held with representatives from manufacturers of down-hole testing equipment to discuss the design and equipment requirements of the tracer injection system. The tracer injection system will allow for the introduction of the tracer into the test zone of interest by injection through the central pipe which supports the packers and all other instrumentation.

Activity 8.3.1.2.3.1.6 - Well testing with conservative tracers throughout the site. No progress during the reporting period; this is an out-year activity.

Activity 8.3.1.2.3.1.7 - Testing of the C-hole sites with reactive tracers. The suite of batch sorption experiments for lithium (Li) bromide was completed. A series of sorption measurements using different fluid concentrations at a specific rock-water ratio was conducted, and the data are being analyzed.

Staff conducted background work on using fluorescent colloids as tracers in the C-well field tests. They investigated using flow cytometry to measure the microsphere concentration in solution as this method can be used to detect low concentrations of microspheres in the presence of natural colloids in solution.

A paper entitled "Thermodynamically Derived Relationships Between the Modified Langmuir Isotherm and Experimental Parameters" (Polzer et al., 1992) was published. The paper discussed the development of modified Langmuir isotherm parameters and thermodynamic ion-exchange properties, leading to a derived relationship between the two. For the binary ion-exchange system, the relationship indicated that a unique set of isotherm parameters can be defined by a minimum set of experimental parameters.

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

Forecast: During FY 1993, critical hydraulic testing will begin at the C-hole complex following several years of test design, equipment fabrication, and analytical-methods development. An analysis of a limited number of past hydraulic tests at the C-hole complex will be completed and a draft report will be prepared. Previously developed numerical and analytical procedures will be applied to analyze the new cross-hole hydraulic and tracer tests as they are conducted at the C-hole complex. Development of additional analysis procedures will continue as the C-hole testing proceeds. Routine monitoring of water levels around Yucca Mountain will continue, as well as special monitoring to quantify the effects of earthquakes on water levels. One or more water-level data reports will be submitted for DOE review and/or will be published during FY 1993. Final plans will be completed for one additional borehole to better define and understand the large hydraulic gradient.

Column sorption tests will be initiated, using a Li bromide tracer. These tests will be compared against the just completed batch sorption studies to evaluate the usefulness of batch sorption data in predicting transport on a laboratory scale. Laboratory fracture-flow transport tests will be initiated, using polystyrene microspheres as tracers. Software certification for computer codes being used in modeling studies will be completed, and preliminary predictions will be made of the behavior of the field tests. Laboratory experimental and modeling work will lead, in the out years, to a suite of field tests at the C-Wells site. The

goal is to demonstrate that laboratory-derived parameters are applicable for predicting field results, and to validate a model for transport of conservative and reactive species in the SZ. These tests will be carried out by LANL in collaboration with USGS.

2.2.1.15 Study 8.3.1.2.3.2 - Characterization of the saturated-zone hydrochemistry

Study Plan 8.3.1.2.3.2 was approved by DOE on April 22 1992, and sent to the NRC on June 5, 1992.

Activity 8.3.1.2.3.2.1 - Assessment of saturated-zone hydrochemical data availability and needs. Previously published and extant hard-file water-chemistry data that had not been entered in the USGS data base since the beginning of geohydrologic support of the weapons and waste programs was compiled. Historic and regional YMP and NTS data, with tentative locations, have been entered into a preliminary data base, and site verification is nearly complete.

A separate spreadsheet file was created with site ground water and precipitation chemical and isotopic data to provide a means to preliminarily assess data suitability at the site scale. Initial perceptions of the quality of site hydrochemical and isotopic data were presented at a workshop on geohydrologic fast paths, jointly organized by the YMP GIT and HIT teams.

Activity 8.3.1.2.3.2.2 - Hydrochemical characterization of water in the upper part of the saturated-zone. Work progressed on assembling information relative to the procurement of a downhole data- and sample-collection system. Meetings and discussions were held with manufacturers and/or suppliers of requisite equipment, including packers, sliding-port sleeves, hoist equipment, pumps, and electrodes. Discussions were held with YMP investigators whose activities include the need for hydrochemical and/or isotopic data and/or samples to ensure that collection methods used will provide requisite data and sample volumes, and will yield samples appropriate to the analyses planned. The development of selected methods has been deferred until downhole sample- and data-collection equipment has been ordered, and until the significance of certain types of information, such as quantification and qualification of ground-water colloids, are better defined. Extant plans for data and sample collection have been examined and informally approved by other YMP investigators and by geochemists from the Swedish, German, French, and British programs. This agreement covered the phases to be sampled, plans for in situ data collection, and the need for rigorous sampling to ensure that samples collected are representative of the geohydrologic system.

Contact was established by USGS with the lead agency involved in the characterization of the ground-water system at the NTS. This will enable USGS investigators to remain aware of ongoing geohydrologic investigations planned by the DOE's Office of

Environmental Restoration. To date, this program has completed two boreholes. One was constructed at a site in the vicinity of Yucca Mountain, but completion efforts did not meet construction objectives, rendering the borehole of little value to YMPO. Three planned holes in the western part of the NTS are of probable interest to YMP investigators. Contact with the contractor responsible for field activities will enable YMP investigators to observe sampling and data collection at the three sites, and to plan for possible YMP sample collection efforts.

Activity 8.3.1.2.3.2.3 - Regional hydrochemical tests and analyses. Meetings were held in Fort Collins, Colorado and Death Valley, California with U.S. National Park Service (NPS) staff to discuss possible sample and data collection at sites within the Death Valley National Monument (DVNM). NPS interest in improving their information base relative to the quantity and quality of waters within the DVNM provides an opportunity to establish a base of hydrochemical and geohydrologic data for generally inaccessible areas. A reconnaissance trip was conducted in May 1992 by NPS and USGS personnel to examine 19 springs within the DVNM that are candidates for sample and data collection. Following the visit, proposed YMP activities within the DVNM were submitted to the DVNM superintendent and natural resources staff for their comment. NPS concerns were identified and addressed in appropriate revisions to planned activities and the tentative schedule. The duration of anticipated work at individual sites will preclude the interruption of wildlife use of the springs, a major NPS concern. A collection permit was obtained from DVNM staff in August 1992, and scoping samples were collected from two springs in the central and southern part of the Monument. An extensive sample- and data-collection effort in the DVNM was planned for the first quarter of FY 1993.

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

Forecast: During FY 1993, assessment of existing hydrochemical data will be completed and new data will be collected throughout the region. Water samples from springs in Ash Meadows and Death Valley will be collected in early FY 1993. Preparations will be made to conduct detailed hydrochemical characterization at and in the vicinity of Yucca Mountain. This will include equipment design, evaluation, and purchases, as well as methods development. Plans will be discussed to purge existing wells at Yucca Mountain in preparation for sampling.

2.2.1.16 Study 8.3.1.2.3.3 - Saturated-zone hydrologic system synthesis and modeling

Study Plan 8.3.1.2.3.3 was revised per YMPO comments on revision 0 and was returned to YMPO on August 28, 1992.

Activity 8.3.1.2.3.3.1 - Conceptualization of saturated-zone flow models within the boundaries of the accessible environment. USGS investigators have completed work on the revised potentiometric map in the vicinity of Yucca Mountain (scale 1:24,000) and the associated report, "Revised Potentiometric-surface Map and Conceptual Model, Yucca Mountain, Nye County, Nevada," (Ervin, et al.). In addition to the revised potentiometric-surface map, a conceptual flow model of the SZ at Yucca Mountain and water-level time trend analyses were developed. The documents are currently in the USGS review process.

The TOUGH2 code, from LBL, was tested for its applicability for modeling the SZ in the vicinity of Yucca Mountain. The code was used to construct a two-dimensional flow model of the large-hydraulic gradient area. Advantages of TOUGH2 are, (1) its ability to simulate a fluctuating water table in a realistic manner with partially saturated conditions above the water table, and (2) its concurrent use to model the UZ at Yucca Mountain.

Activity 8.3.1.2.3.3.2 - Development of fracture network model. LBL completed the draft TRINET user's manual which discusses the theory behind the program, input and output parameters, internal variables and subroutines. The design of the LBL-LANL fracture flow and transport code cross verification was completed. Four cases of LBL-LANL cross verification were conducted. Numerical results were compared to analytical solutions for the one-dimensional transient cases--excellent agreement between the two was obtained. A paper entitled "Fracture-flow Modeling of the Saturated Zone at Yucca Mountain, Nevada" (Karasaki and Ervin) was prepared for publication in late 1992.

USGS investigators continued the mapping of fractures in the Crater Flat Tuff at Raven Canyon to support fracture-network modeling at the UE-25c-hole complex. Seven grid surveys, seven set surveys, and one line survey in the Bullfrog and Prow Pass Members have been completed.

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

Forecast: Work planned in FY 1993 includes refinement of the numerical fracture-network model that will be used to interpret results of hydraulic tests at the C-hole complex. To accomplish this, additional data on fracture networks at Yucca Mountain will be collected through outcrop studies and borehole seismic surveys. These data will be used to condition and constrain the model. The user's manual for the TRINET fracture-network modeling code will be completed. A preliminary design of a porous-media-equivalent model will begin, as well as the synthesis of available data.

2.2.2 Geochemistry (SCP Section 8.3.1.3)

2.2.2.1 Study 8.3.1.3.1.1 - Ground-water chemistry model

The YMPO review of Study Plan 8.3.1.3.1.1 was returned to the principal investigator on May 6, 1992. Comments are now being addressed by LANL.

Activity 8.3.1.3.1.1.1 - Ground-water chemistry model. Two papers were presented at the 7th International Water-Rock Interaction Symposium July 13-18, 1992, in Park City, Utah and were published in the conference proceedings. A paper entitled "Water-Rock Interactions and the pH Stability of Groundwaters from Yucca Mountain, Nevada" (Ebinger, 1992) discussed pH stability of Yucca Mountain ground water during a simulated titration of soluble uranium (U) into different waters. The pH of Yucca Mountain ground water seems to be buffered by bicarbonate and is stable when small perturbations in chemical composition, such as from dissolved U, are introduced.

A paper entitled "Precipitation of Calcite, Dolomite, Sepiolite, and Silica from Carbonate and Tuffaceous Water of Southern Nevada" (Vaniman et al., 1992) was also presented and published in the conference proceedings. The authors discussed the supersaturation of calcite, dolomite, sepiolite, and silica when waters from tuff or carbonate aquifers were evaporated. Calculations were made using PHREEQE and EQ3/6 codes. Model results were reported that compare favorably with samples collected in the field.

Staff modeled pH and Eh in Yucca Mountain ground waters as they related to changes in groundwater chemistry. They also used modeling to measure the solubility of various radionuclides (for example, U and neptunium (Np)) in Yucca Mountain ground water to determine the set of "most-active ground waters," ground waters that dissolve the largest mass of radionuclides.

Forecast: Reviewer comment resolutions from the YMPO review of the Study Plan will be incorporated by March 1993. Preliminary experiments are being designed so that hypotheses concerning pH stability can be tested. Completion of the tests is planned for September 1993. Other activities for FY 1993 are a letter report, "Most-Active Ground-Water, Yucca Mountain, Nevada," to be completed in October 1992, and a report, "pH and Eh Stability of Yucca Mountain Ground-Waters," to be completed in November 1992. An interim report on ground-water chemistry will be completed in September 1993, and results of modeling and experiments related to ground-water chemistry will be completed by September 1994.

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

YMPO asked LANL to prepare a revision to this Study Plan that would incorporate changes required by the ESF design and the changes DOE committed to make in the October 29, 1991 response to comment 1 of the NRC's Phase II review. Final editorial changes for this Study Plan revision began in August 1992 and are in progress.

Activity 8.3.1.3.2.1.1 - Petrologic stratigraphy of the Topopah Spring Member. No progress during the reporting period; this is an out-year activity.

Activity 8.3.1.3.2.1.2 - Mineral distributions between the host rock and the accessible environment. Data were collected and summarized on chemical, mineralogical, petrographic, mechanical, and hydrologic properties for six potential field-testing locations. These locations may be considered for installation of a shallow mined facility for field-testing of rocks analogous to the tuffaceous beds of CH. A report on this work entitled "Geologic Evaluation of Six Nonwelded Tuff Sites in the Vicinity of Yucca Mountain, Nevada, for a Surface-Based Test Facility for the Yucca Mountain Project" (Broxton et al.) is being prepared for YMPO review and approval.

Quantitative x-ray diffraction (XRD) data collection was completed on mineral distributions and their interactions with waste (cation exchange, surface complexation, or co-precipitation). A report describing this work entitled "Mineralogy as a Factor in Radioactive Waste Transport Through Altered Pyroclastic Rocks at Yucca Mountain, Nevada" (Vaniman et al.) is being prepared and is in the YMPO approval process.

Chemical and petrographic studies of 12 calcite samples, from above and below the water table, from drill cores USW G-2 and USW GU-3/G-3, were completed. Trace-element data collected by instrumental neutron activation analysis were used to draw distinctions between drill cores and between calcites above or below the water table. A report on this work entitled "Calcite Deposits in Drill Cores USW G-2 and USW GU-3/G-3 at Yucca Mountain, Nevada" (Vaniman) is being prepared for YMPO review and approval.

Activity 8.3.1.3.2.1.3 - Fracture mineralogy. Data collection was completed on the distribution and mineralogy of fracture-lining manganese-oxide minerals in drill cores from the Yucca Mountain area, and their chemistry, paragenesis, and significance to radionuclide retardation were evaluated. An article on this work entitled "Fracture-lining Manganese Oxide Minerals in Silicic Tuff, Yucca Mountain, Nevada" (Carlos et al.) was prepared, approved by YMPO, and submitted to Chemical Geology.

A preliminary examination of the first 152 m (500 ft) of UE-25UZ#16 was made, and samples of fractures containing silica, calcite, clay, zeolites, and manganese-oxide minerals were requested for further study.

Forecast: Future progress will depend on new drilling within the exploration block or access to the block via the ESF. Studies on core from UE-25UZ#16 will be performed. Work on calcite geochemistry as a guide to relatively recent past transport will proceed, using samples from old core and calcite samples from UE-25UZ#16. A report on the distribution of fracture-lining minerals at Yucca Mountain based on existing (pre-1985) deep core holes will be completed. It is anticipated that core from only one new hole (UE-25UZ#16) will be available for study, and a complete analysis of fracture minerals from that core will be done during FY 1993.

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

The NRC completed its Phase I review and accepted revision 0 of the Study Plan on April 27, 1992. In their acceptance letter, the NRC requested specific references cited in the Study Plan, which DOE sent in a letter dated September 16, 1992.

Activity 8.3.1.3.2.2.1 - History of mineralogic and geochemical alteration of Yucca Mountain. Staff was preparing a working paper that summarized results of calcite-silica studies at Trench 14 and Busted Butte as they pertained to the ground-water upwelling hypothesis around Yucca Mountain.

A paper entitled "Precipitation of Calcite, Dolomite, Sepiolite, and Silica from Evaporated Carbonate and Tuffaceous Aquifers of Southern Nevada, USA" (Vaniman et al., 1992) was presented at the 7th International Symposium on Water-Rock Interaction in July 1992 and was published in the conference proceedings. This paper combined petrographic analysis and modeling to examine the differences in mineral assemblages precipitated from waters that originate either from carbonate or tuffaceous aquifers.

A paper entitled "Preliminary Assessment of Clinoptilolite K/argon (Ar) Results from Yucca Mountain, Nevada, USA: A Potential High-Level Radioactive Waste Repository Site" (WoldeGabriel et al., 1992) was presented at the 7th International Symposium on Water-Rock Interaction in July 1992 and was published in the conference proceedings. This paper discussed the pattern of increasing K/Ar dates with increasing depth that has been documented in four drill holes. WoldeGabriel found that older dates may be crystallization ages, whereas the younger dates may reflect the effects of continued diagenetic reactions of older clinoptilolite with percolating fluids. The results suggested that dating of K-rich zeolites may provide useful information for assessing the zeolitization and zeolite-ground-water interactions at Yucca Mountain.

Data collection was completed on trace-element chemistry and microfossil features used to determine whether or not a calcrete (for example, the calcrete in Trench 14) was of

pedogenic origin. A paper on this work entitled "Pedogenesis of Siliceous Calcretes at Yucca Mountain, Nevada" (Vaniman et al.) was approved by YMPO and is being prepared for journal publication.

Field data were collected and petrographic studies were completed on samples from outcrop sites at Yucca Mountain and Busted Butte that have bearing on evaluating the hypothesis of upwelling water from depth. An abstract on this work entitled "Surface-Discharging Hydrothermal Systems at Yucca Mountain—Examining the Evidence," (Levy, 1992) was prepared for the November 1992 Materials Research Society symposium on the scientific basis for nuclear waste management and published in the symposium program. A full paper is being prepared for the symposium proceedings.

Activity 8.3.1.3.2.2.2 - Smectite, zeolite, manganese minerals, glass dehydration, and transformation. Data collection was completed on the effects of dehydration and rehydration on samples from USW G-4 in the lower vitrophyre of the Topopah Spring Member of the Paintbrush Tuff. The loss of water and volatile elements was assessed, and samples were characterized by x-ray diffraction, infra-red spectral analysis, and chemical analysis. A paper on this work entitled "Dehydration and Rehydration of a Tuff Vitrophyre" (Vaniman et al.) was put into the YMPO review process. Equipment was acquired for the initial stages of long-term steam-heating studies of Yucca Mountain rock samples.

Forecast: During FY 1993, LANL will complete the documentation of research relating to the issue of upwelling ground water. This will include documentation of surface exposures of calcite-silica deposits, breccias, and other altered rocks, their ages and origins. Work will be performed on possible fast fluid pathways and transport processes in the shallow and deep subsurfaces. LANL will collect and study altered rocks and secondary minerals in drill cores and cuttings from UE-25UZ#16 and UE-25JF#3. Studies of K/Ar and Ar/Ar systematics in zeolites and other secondary minerals from Yucca Mountain will continue.

In addition, the first phase of long-term steam-heating studies of Yucca Mountain rock samples will begin. This phase is designed to last one year as a test of equipment and sample-characterization techniques. Other test-related information for ESF design will be provided.

Completion of a letter report on progress in K/Ar and Ar/Ar studies of secondary minerals and completion of a report on chemical transport in zeolitic alteration is expected by September 1993. The second phase of long-term steam-heating studies of Yucca Mountain core samples will begin October 1993. Completion of the final report on laminated calcite-silica deposits in faults is expected by December 1993.

2.2.2.4 Study 8.3.1.3.3.1 - Natural analog of hydrothermal systems in tuff

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

Forecast: No activity is planned for FY 1993.

2.2.2.5 Study 8.3.1.3.3.2 - Kinetics and thermodynamics of mineral evolution

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

Forecast: No activity is planned for FY 1993

2.2.2.6 Study 8.3.1.3.3.3 - Conceptual model of mineral evolution

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

Forecast: No activity is planned for FY 1993

2.2.2.7 Study 8.3.1.3.4.1 - Batch sorption studies

An internal technical review of the Study Plan was completed by LANL in August 1992 and returned to the principal investigator for comment resolution.

Activity 8.3.1.3.4.1.1 - Batch sorption measurements as a function of solid phase composition. Data collection was completed on the effects of crushing and grinding and sieving and washing of samples used in batch sorption measurements of cesium(Cs), Sr, and Np on zeolitized and devitrified tuff. It was found that sorption ratios for all three radionuclides remained essentially the same for tuff size fractions greater than 75 μm. For size fractions under 500 μm, the authors found that unless specific procedures were used to preserve sample bulk composition, mineral fractionation could occur during the grinding process. An abstract on this work entitled "Sorption Characteristics of Yucca Mountain Tuffs as a Function of Particle Size" (Rogers et. al., 1992) was prepared for the November 1992 Materials Research Society symposium on the scientific basis for nuclear waste management and published in the conference program. A full paper (milestone report) was being prepared for the symposium proceedings.

A series of experiments to measure the batch sorption coefficients of Np in crushed-tuff samples under a variety of pH values, carbon dioxide (CO_2) partial pressures, and water compositions was begun. In addition, staff obtained the first atomic-resolution, atomic-force-

microscopy (AFM) images of goethite, an iron oxy-hydroxide mineral with extremely high surface sorption capacity for many cations. Staff began work on hematite using AFM.

A paper entitled "Recent Developments in the Integrated Approach Toward Characteristics of Radionuclide Transport, Yucca Mountain, Nevada" (Simmons and Canepa, 1992) was presented at the Waste Management '92 symposium and published in the symposium proceedings. This paper described the overall and individual strategies of the radionuclide migration program for YMP and how they best suited the YMP's objectives. The focus of the paper was primarily on the minimum K_d strategy. However, the authors also presented substantial information on the radionuclide solubility/speciation testing strategy. A report was published entitled "Proceedings of the DOE/Yucca Mountain Site Characterization Project Radionuclide Absorption Workshop at Los Alamos National Laboratory" (Canepa, 1992) in August 1992.

Activity 8.3.1.3.4.1.2 - Sorption as a function of sorbing element concentrations (isotherms). No progress during the reporting period due to a delay in negotiating the legal aspects of the contract with Stanford University.

Activity 8.3.1.3.4.1.3 - Sorption as a function of ground-water composition. Staff completed experiments and began to prepare a milestone report on the affects on sorption of pre-treating Yucca Mountain tuff samples with a Paleozoic-type ground water. These experiments were intended to reproduce a scenario in which J-13-type ground water, which has flowed through the repository, contacts deeper tuff beds that have previously equilibrated with Paleozoic-type water. It was expected that the additional calcium (Ca) and magnesium (Mg) assumed to be present in Paleozoic-type ground water would compete with the introduced radionuclides for sorption sites, thus reducing the sorptive capacity of the tuffs for leached radionuclides.

Activities 8.3.1.3.4.1.4 and 8.3.1.3.4.1.5. No progress during the reporting period; these are out-year activities.

Forecast: During FY 1993, the batch sorption measurements of Np on crushed-tuff samples under a range of conditions will be completed. LANL staff will continue to follow the minimum K_d strategy and pursue further studies of Np and plutonium (Pu) sorption, at a minimum. Because sorption coefficients for these actinides are so low under conditions expected at Yucca Mountain, it is important that extremely accurate sorption values are available for PA calculations. Submittal of the milestone report on sorption models is scheduled for September 1993.

2.2.2.8 Study 8.3.1.3.4.2 - Biological sorption and transport

A revised version of revision 0 of the Study Plan was submitted to YMPO in September 1992.

Experiments to determine the molecular weight of the siderophore that was isolated from Pseudomonas bacteria were completed. In work related to the chelation of Pu by this siderophore, staff worked on the dissolution of iron oxides by Pseudomonas bacteria.

Progress was made on experimental methods to study the effects of micro-organisms on the transport of metals through unsaturated-soil columns. Crushed-tuff columns were operated under vadose zone conditions, and work was being completed on maintaining sterile conditions within the columns during operation.

Forecast: During FY 1993, procedures will be developed for the study of siderophore/Pu complexation. Other key tasks to be completed are (1) use of iron (Fe) oxides as analogs to Pu oxides, making pure Fe oxides, (2) development of methods to measure Fe dissolution facilitated by micro-organisms, and (3) development of methods to understand the mechanism(s) of microbial-facilitated Fe dissolution.

2.2.2.9 Study 8.3.1.3.4.3 - Development of sorption models

An internal technical review of revision 0 of the Study Plan was completed by LANL in August 1992, and the Study Plan was returned to the principal investigator for comment resolution.

A literature review was completed on far-field transport of CO_2, including retardation mechanisms and possible validation experiments, for management review. Staff evaluated retardation mechanisms for C-14 at Yucca Mountain and potential experimental efforts to determine C-14 retardation.

A paper entitled "A Strategy for the Derivation and Use of Sorption Coefficients in Performance Assessment Calculations for the Yucca Mountain Site" (Meijer, 1992) was published. Meijer presented a strategy for quantifying the interactions between the host rock and important radionuclides including U, Np, C, iodine (I), selenium (Se), and technetium (Tc).

Forecast: Submittal of the milestone report on sorption models is scheduled for September 1993.

2.2.2.10 Study 8.3.1.3.5.1 - Dissolved species concentration limits

All YMPO comments on the Study Plan were resolved by the principal investigator in September 1992. The Study Plan will be submitted to YMPO for verification of comment resolution and subsequent approval.

Activity 8.3.1.3.5.1.1 - Solubility measurements. Staff focused on determining the solubility of Np, Pu, and americium (Am) in UE-25p#1 water under oversaturation and undersaturation conditions.

Three Np oversaturation experiments at 60 °C at pH 6, 7, and 8.5 were completed. XRD patterns for the solids produced were matched to known solids and patterns from previous Np studies at 25 °C in both UE-25p#1 and in UE-25J#13 water. Using solids from the oversaturation experiments at each matching pH, three undersaturation experiments under the same conditions as those testing oversaturation were initiated.

Three Pu oversaturation experiments at 60 °C were begun. Oxidation states were determined at pH 6, 7, and 8.5. Remaining solids were used to begin undersaturation experiments.

Three Am/neodymium (Nd) experiments were begun; all samples underwent gamma pulse-height analysis, and the oxidation states were determined at pH 6 and 8.5. An Am/Nd undersaturation experiment at 60 °C was also begun.

One detailed technical procedure (DP) was completed, and two DPs were in review.

Data collection was completed for a draft paper entitled "Measured Solubilities and Speciation of Np, Pu, and Am in a Typical Ground-water (J-13) from the Yucca Mountain Region" (Nitsche et al.). This paper received YMPO approval and will be published as a LANL report. The authors discussed solubility limits for Np, Pu, and Am in J-13 water at pH values of 6, 7, and 8.5 at 25, 60, and 90 °C from oversaturation. They also provided the oxidation states of the radionuclides in the steady-state solutions and identified many of the solid phases resulting from the experiments.

Activity 8.3.1.3.5.1.2 - Speciation measurements. Recent results on solubility determinations in J-13 water, Pu(IV) speciation using photoacoustic spectroscopy (PAS), and carbonate-ligand exchange processes for U, Pu, and Am actinyl species were presented at an exchange between YMP and the Svensk Karnbranslehantering AB (SKB) in Los Alamos, New Mexico, on May 26-27, 1992.

Pu(IV) EDTA complexation experiments to observe speciation changes in the pH range from 7 to 10 continued, and single crystals of two of these species were grown by slow evaporation from aqueous solution.

Experimental work on the PAS system focused on Pu(IV) in carbonate media. Data were collected as a function of pH, carbonate concentration, Pu concentration, temperature, and presence/absence of Pu(IV) colloid. The absorption spectrum and cross section of bona fide Pu(IV) colloids were determined. Such data are necessary to see if any of the peaks observed in the Pu(IV)-carbonate system correspond to that of a colloid.

Temperature dependence studies on the spectra of Pu(IV) colloid in J-13-like water were completed, and evidence of dissolution of Pu(IV) colloid to dissolved Pu(IV) species was sought. A paper describing part of this work, "Plutonium Carbonate Speciation Changes with pH" (Tait et al., 1992), was prepared and presented at the 203rd National Meeting of the American Chemical Society in San Francisco, April 5-10, 1992. The abstract of the paper was published in the conference proceedings and a complete paper based on this abstract was being prepared.

Carbon-13 Nuclear Magnetic Resonance (NMR) linewidth measurements to characterize ligand exchange were completed for Pu(VI) and Am(VI). A complete series of Am(III) and Pu(III) Oxygen (O)-17 experiments on H_2O exchange were performed. The C-13 NMR experiments to characterize carbonate ligand exchange processes with Am(III) were repeated, and staff devised a new sample tube for use with intensely alpha-active actinides. Based on this work, papers were being prepared describing C-13 NMR characterization of Plutonyl(VI) aqueous carbonate complexes and Americyl(VI) aqueous carbonate complexes. Papers were also being prepared on molecular models for actinide speciation and PAS studies of Actinide(IV) and Actinide(VI) carbonate speciation.

A talk entitled "^{13}C NMR Characterization of Actinyl(VI) Carbonate Complexes in Aqueous Solution" was presented at the Rare-Earth '92 International Conference in Kyoto, Japan, June 1-5, 1992. This talk described the study of carbonate-ligand exchange mechanisms and dynamics for U oxide (UO_2^{2+}), Pu dioxide (PuO_2^{2+}), and AmO_2^{2+} species in carbonate solutions.

<u>Activity 8.3.1.3.5.1.3 - Solubility modeling</u>. No progress during the reporting period; this study was not funded in FY 1992.

<u>Forecast</u>: Activities in FY 1993 will focus on (1) Np, Pu, and Am undersaturation experiments in UE-25p #1 water, (2) Np, Pu, and Am oversaturation experiments in a neutral sodium chloride ($NaClO_4$) electrolyte, and (3) U oversaturation experiments in J-13 water. The PAS development and implementation phase is forecasted to be completed in January 1993. Speciation studies will focus on completion of the PAS study of Pu(IV) in carbonate

media and completion of the NMR study of PuO_2^{2+} in carbonate media. Studies of NpO_2^+ in carbonate media by both PAS and NMR will be initiated. These activities are to be completed in September 1993. All other activities are presently scheduled to remain inactive in FY 1993.

Studies of radionuclide solubility of Np, Pu, and Am from undersaturation in J-13, UE25p #1, and possibly H3 well waters will begin in October 1993. The final phase of speciation determinations for Np, Pu, and Am using PAS and NMR spectroscopies will begin in October 1993, and the final phase of speciation determinations for Np, Pu, and Am will be completed in September 1994. Development and implementation of a thermodynamic data base and solubility and speciation modeling calculations will begin in October 1993.

2.2.2.11 Study 8.3.1.3.5.2 - Colloid behavior

All YMPO comments on the Study Plan were resolved by the principal investigator in September 1992. The Study Plan will be submitted to YMPO for verification of comment resolution and subsequent approval.

Activity 8.3.1.3.5.2.1 - Colloid formation, characterization, and stability. See speciation discussion under Study 8.3.1.3.5.1.

Activity 8.3.1.3.5.2.2 - Colloid modeling. No progress during the reporting period; this study was not funded in FY 1992.

Forecast: Stage 1 studies of Pu colloid will begin in October 1993, and Stage 2 studies of Pu colloid will begin in October 1994.

2.2.2.12 Study 8.3.1.3.6.1 - Dynamic transport column experiments

All YMPO comments on the Study Plan were resolved by the principal investigator in September 1992. The Study Plan will be submitted to YMPO for verification of comment resolution and subsequent approval.

Activity 8.3.1.3.6.1.1 - Crushed tuff column experiments. A paper entitled "Radionuclide Migration Studies for Validating Sorption Data—Past, Present, and Future" (Triay et al., 1992) was published. It describes a strategy to validate batch sorption transport models by conducting advective and diffusive migration experiments on columns of Yucca Mountain tuff.

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Staff completed Np transport experiments under advective and diffusive conditions to elucidate the migration of Np through tuff. Np solutions in J-13 ground water were eluted through columns of crushed and solid Yucca Mountain tuffs. To identify the minerals in tuff responsible for the sorption of Np, the transport studies were complemented by batch sorption studies using pure mineral separates and Yucca Mountain tuff. An abstract on this work entitled "Transport of Np Through Yucca Mountain Tuffs" (Triay et al.) was prepared for the November 1992 Materials Research Society symposium on the scientific basis for nuclear waste management and published in the conference program. Preliminary results indicate that even a trace amount of oxides and oxy-hydroxides in tuffs could result in a significant amount of Np retardation. Results of batch sorption experiments indicate that Fe and manganese (Mn) oxides and oxyhydroxides bind Np strongly with coefficients larger than 10^3 mL/g. A full paper was being prepared for the symposium proceedings.

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

Activity 8.3.1.3.6.1.3 - Unsaturated tuff columns. A milestone report entitled "Measurement of Unsaturated Hydraulic Conductivity in Yucca Mountain Tuff" was in preparation. This report discusses work that has been completed on experimentally determining hydraulic conductivities as a function of water content and evaluating the feasibility of applying an innovative unsaturated-flow technique to transport studies.

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

Activity 8.3.1.3.6.1.5 - Filtration. Staff organized a LANL-sponsored colloid workshop that will be held on May 3-5, 1993.

Forecast: During FY 1993, the analysis of Np transport through solid- and crushed-Yucca Mountain tuff columns and reporting on the results of these experiments will be completed. Initiation of transport experiments to assess the potential for retardation of C-14 at Yucca Mountain and planning and conducting the Yucca Mountain Colloid Workshop are also planned for FY 1993. The primary objective of this workshop will be to evaluate the current data on colloids and determine whether they will significantly increase radionuclide release to the accessible environment at Yucca Mountain. Large block transport experiments and colloid transport experiments using Yucca Mountain Tuffs will begin in October 1993.

2.2.2.13 Study 8.3.1.3.6.2 - Diffusion

All YMPO comments on the Study Plan were resolved by the principal investigator in September 1992. The Study Plan will be submitted to YMPO for verification of comment resolution and subsequent approval.

Activity 8.3.1.3.6.2.1 - Uptake of radionuclides on rock beakers in a saturated system. A paper (Triay et al., 1992) was published (See Study 8.3.1.3.6.1) that discusses the uptake of radionuclides by intact tuff from solutions prepared with water from the NTS well J-13. This paper reported that the diffusion coefficients for tritium in all tuffs studied were on the order of 10^{-6} cm^2/s, the diffusion coefficients for pertechnetate were on the order of 10^{-7} cm^2/s, and large anions (like pertechnetate) were excluded from tuff pores because of their size and charge. The diffusion behavior of the sorbing radionuclides could not be fit assuming reversible, instantaneous, and linear sorption. Results of these studies indicated that conservative transport predictions will result from the diffusion coefficients obtained for tritiated water and batch sorption coefficients obtained for sorbing radionuclides.

Activities 8.3.1.3.6.2.2 and 8.3.1.3.6.2.3. No progress during the reporting period; these are out-year activities.

Forecast: During the next six-month period, LANL will (1) report on available diffusion information for nonsorbing species and (2) complete analysis of and report results for diffusion experiments testing Np transport through Yucca Mountain tuffs. Prototype diffusion tests will begin in October 1993, and will be completed in September 1995.

2.2.2.14 Study 8.3.1.3.7.1 - Retardation sensitivity analysis

The Study Plan was approved by DOE on July 11, 1992, and sent to the NRC on September 1, 1992.

Activity 8.3.1.3.7.1.1 - Analysis of physical/chemical processes affecting transport. To facilitate modeling of radionuclide transport, the computer code FEHMN was used to generate a three-dimensional, finite-element mesh with capability to transport nuclides separately through matrix and fracture materials. In addition, a heat component was added to FEHMN's dual porosity/dual permeability capability.

Activity 8.3.1.3.7.1.2 - Geochemical/geophysical model of Yucca Mountain and integrated geochemical transport calculations. A paper entitled "Sensitivity Analysis of Integrated Radionuclide Transport Based on a Three-dimensional Geochemical/Geophysical Model" (Birdsell et al., 1992) was published. Using a three-dimensional model (TRACRN), the sensitivity of radionuclide migration to the following was assessed: (1) uncertainties in

sorption coefficient, (2) recharge rate, (3) dispersivity length scale, (4) radionuclide species, and (5) source term. Migration of the nuclides ^{99}Tc, ^{135}Cs, and ^{129}I was also studied.

Activity 8.3.1.3.7.1.3 - Transport models and related support. TRACRN, a computer code that models flow and contaminant transport through porous media, was in the certification process in accordance with the LANL software quality assurance plan (SQAP). The design phase was completed and the implementation phase was under way and under review.

In coordination with Study 8.3.1.2.3.1, certification of FEHMN, a code that models heat and mass transfer through porous media, and GZSOLVE, a matrix-solving routine that is a re-use component in FEHMN, TRACRN, and FRACNET, continued in accordance with the LANL SQAP. Work focused on code documentation and verification.

Forecast: During FY 1993, the effects of fracture flow and fracture/matrix interactions on transport in the UZ will be studied. The dual porosity/dual permeability model will be used to model the recent ^{36}Cl data. Questions of scaling with respect to flow and transport in fractures will also be addressed both computationally and by modeling of experimental data.

The minimum K_d sorption strategy will be studied using the following three steady-flow models: (1) uniform properties with the equivalent continuum approach, (2) geostatistical distribution of properties with the equivalent continuum approach, and (3) uniform properties with the dual porosity/dual permeability approach. This approach will test the applicability of the sorption strategy under a range of possible flow scenarios while looking at mechanisms for the introduction of fast paths. Questions of scale concerning the modeling of natural dispersion, both computationally and by modeling experimental data, will also be studied.

Studies of fracture transport, dispersion and diffusion, coupled phenomena, geochemical effects, and colloid transport in the UZ will continue. Additional transport calculations will be run, based on a continually refined geochemical/geophysical model of Yucca Mountain.

Work to enhance code capabilities, perform model validation, and provide documentation in accordance with software QA guidance will continue. TRACRN will be completed by November 1992.

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

Study Plan 8.3.1.3.7.2 was in preparation at LANL.

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

Activity 8.3.1.3.7.2.2 - Field-scale experiments to study radionuclide transport at Yucca Mountain. A conceptual design, which will be incorporated into the Study Plan, for testing radionuclide transport concepts at Yucca Mountain was developed by staff from LBL and LANL. The design uses a combination of geological, geochemical, geophysical, and hydrological techniques to determine flow and solute response over a block of tuff approximately 10 x 10 x 10 m.

A review of existing geologic, geochemical, and hydrologic data from Rainier Mesa, located at the NTS, was completed by LBL, and a report is in internal review.

Activities 8.3.1.3.7.2.3 and 8.3.1.3.7.2.4. No progress during the reporting period; these are out-year activities.

Forecast: Activities in Study 8.3.1.3.7.2 will be deferred. Key tasks needed to complete the Study Plan are (1) building laboratory equipment and writing procedures for using this equipment to measure physical and chemical properties of the rock, modeling experimental design, and developing and building equipment for field application, and (2) resolving the experimental design issue as necessary to provide test-related information for ESF design. It is important to note that Activity 8.3.1.3.7.2.2 also requires test facilities in CH.

2.2.2.16 Study 8.3.1.3.8.1 - Gaseous radionuclide transport calculations and measurements

Activity 8.3.1.3.8.1.1. - Physical transport mechanisms and rates--retardation mechanisms and transport with retardation. (See discussion of gaseous retardation mechanism under Study 8.3.1.3.4.3)

No progress during the reporting period; this study was not funded in FY 1992.

Forecast: No activity is planned for FY 1993.

2.2.3 Rock characteristics (SCP Section 8.3.1.4)

2.2.3.1 Activity 8.3.1.4.1.1 - Development of an integrated drilling program

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

2.2.3.2 Activity 8.3.1.4.1.2 - Integration of geophysical activities

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

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

Study Plan 8.3.1.4.2.1, Activities 1, 2, and 4, were submitted to the NRC on June 22, 1992. Revision 7 of the SCPB eliminated activity 6 of this Study Plan, and moved the scope of work planned for activity 6 to Activity 8.3.1.4.1.2 (Integration of Geophysical Activities).

Activity 8.3.1.4.2.1.1 - Surface and subsurface stratigraphic studies of the host rock and surrounding units. Existing borehole subsurface data were synthesized for inclusion into digital ASCII data bases for eventual incorporation into the LYNX Geoscience Modeling System (GMS). The LYNX software develops multiple stacked cross sections using the subsurface data. The portion of data completed included borehole lithology (from the surface to the base of the Bullfrog Member of the Crater Flat Tuff) for holes within the designated site area (bounded by the Solitario Canyon Fault and the Bow Ridge Fault, on the west and east, respectively, the Yucca Wash Fault on the north, and a east-west line intersecting USW G-3 on the south), downhole survey data, an assumed water table elevation of 730 m (2,395 ft) throughout the site, and topographic data. Cross sections from the Scott and Bonk (1984) map were completed along with nine new cross sections for eventual three-dimensional modeling.

A report on existing boreholes was completed, constituting informal direction to the three-dimensional modeling group. Lithologic and stratigraphic information from water-table boreholes was incorporated into digitized ASCII data bases for the LYNX GMS software package.

An initial log was compiled by reviewing core from the UE-25UZ#16 borehole through 168 m (550 ft) in depth. This depth appears to be near the middle of the nonlithophysal zone of the Topopah Spring Member of the Paintbrush Tuff. The top of the Topopah Spring Member [57.6 m (189 ft) depth] is a pumiceous, vitric tuff with an orange

coloration decreasing downward. Core will continue to be logged as acquired, with final detailed log to be prepared when coring is complete.

Strontium isotopic variations within the Topopah Spring welded and lithophysal units from boreholes USW G-4 and UE-25a#1 were further evaluated to assess the utility of Sr isotopic stratigraphy within the lithologically monotonous repository horizon (cooperative study of the potential repository horizon with LANL). Very high rubidium (Rb)/Sr ratios inherent in the high-silica rhyolite required more accurate measurement of Rb and Sr concentrations by isotope dilution in order to obtain high-precision initial Sr isotopic ratios. In addition, the more recent analyses from USW G-4 were routinely leached with weak acid prior to digestion.

Volcanic units sampled below the water table from boreholes UE-25JF#3 and UE-25J#13 were analyzed for selected trace elements and Sr isotopic compositions. Welded and nonwelded tuffs from these boreholes have been exposed to saturated conditions over long periods of time. Results were added to the Sr data base and will be used to investigate geochemical variations caused by water/rock interactions between volcanic units and ground water.

Activity 8.3.1.4.2.1.2 - Surface-based geophysical surveys. A draft manuscript entitled "Gravity and Magnetic Data of Fortymile Wash, Nevada Test Site, Nevada" (Ponce et al.) was forwarded to the USGS and DOE for approval.

The contract for the seismic reflection profile was completed, and the RFP for the seismic contract was released to potential bidders in June 1992. A site visit for potential bidders was held June 30, 1992, and the location maps of proposed lines were made available. The bid acceptance period closed September 8, 1992, and bids received were submitted for technical evaluation.

Potential locations of shot points were located on strip maps. Area maps for planning of environmental, archeological, test interference, and other pre-work surveys were annotated. Shothole locations were staked to facilitate preactivity surveys.

The proposed USGS bulletin "Status of Regional Geophysical Studies at Yucca Mountain and Vicinity, Nevada and California" (Oliver et al.) containing ten chapters including a geologic summary, and results of gravity, magnetic, magnetotelloric, seismic refraction and reflection, teleseismic stress, and heat-flow studies has been through two technical reviews at the USGS.

Four of the five E-W detailed gravity and magnetic profiles across the Midway Valley area were obtained and have been reduced to help locate the surface of the buried Paintbrush and/or other faults on the east side of Yucca Mountain. The data were presented during a

large NRC site visit on September 18, 1992. The fifth profile in Midway Valley, five E-W lines, and one N-S line in Yucca Wash to the north of Midway Valley were obtained during September 1992. These investigations are designed to support the seismic transect across Yucca Mountain.

The deeper seismic reflections are anticipated to be helpful in describing the contact between rocks of Paleozoic and Tertiary age and the nature of deep faults below Yucca Mountain. Data from this activity will be used to target the location for proposed borehole USW G-5 (currently planned for FY 1994) and will also provide constraints on the interpretation of regional variation in the stratigraphic relationships at Yucca Mountain.

Activity 8.3.1.4.2.1.3 - Borehole geophysical surveys. The evaluation of commercially available downhole electrical logging methods in comparison tests between Dresser-Atlas and Schlumberger in logging runs in USW G-2 culminated in a draft report tentatively entitled "Assessment of Geophysical Logs from Borehole USW G-2, with Recommendations for Future Logging at Yucca Mountain, Nevada" (Nelson and Schimschal) . This report describes an evaluation of a variety of logs and different models of logging tools for acquisition of each log type. The results specify logging tools for future YMP work.

The results and recommendations on logging tools were presented to a "Geophysical Logging Workshop and Forum" held at the Denver Federal Center, Denver, Colorado, in July 1992. Plots of log and core data on 32 boreholes were presented to the UZ modeling group at LBL. Porosity was estimated from the density logs, from core, or from gravimeter logs and was consistently found to be 12-20 percent within the Topopah Springs Member. There was good success determining saturation from the epithermal neutron and dielectric logs in boreholes with diameter less than 35.5 cm (14 in.).

Temperature logs were incorporated into the data base. These will be very useful in assessing hydrological flow units. An algorithm was developed and tested to compute air-filled and water-filled porosity in the UZ, using the density and dielectric logs. A test on the USW G-2 data produced very reasonable porosity logs.

Work was begun in May on the calibration of the magnetic susceptibility tool at the test pits at the Denver Federal Center, Denver, Colorado preparatory to writing technical procedures for operating the tool at Yucca Mountain. Technical procedures for operating the magnetic susceptibility tool and for magnetometer logging were submitted for technical review.

Activities 8.3.1.4.2.1.4 and 8.3.1.4.2.1.5. No progress during the reporting period due to lack of funding.

Activity 8.3.1.4.2.1.6. Revision 7 of the SCPB eliminated this activity from this study because the scope of work is redundant with Activity 8.3.1.4.1.2 (Integration of Geophysical Activities), where integration of geophysical activities, across the program, will take place.

Forecast: In FY 1993, this study will focus on the synthesis of geologic and geophysical data and collection of subsurface geologic and geophysical data from new boreholes, supplemented by outcrop exposures and data collected under Study Plan 8.3.1.4.2.2.

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

Two additional activities (3 and 5) were sent to the NRC on June 15, 1992, as revision 1 to the Study Plan. Work is progressing on another revision to the Study Plan to accommodate the changes needed to adapt Activity 4 to perform ramp wall mapping from the shaft wall mapping envisioned in revision 0.

Activity 8.3.1.4.2.2.1 - Geologic mapping of zonal features in the Paintbrush Tuff. A series of whole-rock tuff samples from the Raven Canyon geochemical reference section were analyzed for selected trace elements and Sr isotopic compositions. Samples consisted of welded and nonwelded units collected in outcrop. Results of mineralogic and petrographic investigations have suggested that the tuffs in this section have never been saturated with ground water. This volcanic section therefore contains some of the least altered lithologic units in the Yucca Mountain vicinity. As such, analyses of lithostratigraphic units from the Raven Canyon section will be used for baseline values to which analyses from the same units sampled in drill core beneath Yucca Mountain can be referenced. These comparisons will allow assessment of the chemical variations and elemental mobility induced by water/rock interactions occurring below the paleo water table. A preliminary extended abstract entitled "Trace-element Variability in Altered and Unaltered Tuffs at Yucca Mountain, Nevada" (Peterman et al.) summarizes results from the Prow Pass and Bullfrog members of the Crater Flat Tuff sampled from the Raven Canyon geochemical reference section and from boreholes UE-25a#1 and UE-25b#1. This report was submitted to the American Nuclear Society (ANS) for presentation at the 1993 IHLRWM Conference.

Mapping and measurement of fault parameters along and within the Ghost Dance Fault on Yucca Mountain continued during the reporting period. The work utilized detailed (1:240 scale) mapping on the rectilinear grid discussed in PR 6. More than 50 percent of the mapped area has some rock exposure, allowing very detailed mapping. The exposures have required differentiation of Quaternary colluvium into two subdivisions. All 61 map areas [61 m x 61 m (200 ft x 200 ft) each] in the original tract have been mapped. The grid for future mapping at this scale was extended south to the proposed location of the ESF south

ramp. This includes an additional 60 grid areas with a total width of 357 m for the mapped area. This extended map area is designed to cover all mapped splays of the Ghost Dance Fault (Scott and Bonk, 1984).

Construction was begun of isopach maps and 2.5-dimensional views of the total lithologic thicknesses of the Tiva Canyon, Yucca Mountain, Pah Canyon and Topopah Spring Members of the Paintbrush Tuff, and tuffaceous beds of CH, Prow Pass, and Bullfrog Members of the Crater Flat Tuff. A data base consisting of borehole and measured-section locations with respect to all of these members was constructed. Three-dimensional illustrations using Dynamic Graphics software to depict the spatial distribution and total thickness of major ash-flow sheets were prepared. The data consisted of borehole and measured-section locations which were converted to a grid-mesh that was interpolated by the Dynamic Graphics software system to create and graphically edit two-dimensional surface models into a three-dimensional display model. These data sets are the first step in the development of the three-dimensional geologic modeling of Yucca Mountain. Installation of the LYNX GMS was completed and the system will be used to generate a three-dimensional display of the geologic framework.

A digitized data base for incorporation into the LYNX system was compiled, verified, and put into ASCII files. Work started on refining cross sections from Scott and Bonk (1984) for incorporation into the three-dimensional model, and for the creation of new cross sections. Work also began on a conceptual approach to a three-dimensional confidence model for the geologic model.

Investigation of stratigraphically and structurally complex terrains at a scale of 1:12,000 in the area north and east of Prow Pass identified numerous faults in the upper units of the Paintbrush Tuff. In May 1992, a portion of the rhyolite of CH was mapped in detail, and a stratigraphic section 183 m thick was measured and sampled in upper Paintbrush Canyon.

An area 2 km x 0.5 km of stratigraphically complex rhyolite of CH has been mapped in detail in upper Paintbrush Canyon. Six separate rhyolite flows were mapped, one of which was identified as a compound flow unit containing two distinct rhyolite lavas. Three separate bedded tuffs with probable time-stratigraphic significance were also mapped, with sedimentary and surge features observed in several. Local angular unconformities were recognized within two of these units. Numerous previously unmapped faults were mapped, with the faults variously displaying strike-slip, dip-slip, and oblique movement. Samples were taken for petrographic studies of lava flows and tuffs within the rhyolite of CH. Additional previously published data were gathered in view of further defining the source and relationships of CH rhyolite to other volcanic rocks in the greater Yucca Mountain area. Compilation of outcrop sections of the Paintbrush Tuff is under way, and field checking of sections began in August 1992.

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A preliminary map of the "East of Beatty Mountain 7.5' Quadrangle" (Fridrich et al.) covering northern Crater Flat was completed in June 1992. An abstract entitled "Tectonic Framework of Crater Flat Basin, Adjacent to Yucca Mountain, Nevada: A Preliminary Report" (Fridrich) described increased faulting and tilting with age, and will be presented at the GSA national meeting in October 1992. Future mapping is planned to test the differing predictions of strike-slip and detachment-fault models.

A stratigraphic correlation chart of rock units exposed near Yucca Mountain is under development. This chart attempts to clarify stratigraphic nomenclature between previous workers.

Activity 8.3.1.4.2.2.2 - Surface-fracture network studies. Statistical analysis for existing stations in the Tiva Canyon Member of the Paintbrush Tuff was completed in June 1992 (histograms and stereo-analysis). Histograms of azimuth and dip were completed, data were verified against field sheets, and stereo analysis was completed.

Fracture data were collected at four bedded-tuff stations and one upper-lithophysal station. The bedded tuff outcrops are located on the west side of Fran Ridge in the vicinity of borehole UE-25p#1. The station in the upper lithophysal is at the location of the UE-25NRG#1 borehole. Fracture data analysis for the bedded tuff stations and cluster analysis to identify fracture sets was completed.

Six traceline surveys approximately 100 feet long were added to the data base to supplement existing data. Evaluation of the fault mapping by Scott and Bonk, 1984, at Pavement 500 was completed. There are no major faults at this location. A correction needs to be made to the Site and Engineering Properties Data Base (SEPDB) as this pavement was incorrectly located on YMP maps.

Three data stations (tracelines) were collected in Solitario Canyon in the bedded tuffs immediately above Topopah Spring rounded-step outcrops and south of the USW UZ-6 borehole. An additional traceline was collected across the location of the minor fault near the UE-25NRG#1 drill pad on the east side of Exile Hill. These data will be incorporated into the local three-dimensional fracture model composed of the UE-25NRG#1 core, surface data stations and the cleared pavement topographically above the UE-25NRG#1 corehole. Clearing of this pavement was started in late August 1992. Work to clear the rock pavement at Fran Ridge prototype test pit started in the last week of August 1992.

Vertical continuity data collection started in late July 1992 in Solitario Canyon. Thirteen data stations were collected in vertical sections near USW H-5 and USW UZ-6. Three data stations were collected at Prow Pass in the Topopah section.

Activity 8.3.1.4.2.2.3 - Borehole evaluation of faults and fractures. Lotus data files for some 29 boreholes were edited and converted to modified ASCII files. Ten percent of available borehole deviation surveys were scanned into the master data base. Television data were prepared for entry into DIPS and STATPAK interpretational software packages. Existing directional data from USW G-2 were transferred to the EXCEL format.

A draft review report describing and evaluating available commercial televiewer imaging capabilities was submitted in September 1992 for technical review.

The basic design of a data base to accommodate integration of borehole and surface fracture distribution studies was completed.

Activity 8.3.1.4.2.2.4 - Geologic mapping of the Exploratory Studies Facility. Work for the Fran Ridge prototype test pit deepening and pavement clearing was begun in August 1992. The bottom of the northern pit was cleaned and rock bolts were installed in the walls of the existing pit. The pit was deepened to a total depth of 6.1 m (20 ft) and 4.3 m (14 ft) nominal diameter. The pit was excavated in the middle nonlithophysal subunit of the Topopah Spring Member of the Paintbrush Tuff. The pit was the site of Throckmorton and Verbeek's fracture collection station Tob-1. The excavation was completed on September 11, 1992.

Activity 8.3.1.4.2.2.5 - Seismic tomography/vertical seismic profiling. Validation and testing of interpretational computer codes ANI90 and VELIN3D continued with improvements to the user interface and to output graphics. These enhancements were developed with actual borehole data from Yucca Mountain to ensure compatibility with the proposed repository setting. Data obtained from previous drilling in the C-hole complex were incorporated into a data base for use in preliminary modeling efforts. This data modeling and code testing determined initial design parameters for the vertical seismic profiling (VSP) field work anticipated for late 1992. Testing of ANI90 and BEAM87 codes was performed with cross-well data from the C-complex holes. Work with ANI90 involved modeling the VSP work planned for the P-1/C-complex wells. The V_p and V_s profiles obtained from well logs in the C-hole complex (V_s derived using a Poisson ratio of 0.27) were used as an input model for the matrix velocity. Various combinations of anisotropy, as derived from fracture density logs in the wells, were used to model the effect of fracture anisotropy on the VSP source locations.

P-wave attenuation and elastic scattering were evaluated in July 1992. Theoretical formulations for S-wave scattering off a sphere were developed and are being considered for inclusion into ANI90. Validation activities using borehole data from the C-holes revealed that the ANI90 and BEAM87 codes will model mean arrivals.

An additional length of seismic line to link VSP with the planned seismic line will be incorporated with the planned seismic reflection survey. The link with the VSP is important to establish the visibility of the fractures below 500 Hz in order to assess the utility of VSP for site-scale characterization. This VSP is intended to be used in borehole UE-25UZ#16.

Initial modeling of the VSP offset distance was performed, including calculation of synthetic seismograms at near and far offsets. Modeling of the VSP was completed determining that the target hole will be either in UE-25p#1 or a C-complex well to interpret and validate the seismic reflection. Cross-hole seismic work done on the C-complex holes revealed surprising high-frequency propagation through the SZ, and fractures were seismically visible in the frequency range being used. It was determined that VSP in UE-25p#1 requires removal of two strings of tubing prior to work. One string carries instrumentation for temperature measurement, and the other is for hydrologic measurements. If UE-25p#1 cannot be used, then VSP will be done in a C-hole location. This would be advantageous because of "piggy-backing" with current cross-hole seismic work being done on the C-complex holes under other activities.

A paper entitled "High-Resolution Seismic Imaging for Characterizing Fractures in Potential Sites for Nuclear Waste Repositories" (Majer et al., 1992) was presented at the 1992 IHLRWM Conference.

Forecast: In FY 1993, emphasis will be on the detailed structural analysis of fault zones within the potential repository area and within the 30-square-km site area of the UZ model. Mapping of the northern part of the Ghost Dance Fault at 1:240 scale will be completed, as will mapping of critical areas east and west of the fault zone to determine the zone of disruption associated with this important fault. Mapping of fracture characteristics will continue.

2.2.3.5 Study 8.3.1.4.2.3 - Three-dimensional geologic model

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

Forecast: No activity is planned for FY 1993.

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

Study Plan 8.3.1.4.3.1 completed comment resolution and verification stages at YMPO.

Activity 8.3.1.4.3.1.1 - Systematic drilling program. A small rock-properties laboratory has been established at SNL to support continued outcrop scoping studies, the Systematic Drilling Program, and the activities in the SNL unsaturated flow and transport laboratory. Equipment installation and shakedown has been mostly completed, and development of technical procedures for quality-affecting activities initiated.

Scoping activities during the reporting period continued to be directed toward refining preliminary estimates of spatial continuity patterns of hydrologic properties in tuff. This work is a collaborative undertaking by SNL and USGS. Recent efforts have consisted of completing the laboratory measurements, conducted principally by the USGS at the HRF, on outcrop samples collected previously and evaluating the results (conducted largely by SNL) statistically and geostatistically.

The strong spatial trends reported by Rautman and Flint (1992), particularly within the basal portion of the Tiva Canyon Member of the Paintbrush Tuff, have been confirmed by the detailed results of the two-dimensional "grid" (which is actually a sequence of 26 short vertical transects measured from a common base) covering this interval on the west side of Yucca Mountain. In fact, the distribution of hydrologic properties now indicates a significant degree of control by stratigraphic units smaller than the microstratigraphic units of Scott and Bonk (1984). This information confirms the interpretation of Rautman and Flint that deterministic geologic processes, operating at both small and large scales, are the primary determinant of material properties at Yucca Mountain. A paper summarizing the field data is being prepared for submission to the 1993 IHLRWM Conference. The use of results from these types of scoping studies is described in the next section (Study 8.3.1.4.3.2, Three-Dimensional Rock Characteristics Models).

A limited natural-analog outcrop-sampling study has been initiated with the collection of several vertical and horizontal transects of the Quaternary Bandelier Tuff near Los Alamos, New Mexico. The Bandelier Tuff consists of well-exposed nonwelded ash flow and air fall units that may be analogous to portions of the vitric tuffaceous beds of CH that are only poorly exposed in the vicinity of Yucca Mountain. In addition, the Bandelier Tuff exhibits a welded facies that is directly analogous to the Paintbrush Tuffs that have been the focus of work at Yucca Mountain. Existence of the same types of spatial correlation patterns, particularly when adjusted for changes in thickness or known lateral extent, would increase confidence that the continuity patterns identified at Yucca Mountain represent some essential property of volcanic tuff (or the processes that produce ash flow deposits). A total of some 200 samples in five transects has been collected to date with laboratory measurement of porosity and bulk density in progress. Geostatistical evaluation of the data will follow.

Further development of the field gas permeameter reported previously (in cooperation with Subactivity 1.6.2.1.1) was deferred pending evaluation of a commercially available apparatus. However, the evaluation unit repeatedly malfunctioned, preventing field testing in

the locally available Bandelier Tuff as planned. Although the equipment issue is unresolved at present, the overall problem remains: Many of the most porous and permeable units encountered at Yucca Mountain (and in the Bandelier Tuff) are too incompetent to be cored for laboratory measurements. It appears to be critical to understand spatial variability of these units because of their potential importance in site performance. If core recovery problems persist during actual site characterization drilling at Yucca Mountain, the issue of how to characterize and model the vitric portion of the tuffs of CH may take on added significance. In situ testing of natural analogs may evolve as the only reasonable means of characterization for these types of units.

Forecast: During FY 1993, the Study Plan will be approved by DOE and sent to the NRC. Scoping activities will focus on completing the work on the two-dimensional transect-grid through the basal Tiva Canyon Member and finalizing the interpretations and implications of those data for the planned conduct of the Systematic Drilling Program. Presentation of this work is anticipated at the 1993 IHLRWM Conference.

Commencement of actual drilling activities under the Systematic Drilling Program and completion of those holes cannot be predicted because of dependence upon other Project activities, specifically other drilling programs. The initiation of drilling activities under this study may be moved up in the schedule upon completion of YMPO review of the overall drilling sequence and schedule. Although the impact of any such schedule revisions cannot be predicted in detail, increased emphasis is being placed on completing all prerequisites for beginning quality-affecting activities.

2.2.3.7 Study 8.3.1.4.3.2 - Three-dimensional rock characteristics models

Preparation of the Study Plan is scheduled to begin during FY 1993.

Activity 8.3.1.4.3.2.1 - Development of three-dimensional models of rock characteristics at the repository site. A set of new geostatistical simulations of hydrologic properties at Yucca Mountain have been generated. The new models are for a limited portion of the stratigraphic section overlying the potential repository, and they incorporate both new data obtained from the shallow neutron-hole drilling program (holes USW UZN-54 and USW UZN -55) and the spatial continuity models developed by Study 8.3.1.4.3.1 (see Section 2.2.3.7). Sequential Gaussian simulation methods have been used to generate alternative stochastic images of porosity and saturated hydraulic conductivity in a two-dimensional cross section approximately 61 m (200 ft) in length and 76 m (250 ft) in thickness extending between the two boreholes. Measurements of porosity and conductivity reported approximately every meter (2-3 ft) on core samples from these holes condition the simulations. The technique produces geologically very reasonable models of the welded lower Tiva Canyon Member of the Paintbrush Tuff, the underlying "Paintbrush non-welded

interval," and the uppermost welded portion of the Topopah Spring Member. Variability among the simulations is relatively small, as expected for a highly conditioned situation where all portions of the model are within the range of correlation of measured data. Eventual computation of ground-water flow though these models will yield a good estimate of the uncertainty associated with a lithologically variable, yet well-described, stratigraphic interval. The important result of this simulation exercise is that it has been possible to produce reasonable models that incorporate both deterministic features (layers) and spatial continuity in a single computational pass, as suggested by Rautman and Flint (1992). The ability to generate complex geologic models without recourse to a large number of computationally separate (and therefore quasi-independent) modeling steps is essential in the uncertainty assessment methodology applied to the Yucca Mountain site by Rautman and Treadway (1991).

One of the major concerns in hydrologic modeling is that material properties data are measured on one scale (in this case, small core samples), yet the modeling of flow and transport must be conducted using the properties applied at a much larger scale. The new geostatistical simulations are being used to develop a computationally efficient method for upscaling material property measurements to represent the corresponding block-effective properties. Geostatistical simulation algorithms can produce models at essentially core-plug scale. The upscaling approach being investigated is to use very detailed models, impose an arbitrary grid of the approximate scale appropriate for hydrologic modeling, and then adapt that grid in an iterative manner until the individual large blocks are as homogeneous as possible. The concept is that an "average" property value computed for a quasi-homogeneous block is more valid as an effective property for that block than would be an equivalent average computed on a highly heterogeneous assemblage of small-scale values. Although this approach explicitly discards the effects of within-block continuity and is only an approximation of the effective "average" for a property such as conductivity, the method is computationally tractable compared with a number of other alternatives. Application of the preliminary adaptive-grid algorithm to the two-dimensional simulations described in the preceding paragraph results in block-scale models that preserve the layered aspects of the physical system. A paper describing both the new geostatistical models and the adaptive gridding algorithm is being prepared for presentation at the 1993 IHLRWM Conference.

Development of modeling capabilities using the LYNX GMS has been limited. Down-hole survey and geologic information from the existing boreholes and the digital, geophysical well-log information from Nelson et al. (1991) have been prepared in LYNX format and entered into the GMS data base. Concurrently with this preparatory development, the investigators from the USGS have acquired a "parallel" LYNX software/hardware installation for use in Study 8.3.1.4.2.1.1 (PR Section 2.2.3.3). SNL staff have transferred copies of the existing data files to the USGS, and the two groups are collaborating on the development of initial models. Such a cooperative effort is desirable because the first aspect of the geology that must be modeled is the geometry ("vertical and lateral distribution") of the

various rock units at the site, which are then superimposed upon that geometric framework. LYNX Geosystems, Inc., the software vendor, is in the process of improving the geostatistical capabilities of the GMS package (including the addition of simulation capabilities, based in part on feedback provided by this activity). Release of the new software version (anticipated early in calendar year 1993) will allow a resumption of more active SNL involvement in the development of LYNX models for Project use.

An integrated collection of advanced geostatistical algorithms and implementing FORTRAN subroutines, developed by the Stanford (University) Center for Reservoir Forecasting (SCRF) with partial funding by the YMP, will be published (Deutsch and Journel). SNL has been utilizing several of these algorithms for several years as a consequence of Project sponsorship of SCRF; however, more widespread availability of the algorithms and software library should dramatically increase exposure and acceptance of these techniques within the broader scientific community. Such acceptance should result in greater confidence in defending estimates of ground-water travel time (GWTT) and material transport for the Yucca Mountain site that are made using those techniques.

Presentation and favorable reception by oversight groups of YMP efforts in geostatistical simulation and its application to assessing uncertainty is also increasing the confidence of SNL staff that this methodology is gaining acceptability in the scientific community. A presentation to SCRF staff and other members of the industrial consortium entitled "Applications of Geostatistics to Nuclear Waste Repository Programs" (Rautman, 1992a) indicates that the YMP application of the simulation approach is judged appropriate by the philosophical originators of the methodology. A second, invited presentation at a special session of the 29th International Geological Congress on advanced methods in engineering geology, "Advanced Geostatistical Methods Applied to the Yucca Mountain High-Level Nuclear Waste Program" (Rautman, 1992b), suggests that the simulation approach to uncertainty assessment is gaining recognition in the international scientific community as well.

Forecast: During FY 1993, the Study Plan will be prepared and submitted for YMPO review. The current set of two-dimensional simulations of both detailed and block-scale properties will be completed and reported, tentatively planned through the forum of the 1993 IHLRWM Conference. The two-dimensional simulations may be extended into three dimensions to develop these capabilities. The integrated software package being used for these simulations should be available on a production basis in time to support PA calculations for ACD. Modeling to meet the needs of the PA group should begin at that time. The specific types of modeling activities attempted for the later PA calculations will be strongly influenced by the results of the ACD exercise.

2.2.4 Climate (SCP Section 8.3.1.5)

2.2.4.1 Study 8.3.1.5.1.1 - Characterization of modern regional climate

A draft of Study Plan 8.3.1.5.1.1 was prepared and is currently being internally reviewed by the USGS.

Activity 8.3.1.5.1.1.1 - Synoptic characterization of regional climate. Work conducted during the reporting period primarily involved technical planning and writing a draft Study Plan.

Forecast: In FY 1993, the Study Plan will move through YMPO review. In addition, precipitation data will be obtained and analyzed from the regional network. This will become an ongoing monitoring activity with data generated when precipitation has been collected, with later syntheses and analyses supporting broader objectives of the climate and geohydrology programs.

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

The NRC accepted the Study Plan on April 27, 1992, with no comments.

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

Activity 8.3.1.5.1.2.2 - Analysis of the stratigraphy-sedimentology of marsh, lacustrine, and playa deposits. Ostracode samples were collected from an outcrop near the Waste Isolation Pilot Plant (WIPP) site in New Mexico to develop a method for linking the Sr isotope composition in ostracodes to the saline composition of the host waters. The method is for use in southern Nevada to help reconstruct mean annual air-temperatures and precipitation, and the seasonal timing of precipitation events.

A new Finnigan MAT 262 thermal ionization mass spectrometer was installed, tested, and accepted. Dissolved Sr concentrations were determined from water samples collected from the Pahrump and Amargosa Valleys.

Software code was written for generic (rather than element specific) exponential mass discrimination and spike subtraction corrections for isotopic data obtained by solid-source mass spectrometry (MS). This code was written in preparation for implementation on the new Finnigan MAT 262. Code was tested on Nd, Sr, and Ca mass spectrometer data and found to work correctly for all cases sampled. In addition, a new procedure for naming files

in the new mass spec was implemented, and a method of accessing previous run data was established. The Finnigan Mat 262 yields much higher precision than previously used spectrometers.

A 19-mile traverse of the Mt. Charleston area of the Spring Mountains at high elevations was conducted to observe geomorphic and stratigraphic evidence for cold climate features that would indicate presence of glaciers during the past.

Activity 8.3.1.5.1.2.3 - Geochemical analysis of lake, marsh, and playa deposits. This is an out-year activity, but because some planned work in Study 8.3.1.5.1.3 was rescheduled for FY 1993, some Sr isotopic scoping work was performed on ostracode valves to assess their utility in paleoclimate and hydrological studies. Ostracodes from the WIPP site in New Mexico were analyzed to determine whether the Sr incorporated into the animals' valves has the same isotopic composition as the water in which they lived. The analyzed samples contained very high Sr abundances [about 2,000 parts per billion (ppm)] which allows determination of Sr isotopic composition on very small sample sizes (about 0.1 mg). In general, isotopic compositions in the analyzed valves were found to be in agreement with coeval waters, implying the technique may prove very useful for identifying water sources.

Activity 8.3.1.5.1.2.4 - Chronologic analyses of lake, marsh, and playa deposits. No progress during the reporting period; this is a out-year activity.

Forecast: The studies in FY 1993 are designed to examine the chemical and physical history of water from a marsh (Las Vegas Valley sediments) and from a shallow lake (southern Pahranagat Lake). These studies are closely integrated with those from the terrestrial paleoecology part of the YMP environmental program.

2.2.4.3 Study 8.3.1.5.1.3 - Climatic implications of terrestrial paleoecology

The NRC accepted the Study Plan on August 27, 1992, and requested copies of specific references cited in the Study Plan.

Activity 8.3.1.5.1.3.1 - Analysis of pack rat middens. This activity has been re-scheduled for FY 1993.

Activities 8.3.1.5.1.3.2 and 8.3.1.5.1.3.3. No progress during the reporting period; these are out-year activities.

Forecast: In FY 1993, these studies will proceed, using both paleontologic and isotopic records to identify climate change in southern Nevada. They will be closely integrated with the lakes, playas, and marshes study. A meeting will be held with participants

in this study and other climate and paleoclimate studies to evaluate progress and to plan the next series of studies or modify existing plans as needed.

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

On September 16, 1992, DOE responded to three concerns in NRC's acceptance letter of December 6, 1991. DOE also provided references cited in the Study Plan that were requested by NRC. On August 21, 1992, DOE responded to 18 State of Nevada concerns regarding the rock-varnish dating technique and its application to this Study Plan, as well as to other applications of the technique during site characterization. A copy of these responses was sent to the NRC in a letter dated September 3, 1992.

Activity 8.3.1.5.1.4.1 - Modeling of soil properties in the Yucca Mountain region. No progress during the reporting period; this is an out-year activity.

Activity 8.3.1.5.1.4.2 - Surficial deposits mapping of the Yucca Mountain area. Initial mapping of the 3.75-minute quadrangle #26 (1:12,000) was completed. This quadrangle includes extensive surficial deposits along Fortymile Wash from just south of the mouth of Pah Canyon to just north of the mouth of Yucca Wash. It also includes the lower Yucca Wash and northernmost Midway Valley north of the area mapped by Wesling et al. (1992). The area overlaps the area mapped by Taylor (1986). In addition, mapping was initiated of the 3.75-minute quadrangles #20 and 21 (1:12,000). These quadrangles include extensive surficial deposits along upper Yucca Wash.

Field checks were conducted of surficial deposits in Fortymile Wash and confluent side canyon drainages. Recent natural exposures of surface deposits, including surficial and buried soils underlying surficial deposits, were noted, which are useful in constraining deposit thicknesses and the geomorphic/climate history. These exposures were used to relate field surface characteristics to mappable photogeologic characteristics of units. Some of these exposures may be used as sampling sites for soil sedimentology and isotopic analyses for deposit age estimation.

Sampling of carbonate-bearing materials in Midway Valley soil pits was initiated for geochronological purposes. Samples consist of clast-coating rinds, massive carbonate from the best-developed K horizons or the most carbonate-rich zones within Bk horizons from older surfaces (Q1 through Q5). Carbonate development in soils from younger surfaces may not be sufficient for U-series dating. Data from these samples will help to provide absolute ages for alluvial surfaces identified through Quaternary mapping and establish a time frame for estimating past states of effective moisture. In addition, samples have been collected from a single horizon within buried Q3 soil exposed over 300 m in trench T5a in Midway Valley.

These samples represent a unique opportunity to assess the consistency of the U-series dates of carbonate developed within a single soil profile that has been imposed on several different lithologic units and slope gradients

Activity 8.3.1.5.1.4.3 - Eolian history of the Yucca Mountain region. Leach studies on soils from playas in the Yucca Mountain area continued. Soils were leached with 10 percent acetic acid, and the leachates were extracted to determine Sr isotopic ratios. These were compared to the Sr isotopic compositions leached with 1.0 N HCl to determine the optimum technique for extraction of authigenic Sr components.

Playa samples from the Yucca Mountain vicinity were analyzed for Sr isotopic compositions and trace element contents. The purpose of this work was to evaluate possible contributions of finely dispersed playa-derived components in Yucca Mountain soil carbonates.

Lead (Pb), U and thorium (Th) isotopes were analyzed in materials from Yucca Mountain and surrounding vicinity. As an means of tracing $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$ ratios within surficial deposits, Pb isotopes were studied from known eolian-derived dust samples, and from some of the units of Paleozoic age in surrounding uplift blocks (Black Marble Mountain, Tarantula Canyon, Curare Canyon, Bare Mountain, Striped Hills). The results of these and other analyses, combined with Sr isotopic and trace element geochemical data, were used to model various constituents and to calculate mass balance mixtures to better define the origins of Yucca Mountain surficial deposits.

Samples from playa deposits (Stewart Valley, Pahrump Valley, Amargosa Valley, Ash Meadows, Mesquite Flat, Alkali Flat, Sarcobatus Flat, and Bonnie Claire playas) were analyzed for selected major- and trace-element abundances as well as Sr isotopic compositions. Leaching studies were performed using different weak acids to determine the amount and composition of acid-soluble Sr. Data were compiled in the YMP Isotope and Geochemistry Support Group (IGSG) Sr data base and will be used to characterize unique chemical components within individual playas.

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

2.2.4.5 Study 8.3.1.5.1.5 - Paleoclimate-paleoenvironmental synthesis

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

Forecast: In FY 1993, samples from the playas will be analyzed for Sr and if necessary, O and C isotopic composition.

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

Incorporation of YMPO review comments on the draft Study Plan is underway.

Activity 8.3.1.5.1.6.1 - Global climate modeling. A test plan was developed for the global ice sheet dynamic model to be implemented by the University of Maine prior to final production runs of ice sheet configurations (climate change scenarios). This effort was completed in September and preparations made for both the test run and production runs to be completed early in FY 1993.

As part of the global atmospheric modeling effort, work continued on preparations for runs with the general circulation model (GCM), GENESIS. Because of the size and complexity of the model, initial work involved QA training and familiarization with subroutines and diagnostic packages. Sets of model design features were identified for testing. Because the model is acquired in complete form from the National Center for Atmospheric Research (NCAR), most model functions cannot be examined explicitly. Therefore, during September, test exercises were developed for the verification and validation of GENESIS to test their performance implicitly.

Preparations began for the initial general circulation model runs with GENESIS. A GENESIS control run, with a mixed-layer ocean, was set up during September 1992. The output of this file will be sent to NCAR for a meso-scale model run. Plans are to start work on this run in late October or early November 1992.

The CLIMAP data base was acquired from NCAR. The data base will be formulated as boundary conditions for the GENESIS hindcast simulation of the last glacial maximum. The data base includes sea-surface temperatures, topography, glacial and sea-ice extents, vegetation, and soil types.

Activity 8.3.1.5.1.6.2 - Regional climate modeling. The analysis of the present-day climate using the RCM nested in a GCM was continued as part of the RCM validation analysis, phase II. The analysis focused on relevant spatial and temporal characteristics of surface climatic variables (e.g., temperature and precipitation) and hydrologic variables (e.g.,

snow cover, evaporation, and infiltration) simulated by the regional model compared with available observation and the output of the driving GCM. Spatial and temporal variability of the model was examined through the use of objective measures of skills such as biases, temporal and spatial standard deviations, correlation coefficients, root mean square errors, and precipitation density functions. Spatial scales ranging from 60 to 800 km and temporal scales from daily to seasonal and interannual were considered. Besides validation of the regional model, one of the objectives of the analysis is to identify improvements obtained with the use of the regional model compared to the GCM. The following are some of the findings:

- The GCM represents the basic seasonal migration of the jet stream, but its large-scale climatology over the region differs substantially from the observed long-term climatology.

- Model nesting is most important over the western United States and the Great Lakes region. Little effect due to coastline representation in the Gulf Coastal areas is produced. (Higher resolution is needed.)

- The GCM and RCM surface air temperatures had similar large-scale patterns and, when regionally averaged, were mostly within 1 °C of each other and 2.5 °C of observations.

- The GCM and RCM precipitation amounts differ substantially.

- Over the western United States, the RCM precipitation agrees more closely with observations from the GCM precipitation in every subregion in every season.

- Simulated precipitation seasonal patterns agree well with observations when averaged over the whole United States; however, the model seasonal performance varies widely from season to season.

- The RCM produces noticeable mesoscale details that compare well with observations during the cold season. In the warm season, the model predictions are much greater than observed (but the observations are averaged over many more years).

- The RCM typically produces precipitation events too frequently, but with less intensity than observed. Accurate simulation of the frequency and intensity of precipitation is important for their effects on surface hydrology.

A paper summarizing some of the results of the RCM validation analysis, phase I, "Simulation of the Arid Climate of the Southern Great Basin Using a Regional Climate Model" (Pollard and Behl, 1992), has been accepted for publication in the Bulletin of the

American Meteorological Society. Some additional analysis of the precipitation field was recently performed. This analysis suggests that the phase I validation analysis should be continued to identify and implement model changes to improve agreements between model results and observations.

The paper "An Overview of the Yucca Mountain Global/Regional Climate Modeling Program" (Sandoval et al., 1992) was presented at the 1992 IHLRWM Conference. A key address was given on regional climate modeling (RCM)at the 26th Annual Congress of the Canadian Meteorological and Oceanographic Society, which was held June 8-12, 1992, in Quebec City, Canada. A journal article, "Precipitation Variations in Southern Nevada: Implications for the Potential Yucca Mountain High-Level Nuclear Waste Site" (McGuirk et al.) was approved for publication by YMPO.

The QA software evaluation of the RCM was performed. The RCM consists of six stand-alone computer codes: MM4BAT is the main code with the other five codes only performing the pre- and post-processing functions. The software evaluation reports for pre- and post-processing software has been completed. The evaluation of MM4BAT is ongoing. The flowchart of MM4BAT has been developed and the subroutines with no formal documentation have been identified. These codes do not have a documented sample run. Therefore, a sample run for the RCM for documentation purposes has been planned and executed.

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

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

Forecast: Review comments on Study Plan 8.3.1.5.1.6 will be resolved in early FY 1993. The study had been targeted for completion at the end of FY 1994. However, based on the results of model validation analysis performed so far, the RCM validation analysis will be continued for a year beyond the current plans. Accordingly, the target date for completion of the study will be shifted to the end of FY 1995. In addition, the schedule of other tasks to be performed in support of this study are currently being reviewed. This may impact the completion date for the study. Over the next 12 months, the RCM (Activity 8.3.1.6.1.6.2) will be continued.

2.2.4.7 Study 8.3.1.5.2.1 - Characterization of the Quaternary regional hydrology.

Revision 2 of the Study Plan was submitted to YMPO for verification of comment resolution on March 31, 1992. A change request to the SCPB to accomplish Activity 8.3.1.5.2.1.2 under the scope of work for Study Plan 8.3.1.2.2.7 is being prepared.

Activity 8.3.1.5.2.1.1 - Regional paleoflood evaluation. Paleoflood channels, drainage basins, alluvial fans, and geomorphic surfaces in the southern Nevada/Yucca Mountain region were evaluated and techniques were developed to investigate regional paleoflood features using a geomorphometric approach. Satellite imagery, aerial photographs, and additional digital data sets were utilized for the regional paleoflood evaluation. Preliminary mapping of the Amargosa River drainage basin and its subbasin boundaries was completed, as was a climatic data base of monthly precipitation for the southern Nevada and southeastern California region for the period 1968-1992.

Field inspections were conducted at the following sites: (1) Potosi Mountain; (2) alluvial fans along the west margin of the Las Vegas Valley; (3) White River drainage system, east of the NTS; (4) Copper Canyon, near Walker Lake; (5) Lower Mojave River, Silver Lake basin and the lower Amargosa River; and (6) Fortymile and Coyote Washes, near Yucca Mountain. Further study of those sites in FY 1993 will provide data on the mechanics of hydrologic transport related to past and present floods. These data will ultimately enable development of a region-wide model relating the magnitude and frequencies of streamflow events to past changes in climate.

Activity 8.3.1.5.2.1.2 - Quaternary unsaturated zone hydrochemical analysis. A change request is being prepared for the SCPB to accomplish this activity's scope of work under Study Plan 8.3.1.2.2.7.

Activity 8.3.1.5.2.1.3 - Evaluation of past discharge areas. Vegetation distribution mapping in the Amargosa Desert has continued. During bloom season, similar plant species were identified and classified. Using the transect data, vegetation species importance indices were computed using standard plant ecology procedures. Hierarchical classification methods were performed on these indices and seven major vegetation communities were identified and then subdivided into 16 subcommunities. Road survey data were correlated to these sub-communities and the resulting correlation data entered into the IDRISI GIS program to develop quantitative vegetation maps of each subcommunity and finally quantitative vegetation communities maps at various probability levels.

Landsat data sets were obtained from the federally owned Landsat Data Library. Thematic Mapper (TM) data tapes have been received in various file formats from different

federal agencies. Vegetation density maps were produced from the imagery. These density maps were overlain on the land use maps and were compared. The imagery is also being compared to the geology and structure maps.

Ostracodes collected in March 1992 have been picked and are being identified. Ostracode distribution data from a scoping study has been compiled in a report entitled "Springs, Water Chemistry, and Ostracode Occurrences in Colorado, Kansas, and New Mexico" (Gutentag et al.), which is in internal USGS review.

Spring and well water samples from the Yucca Mountain region continued to be an important analytical focus contributing to the geochemical characterization of local and regional ground-water flow systems. Advances in analytical techniques resulted in extending the x-ray fluorescence capability to very small sample sizes (50 mL). Also, acquisition of a new thermal ionization multicollector mass spectrometer has allowed routine isotopic data collection at significantly improved levels of precision. New ground-water data from both the Paleozoic carbonate aquifer and the Tertiary volcanic aquifer were collected from a variety of spring and well sites including samples from the Ash Meadows and Amargosa flow systems, from Pahute Mesa, Pahrump, Stateline, UE-25JF#3, UE-25J#12, UE-25J#13, Army #1, Nevares Spring (Death Valley), Crater Flat wells, Franklin Playa, Virgin Spring (Black Mountains), and King (GMC) Spring. All analyses have been compiled in the USGS Yucca Mountain Project Branch/Isotope and Geochemistry Support Group Sr data base and plotted on the 1:250,000 base map from open-file report 90-355. Sr isotopic compositions have received the greatest attention and have been used to suggest flow system pathways which, in some cases, are not consistent with hydrologic models. Several hypotheses have been suggested to explain these data. However, the inherent difficulty of acquiring a large number of closely-spaced, high-quality ground-water samples continued to present the greatest problem to testing hypotheses and resolving issues of flow system pathways.

The following reports related to characterization of ground-water flow systems have been prepared or published during the reporting period. A report entitled "Strontium Isotope Characterization of the Ash Meadows Groundwater System, Southern Nevada, USA" (Peterman et al., 1992) was published in the Proceedings of the 7th International Symposium on Water-Rock Interaction. A preliminary report entitled "Isotopic evidence of complex ground-water flow at Yucca Mountain, Nevada" (Peterman and Stuckless) was submitted for presentation at the 1993 IHLRWM Conference. A draft manuscript entitled "Application of Natural Tracer Isotopes to Paleohydrologic Studies" (Peterman and Stuckless) has been prepared that describes general techniques and theory of natural radioactive decay of Sr, U, Pb, Ca, and Nd isotopes in ground-water systems with specific findings from studies at Yucca Mountain and elsewhere.

In response to recommendations from the NAS (Raleigh et al., 1992), considerable effort was directed towards isotopic characterization of ground water and spring deposits in

Crater Flat. Three well water samples from well USW VH-2 collected over a one-year period yielded identical Sr isotopic compositions values that were considerably greater than other ground-water samples analyzed from the Tertiary aquifer at Yucca Mountain. Sr isotopic compositions from ground water sampled in well USW VH-2 were compared with carbonate paleodischarge deposits at the south end of Crater Flat. A draft report summarizing some of the results of these activities entitled "Strontium Isotopic Evidence for a Higher Water Table at Yucca Mountain" (Marshall et al.) was submitted for presentation for the 1993 IHLRWM Conference.

Carbonate-rich paleodischarge deposits at the southern end of Crater Flat were also the focus of uranium-disequilibrium dating activities. A draft report summarizing the findings of these activities entitled "U-Series Ages of Quaternary Ground Water Discharge, Crater Flat, Nevada" (Paces et al.) was submitted for presentation at the 1993 IHLRWM Conference.

Water and tufa samples collected from Nevares Spring, Death Valley, were analyzed for selected trace-element contents and Sr isotopic compositions to aid in characterization of regional paleodischarge. Several spring water samples were collected approximately one year apart to determine how well the Sr budget of this flow system may be buffered at this time scale. In addition, a suite of tufa samples collected from the spring mound have also been analyzed. Sr contents in seven samples collected from varying stratigraphic position within the mound were determined to see if tufa compositions may record a systematic change in the composition of the discharging water with time.

Forty-three ground-water samples from a spectrum of wells and springs were analyzed for $^{234}U/^{238}U$ ratios and U concentrations. An important aspect of this research has been the identification of a limited U isotopic compositional range for ground waters from the regional carbonate aquifer in contrast to a much larger degree of variation found in waters from the Tertiary volcanic aquifer. These observations will have a significant impact on future studies directed at understanding communication between these two reservoirs. Results were summarized in an extended abstract entitled "$^{234}U/^{238}U$ Ratios as a Ground Water Flow Tracer, SW Nevada-SE California" (Ludwig et al.), which was submitted for presentation at the 1993 IHLRWM Conference.

A project to determine $^{87}Sr/^{86}Sr$ compositions of precipitation samples was initiated. Rain collected during the rare March-April 1992 storms was analyzed for selected trace element contents and Sr isotopic composition. Samples were obtained from four different storms, one of which was sampled sequentially for a total of seven subsamples. These samples provide data for use in understanding the history of Sr isotopes in ground water at the point of recharge.

<u>Activity 8.3.1.5.2.1.4 - Analog recharge studies</u>. Four field trips were conducted to the East Stewart and Kawich Creek study sites. Several snow course surveys were made during

the April 1992 site visit. These data will help in evaluating areal distribution of water equivalents over the respective basins. Above average temperatures and below normal precipitation in the months of April and May 1992 resulted in early spring runoff in both basins.

Long-term air temperatures and precipitation data for Austin, Nevada, were statistically analyzed to develop a perspective of the time-sampling characteristics of the meteorological data collected at the analog sites.

Data from 1985 through 1991 were compiled and a summary report was prepared and submitted for review. The data were used to develop a water data management file to support watershed modeling applications using the precipitation-runoff modeling system (PRMS). The analog recharge study basins were subdivided into hydrologic response units (HRUs) on the basis of slope, aspect, elevation, soil type, and vegetation type to facilitate the testing of PRMS. The testing demonstrated that the available data are adequate for developing accurate simulations of hydrologic water-balance components in these two diverse hydrologic settings (observed annual runoff is an order of magnitude different in the respective basins).

Data on chloride ion concentrations from the bulk precipitation collectors and also from periodic grab samples of streamflow were used to compute average concentrations at the various collections sites. These estimates were used in the first step of the chloride-ion balance equations to estimate average annual "effective losses" (sum of all returns to atmosphere). The difference between average annual precipitation input and these estimates of losses yields estimates of average annual effective moisture (sum of recharge and runoff). Average annual runoff at East Stewart Creek is about 33 cm (13 in.). The comparable figures for estimates of average annual effective moisture range from about 28-33 cm (11-13 in.). Average annual runoff at Kawich is about 1.3 cm (0.5 in.). Estimates of average annual effective moisture range from 2.5-5.1 cm (1-2 in.).

The April and July 1992 quarterly bulk precipitation samples were collected from Organ Pipe Cactus National Monument and Oliver Knoll, Arizona, and were processed as scheduled. Development work on the long-term meteorological instrumentation was completed. Instrumentation was installed at three different levels on the 33-m tower at Organ Pipe Cactus National Monument, and long-term data collection was initiated on August 4, 1992. Final selection and initial survey of the five micro watersheds in the National Monument was completed.

The New Mexico Institute of Mining and Technology completed the following work supporting arid-zone geochemistry during this period: (1) measured the soil water content of 13 soil samples; (2) analyzed 24 soil water samples for deuterium and $^{18}0$; (3) collected 20 samples of caliche, soil and boulders; (4) completed whole rock analyses of 12 samples; (5) performed gadolinium (Gd) and B analyses on 7 samples; (6) extracted 15 boulder samples

for ^{36}Cl; (7) analyzed 27 leachates for chloride; (8) submitted 26 samples for ^{36}Cl analysis; and (9) completed ^{36}Cl analyses of 8 boulder samples.

Activity 8.3.1.5.2.1.5 - Studies of calcite and opaline silica vein deposits. Much of the work in this activity was involved in preparing samples for analysis by MS. The Finnigan MAT 252 installation was completed in September 1992. The "Trapping Box," an automated device for removing water and non-condensables from CO_2, and a Gilson Autosampler, an automated device for the extraction and purification of samples of gas mixtures such as air or CO_2 and water, were prepared for installation. These instruments alone will enormously increase the laboratory's capacity to produce stable isotopic data from carbonates, water samples, and silicates and oxides. In addition, the existing Finnigan MAT 251 mass spectrometer was retrofitted to be compatible with the latest versions of Finnigan's automation software and was equipped with an automated "Kiel" carbonate extraction device. The latter instrumentation will permit the automated analysis of as many as 46 carbonate samples a day. Furthermore, the Finnigan MAT 251 is now capable of analyzing extremely small samples (samples of CO_2 as small as 5 nanomoles have been analyzed) and analysis of 200- to 300-nanomole samples will be routine.

Oxygen isotopic data from opaline silica from trench 14 calcrete and secondary mineralization in Yucca Mountain drill core samples were reviewed to determine formation temperatures for the coexisting calcite in the UZ.

Fluid inclusion studies were performed to determine if boreholes USW G-1 and USW G-2 have inclusions suitable for study. Heating, freezing, and crushing studies progressed during the period.

Calcite samples from site 106 were analyzed for $\Delta^{13}C$ and $\Delta^{18}O$ to determine if these isotopic compositions are consistent with a pedogenic origin. The $\Delta^{13}C$ and $\Delta^{18}O$ values of calcite from the paludal deposits from Site 199 were also determined to compare with those of pond/marshland/playa deposits studied by Hay et al. (1986) and to see if some evaporation of the depositing waters occurred prior to calcite precipitation. This would be consistent with the wetland depositional environment postulated by Taylor (1991).

Arrangements were completed for detailed sampling of trench 14D, the long trench east of Exile Hill, and of sand ramp calcretes and fault-filling calcretes at Busted Butte. Relationships between fault events and cross-cutting mineralization at these trenches and exposures were recently mapped in detail providing the opportunity to date faulting events and to determine the stable isotope systematics of age-constrained pedogenic calcrete samples.

A report entitled "Characterization of Fault-Filling Deposits in the Vicinity of Yucca Mountain, Nevada" (Stuckless et al., 1992) was published. A USGS Open File Report was published entitled "Safety of Proposed Yucca Mountain Nuclear Repository as Regards

Geological and Geophysical Factors: Evaluation of Minority Report by Archambeau and Price" (Evernden, 1992). This report examines and reviews various field relationships, and geochemical and isotopic lines of evidence germane to the ground-water upwelling hypothesis.

Geochemical and isotopic data were collected to evaluate the total carbonate system. The bulk of this work centered on deep vein carbonates in the unsaturated and SZs from drill holes USW G-1, USW G-2, USW G-3/GU-3, and USW G-4. Sr and Nd isotopic compositions of veins and whole-rock leachates were used to continue investigating the origins of the deep carbonate. Studies conducted during the reporting period focused on the extent carbonate chemistries represent local equilibrium with host volcanics, what extent represents exotic components transported by ground-water solutions, and what were the origins of fluids from which carbonate was deposited. In addition, samples from a variety of Paleozoic carbonate rocks in the Yucca Mountain vicinity were analyzed for Sr isotopic compositions. Resulting analyses have been added to the data base to assess their possible contributions as source areas which have supplied some of the eolian components to Yucca Mountain soils.

Several technical papers summarizing some of these results were published or prepared during the reporting period. A report entitled "Strontium Isotope Geochemistry of Calcite Fracture Fillings in Deep Core, Yucca Mountain, NV - A Progress Report" (Peterman et al., 1992) was published in the 1992 IHLRWM Conference Proceedings. A report entitled "Isotopic Studies of Fracture Coatings at Yucca Mountain, Nevada, USA" (Marshall et al., 1992) was published in the Proceedings of the 7th International Symposium on Water-Rock Interaction. A draft manuscript entitled "Isotopic Studies of Cavity Filling and Fracture Coating Minerals as an Aid to Understanding Paleohydrology, Yucca Mountain, Nevada, USA" (Marshall et al.) was prepared for submission to the Organization for Economic Co-operative and Development/Nuclear Energy Agency meeting in France.

Twenty-four samples previously analyzed for Sr isotopes were analyzed for U, Th, and Pb contents as well as Pb isotopic compositions. Results were summarized in a report entitled "Pb Isotopic Composition of Carbonate Rock and Eolian Dust from the Vicinity of Yucca Mountain, Nevada" (Zartman and Kwak) for presentation at the 1993 IHLRWM Conference.

Uranium-disequilibrium series dating was attempted on very thick, well-developed pedogenic calcrete samples that were collected from the southern end of Yucca Mountain off Stagecoach Road (Solitario Canyon/Windy Wash). Initial results were complicated by open-system behavior of decay products and unusual, but reproducible, residue compositions. Additional experiments have been designed to further test whether these deposits can be dated. Personnel completed data documentation requirements in support of the Trench 14 closure package. A report entitled "Origin of Carbonate Deposits in the Yucca Mountain

Area: Results of Strontium-isotope Analyses at Trench 14 and Busted Butte" (Marshall et al.), received final revisions and will be published in a Water Resources Investigations Report (CASY volume).

Forecast: In FY 1993, regional paleoflood evaluations (SCP 8.3.1.5.2.1.1) will focus on geomorphic analysis of possible paleoflood features in the vicinity of Yucca Mountain using map data, digital landscape models, and aerial/satellite images. Results of geomorphic analysis will be combined with field-reconnaissance data to select paleoflood deposits for detailed study. A preliminary summary report on paleoflood studies will be prepared and will describe a comparison of modern and ancient geomorphic features as they relate to paleoflooding. An evaluation of several paleodischarge sites around Yucca Mountain will continue (SCP 8.3.1.5.2.1.3). This evaluation will identify potential discharge sites, attempt to determine whether they were active in the recent geologic past, and ascertain if they were discharge points for perched, local, or regional systems. The initial round of hydrologic, geochemical, and biologic data collection from wet and dry playas and springs, over a broad geographic area, will be completed. Data collection at the two analog-recharge sites will be completed (SCP 8.3.1.5.2.1.4). Historical data from the sites will be analyzed using a precipitation-runoff model. An interpretive report describing the hydrologic balance and net infiltration for the basins will be prepared. The arid-zone infiltration site will be fully instrumented to determine the development of soil geochemistry under different climatic conditions.

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

Study Plan 8.3.1.5.2.2 was revised in response to YMPO review comments and returned to YMPO for a verification review on April 30, 1992.

Activity 8.3.1.5.2.2.1 - Analysis of future surface-water hydrology due to climate changes. Surface-water flow models are being evaluated. The models currently under evaluation include PRMS, HSPF, A634P, and DR3M. These models are available with documentation and are fully supported by the USGS. When complete, the evaluation will define how applicable each model is for use in the arid environment of Yucca Mountain, and how effective it is in terms of predicting (modeling) large-magnitude (flash flood) runoff conditions common to the area.

Activity 8.3.1.5.2.2.2 - Analysis of future unsaturated zone hydrology due to climate changes. A change request for the SCPB was submitted to the YMPO CCB. This change proposes the elimination of this activity because the scope of work will be performed in Activity 8.3.1.2.2.9.5 (Site Unsaturated-Zone Integration and Synthesis).

Activity 8.3.1.5.2.2.3 - Evaluation of possible future changes of the climate and regional geologic framework on the regional saturated zone hydrology. A complete structural analysis of the regional study area was conducted in an attempt to evaluate the effects of stress regimes on ground-water fracture flow. A report entitled "Hydrogeologic Characterization of Structural Discontinuities of Death Valley Region, Nevada and California" (Faunt) describing results of this study is in review. Map products from the study include mapped faults and orientations, structural zones, regional principal stresses, and potential regional flow paths. Flow paths hypotheses are undergoing continual testing with regional geology and within the three-dimensional hydrogeologic framework model.

Regional studies into the mechanism of recharge and discharge continued including both remote sensing and GIS analysis. Regional mapping of vegetation using Landsat TM data was conducted. The products of this work include vegetation distribution and density maps that will be used for three-dimensional ET studies in present, past, and future ground-water flow modeling. Methods are presently being developed that will utilize both comparative and quantitative data in recharge and discharge estimation. Work was completed on the Amargosa vegetation study that will be used as a training set and analog to regional vegetation studies.

Regional Geoscience Information System (GSIS) data base draft reports describing the conversion of geology, surface hydrology, and fault maps into digital format were completed and are in peer review. These draft reports are: "Digital Geologic Maps of the Mariposa, Kingman, Trona, and Death Valley Sheets, California" (Faunt et al.) ; "Digital Hydrographic and Land Use-Land Cover Maps of the Death Valley Region, Nevada-California" (D'Agnes, et al.) ; and "Digital Fault Trace Compilation of the Death Valley Region, Nevada and California" (Faunt et al.). A hydrogeology map report entitled "Hydrogeology of the Death Valley Region, Nevada-California" (Faunt et al.) has been developed and is in review. This surface model (map) will be "digitally linked" to regional cross sections so that construction of the solid model can proceed.

Forecast: This study will be suspended during FY 1993. The future surface-hydrology activity (8.3.1.5.2.2.1) will be suspended until a sufficient base of field data has been accumulated to support precipitation-runoff modeling of basins or subbasins in the vicinity of Yucca Mountain. The future saturated-zone activity (8.3.1.5.2.2.3) will be suspended while the regional three-dimensional ground-water flow model is developed (SCP 8.3.1.2.1.4.4).

2.2.5 Erosion (SCP Section 8.3.1.6)

Work on Study Plan 8.3.1.6.1.1 has been deferred until the NRC has responded to the topical report on erosion.

Technical chapters for the DOE topical report on erosion were completed. Time and effort for this activity were transferred from work that had been planned for 8.3.1.17.4.6. YMP staff gave an oral presentation to the NRC on the technical basis for DOE's conclusions on erosion rates and processes at Yucca Mountain to the NRC in May 1992 and wrote the technical chapters for the DOE topical report in August and September 1992. Minor revisions or responses to comments are anticipated in early FY 1993. A report entitled "Erosion Rates of Yucca Mountain: Technical Assessment and Qualification of Data," (Distel, 1992) was completed. This report documents the technical assessment team's findings and the recommendation that the erosion data be qualified. A paper entitled "Qualification of Existing Data for the Yucca Mountain Site Characterization Project," (Bjerstedt, et al.) was submitted for presentation at the 1993 IHLRWM Conference.

An abstract entitled "Photogrammetric Analysis of Modern Hillslope Erosion at Yucca Mountain, Nevada" (Coe et al., 1992) was published and a manuscript entitled "Volumetric Analysis of Debris Eroded off a Hillslope near Yucca Mountain, Nevada during a Convective Rainstorm" (Coe et al.) was submitted for USGS review with eventual plans to submit to the journal Water Resources Research. These studies documented the processes, results, and implications of modern hillslope erosion at Yucca Mountain through the use of analytical photogrammetric techniques. Volumetric studies were used to determine the amount of available hillslope colluvium eroded from Jake Ridge (about 6 km east of Yucca Mountain) by debris flows during an intense summer rainstorm in 1984 that spanned two days. The report also considers the frequency of these storm events at Yucca Mountain.

A follow up study related to the long-term erosion rate work of Harrington and Whitney (1991) is nearing completion. This study uses photogrammetric methods to calculate the volume of material eroded from relict colluvial boulder deposits on Yucca Mountain. These volumes, used in combination with dates derived from rock varnish on the surface of the deposits, will be used to calculate long-term volumetric erosion rates for the mountain.

Forecast: No Study Plan development or future data gathering activities specifically to assess erosion are presently planned. Response to NRC comments on the erosion topical report is expected in 1993.

2.2.6 Postclosure tectonics (SCP Section 8.3.1.8)

2.2.6.1 Study 8.3.1.8.1.1 - Probability of magmatic disruption of the repository

NRC completed a detailed technical review (Phase II) on July 10, 1992, where 13 comments and one question were offered. A one-day video conference was held with the NRC on August 25, 1992 to discuss their comments, which are now being addressed.

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

Activity 8.3.1.8.1.1.2 - Evaluation of the structural controls of basaltic volcanic events. Revised tables of E1 (recurrence rate) and E2 (disruption ratio) were completed. They included new calculations by the State of Nevada for E1 and E2 and new calculations by M. Sheridan (University of Buffalo) for E2.

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

Activity 8.3.1.8.1.1.4 - Probability calculations and assessment. A paper entitled "Recurrence Models of Volcanic Events: Application to Volcanic Risk Assessment" (Crowe et al., 1992a) was presented at the 1992 IHLRWM Conference and published in the conference proceedings. The paper presented a probability model for volcanic risk assessment for the Yucca Mountain site. Using a simple Poisson model, the recurrence rate of volcanic events was calculated for a range of time-distribution models. Bounds for these rates were estimated from the record of volcanism at active basaltic volcanic fields in and around the Great Basin.

A paper entitled "Recent Progress in Volcanism Studies: Site Characterization Activities for the Yucca Mountain Project" (Crowe et al., 1992b) was presented at the Waste Management '92 symposium in Tucson, Arizona, and was published in the conference proceedings. The paper summarized the progress of volcanism studies for the YMP during 1991 and 1992. Geochronology, geologic mapping, and trenching studies as well as new petrology and volcanic effects are described for the Crater Flat and Paiute Ridge areas. Calculations were performed on the probability of magmatic disruption using new and previously published models. The first draft of the technical report on volcanism is in internal review.

Forecast: During FY 1993, an initial review draft of the major technical report, summarizing more than a decade of site characterization work on volcanism will be completed. Interactions with the NRC on issue resolution for volcanism studies will continue. Values of E1, the recurrence rate of volcanic events, and E2, the probability of repository disruption, will be compiled, based on the most current volcanism data. Integration of structural models of the Crater Flat area with tectonic studies of the USGS will proceed. New structural models from recent mapping performed by USGS will be incorporated in the revisions of E2. A contract to review the existing geophysical data, and its quality, will be let to an external consultant. Study Plan 8.3.1.8.1.1 will be revised in accordance with responses provided to NRC's Phase II review comments.

The major goal of this study is to put the technical report, referenced above, into formal DOE review. Field studies at Lathrop Well center will be completed by September 1993, and revised E1 and E2 tables will also be completed in the same time frame. E3 calculations will also be developed in September 1993.

2.2.6.2 Study 8.3.1.8.1.2 - Physical processes of magmatism and effects on the repository

The draft Study Plan 8.3.1.8.1.2 was completed by LANL in September 1992, and is expected to be submitted to DOE in early FY 1993.

Activity 8.3.1.8.1.2.1 - Eruptive Effects. A paper entitled "Physical Processes and Effects of Magmatism in the Yucca Mountain Region" (Valentine et al., 1992) was presented at the 1992 IHLRWM Conference in Las Vegas, Nevada, and published in the conference proceedings. This paper describes studies of possible eruptive and subsurface effects of Yucca Mountain site disruption by basaltic volcanism. The effects are studied using field characterization of analog volcanic centers and modeling of geologic processes.

Activity 8.3.1.8.1.2.2 - Subsurface effects of magmatic activity. A second phase of field work was completed at the Paiute Ridge intrusion complex, east of Yucca Flat.

Activity 8.3.1.8.1.2.3 - Magma system dynamics. A literature survey on compaction, magma segregation, mantle ascent, magma storage, and crustal ascent was completed.

Forecast: During FY 1993, the Study Plan is expected to be submitted to DOE in early FY 1993. Field work in the Fortification basalt field and the Vulcans Throne area of the Grand Canyon to determine the depth of derivation of lithic fragments in basaltic pyroclastic and lava deposits will begin. Field work will also continue for these topics in the Paiute Ridge and Crater Flat area. First calculations of E3, the probability of exceeding regulatory releases from magma ascending through a repository and erupting at the surface will be completed. These calculations will be incorporated in Study Plan 8.3.1.8.1.1, "Probability of Magmatic Disruption of the Repository." Geologic literature and physical models on the depth of development of the fragmentation surface, conduits, and intrusions below basalt centers of the Great Basin will be evaluated.

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

Study Plan 8.3.1.8.2.1 was sent to YMPO in August 1992 for a verification of comment resolution in August 1992.

Activities 8.3.1.8.2.1.1 through 8.3.1.8.2.1.7. There has been no progress during the reporting period in these activities; they are out-year activities.

2.2.6.4 Study 8.3.1.8.3.1 - Analysis of the effects of tectonic processes and events on average percolation flux rates over the repository

Activities 8.3.1.8.3.1.1 through 8.3.1.8.3.1.7. There has been no progress during the reporting period in these activities; they are out-year activities.

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

Activity 8.3.1.8.3.2.5 - Effects of faulting on water-table elevation. A report on the large hydraulic gradient under Yucca Mountain entitled "A Hydrogeologic Analysis of the Saturated-Zone Groundwater System under Yucca Mountain, Nevada" (Fridrich et al.) has been revised following USGS internal review, and will now be submitted for DOE concurrence and publication in the Journal of Hydrology.

Work supported by this activity contributed to the geologic mapping study 8.3.1.4.2.2.1. An abstract entitled "Tectonic Framework of Crater Flat Basin, Adjacent to Yucca Mountain Nevada" (Fridrich) underwent USGS and DOE review and was submitted to GSA for presentation at the annual convention in Cincinnati, Ohio, and publication in the convention proceedings.

Forecast: The USGS has proposed that one consolidated plan be developed for the current SCP investigations of the effects of tectonic processes and events on containment, the hydrologic system, and geochemical properties. YMPO is currently evaluating the proposed change.

2.2.6.6 Study 8.3.1.8.3.3 - Analysis of the effects of tectonic processes and events on local fracture permeability and effective porosity

Activities 8.3.1.8.3.3.1 through 8.3.1.8.3.3.3. There has been no progress during the reporting period in these activities; these are out-year activities.

2.2.6.7 Study 8.3.1.8.4.1 - Analysis of the effects of tectonic processes and events on rock geochemical properties

Activities 8.3.1.8.4.1.1 through 8.3.1.8.4.1. 4. There has been no progress during the reporting period in these activities; these are out-year activities.

2.2.6.8 Study 8.3.1.8.5.1 - Characterization of volcanic features

The NRC accepted Study Plan 8.3.1.8.5.1 on August 20, 1990. The NRC completed a detailed technical review (Phase II) on March 18, 1991, where three comments were offered. DOE sent a response to those three comments to the NRC on July 23, 1991.

Activity 8.3.1.8.5.1.1 - Volcanism drillholes. No progress during the reporting period due to lack of funding.

Activity 8.3.1.8.5.1.2 - Geochronology studies. A paper entitled "Lathrop Wells Volcanic Center: Status of Field and Geological Studies" (Crowe et al., 1992c) was presented at the 1992 IHLRWM Conference in Las Vegas, Nevada, and was published in the conference proceedings. This paper describes the status of field and geochronology studies at the Lathrop Wells volcanic center: conventional K-Ar and $^{40}Ar/^{39}Ar$ ages for the center are about 100 to 200 ka; the U-Th chronological age of Ql_4 (lava flow) is 150 ± 40 ka; the cosmogenic helium (He) age of the main cone is 25-45 ka and the age of the lavas is 65-70 ka; thermoluminescence ages range between 10 and 25 ka. Soils and geomorphic studies suggest a late Pleistocene or early Holocene age of the main cone.

An article entitled "Measuring the Age of the Lathrop Wells Volcanic Center at Yucca Mountain" (Wells et al., 1992) was published in Science on July 24, 1992. The article is a comment on the Turrin et al. (1991) article also published in Science. Alternative interpretations of $^{40}Ar/^{39}Ar$ age determinations, which incorporate the uncertainty of the measurements and the secular variation of the magnetic field, were presented.

Paleomagnetic data was evaluated for the lava flow units Ql_6, and Ql_5, and the buried lava flow (now labeled Ql_7) at the Lathrop Wells volcanic center, and a U-Th isochron was obtained for the Ql_6 lava. A large trench was constructed on the north side of the center; chemical analyses of various soils from various trenches were obtained. Calibration analyses of thermoluminescence age estimates for sample suites obtained from soils beneath lava flows in the Snake River Plains were completed.

A Detailed Technical Procedure, DP EES-13-610, "Extraction and Analysis of Noble Gases from Solid Samples," was issued.

Activity 8.3.1.8.5.1.3 - Field geological studies. Three phases of trenching at the Lathrop Wells volcanic center were completed with a total of 35 trenches excavated. A second phase of trenching at the Black Tank cone of the Cima volcanic center was completed with 9 trenches excavated. R.V. Fisher of the University of California, Santa Barbara, examined the quarry tephra units of the Lathrop Wells volcanic center and provided information on the origin of the tephra deposits. Safety plans and standard operating procedures for operation of the truck-mounted back-hoe were revised.

Activity 8.3.1.8.5.1.4. - Geochemistry of scoria sequences. Trace-element data for 40 samples were obtained and evaluated for the Lathrop Wells volcanic center.

Activity 8.3.1.8.5.1.5 - Geochemical cycles of basaltic volcanic fields. Isotopic analysis for Pb were obtained for samples of basalt from Crater Flat.

Forecast: Completion of field work and the major phase of trenching at the Lathrop Wells volcanic center is planned. Trenching and sampling at the Sleeping Butte and Crater Flat volcanic centers will begin. Evaluation of the evolutionary cycles of volcanic fields will be expanded to volcanic fields of the Great Basin and Study Plan 8.3.1.8.5.1 will be revised to make it consistent with 8.3.1.8.1.2 and 8.3.1.8.1.1.

2.2.6.9 Study 8.3.1.8.5.2 - Characterization of igneous intrusive features

Study Plan 8.3.1.8.5.2 was completed and underwent USGS internal review. The revised Study Plan was transmitted to YMPO for DOE review in September 1992.

Activities 8.3.1.8.5.2.1 through 8.3.1.8.5.2.3. No progress during the reporting period due to lack of funding.

Activity 8.3.1.8.5.2.3 - Heat flow at Yucca Mountain and evaluation of regional ambient heat flow and local heat flow anomalies. Preparations were made for data collection activities including preparation and approval of all three required technical procedures, and routine maintenance of lab and field equipment. Additionally, lab balances and secondary weight standards were calibrated, a National Institute for Standards and Testing (NIST) calibration for a newly acquired standard thermometer was ordered, and modifications were made to the temperature calibration bath to improve its performance. Plans were made to collect data in the field and temperature logging was conducted in several holes that penetrate Tertiary volcanic rocks adjacent to faults on Yucca Mountain to determine the possible thermal effects of the June 29, 1992 earthquake. Reduction of the logging data was conducted. An abstract entitled "Thermal Evidence for Ground Water Flow Paths at Yucca

Mountain, Nevada" (Dudley and Sass) was submitted for presentation at the 1993 IHLRWM Conference. The abstract addresses the application of temperature data to define ground-water flow paths.

Forecast: During FY 1993, Study Plan 8.3.1.8.5.2 will be submitted to DOE. Variations of temperature with depth will be measured in existing boreholes, and thermal conductivities will be measured on core and cuttings samples.

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

Activity 8.3.1.8.5.3.1 - Evaluation of folds in Neogene rocks of the region. No progress during the reporting period; this is an out-year activity.

Forecast: No activity is planned for FY 1993.

2.2.7 Human Interference (SCP Section 8.3.1.9)

2.2.7.1 Study 8.3.1.9.1.1 - An evaluation of natural processes that could affect the long-term survivability of the surface marker system at Yucca Mountain

Activities 8.3.1.9.1.1.1 and 8.3.1.9.1.1.2. No progress during the reporting period; this is an out-year study.

Forecast: No activity is planned for FY 1993.

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

The Study Plan is ready for YMPO approval, but is on hold pending a management review to ensure that relevant SCA open items are addressed in the Study Plan.

A USGS open-file report ,"Geophysical Characterization of Mineral and Energy Resources at Yucca Mountain and Vicinity, Nevada," was published (Langenheim et al., 1991).

Forecast: Investigations in FY 1993 will include geochemical sampling and analysis for mineral potential, radiometric age dating, evaluation of pre-existing geophysical surveys for anomalies of economic significance, and assessment of hydrocarbon potential in the region

by studies of potential source rocks in the recent Amargosa wildcat wells, hydrocarbon accumulations in Railroad Valley, and a search for potential source rocks in Tertiary sediments near Yucca Mountain.

2.2.7.3 Study 8.3.1.9.2.2 - Water resource assessment of Yucca Mountain, Nevada

The NRC accepted the Study Plan on May 4, 1992. They expressed one concern in their Phase I review letter, concerning how ground water was being regarded as a potential resource, and they requested specific references that were cited in the Study Plan. The former concern was responded to by DOE in a letter dated June 29, 1992, and the latter in a letter dated September 16, 1992.

Activity 8.3.1.9.2.2.1 - Projected trends in local and regional ground-water development, and estimated withdrawal rates in Southern Nevada, proximal to Yucca Mountain. No progress during the reporting period; this is an out-year study.

2.2.7.4 Study 8.3.1.9.3.1 - Evaluation of data needed to support an assessment of the likelihood of future inadvertent human intrusion at Yucca Mountain as a result of exploration and/or extraction of natural resources

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

Forecast: No activity is planned for FY 1993.

2.2.7.5 Study 8.3.1.9.3.2 - An evaluation of the potential effects of exploration for, or extraction of, natural resources on the hydrologic characteristics at Yucca Mountain

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

Forecast: No activity is planned for FY 1993.

2.2.8 Meteorology (SCP Section 8.3.1.12)

2.2.8.1 Study 8.3.1.12.1.1 - Characterization of the regional meteorological conditions

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

Forecast: No activity is planned for FY 1993.

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

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

Forecast: No activity is planned for FY 1993.

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

Revision 0 of Study Plan 8.3.1.12.2.1 was accepted by the NRC on November 12, 1991. YMPO review comments on Revision 1 were sent to the principal investigator on June 17, 1992.

Activity 8.3.1.12.2.1.1 - Site meteorological monitoring program. Meteorological monitoring continued at the five original sites with no significant equipment problems. The monitoring is focused on acquiring atmospheric dispersion information, that is, measurements of airflow and diffusion, but includes other meteorological monitoring for general environmental characterization that could be used for other purposes. Past data were processed in preparation for an upcoming five-year report. Three new stations began operations as of July 1, 1992. These stations were added to provide a finer resolution of airflow and general meteorological characteristics in the area near the ESF work with focus on the nighttime drainage wind patterns. The new stations are as follows: site 6 is "WT-6," at the WT-6 wellpad in upper Yucca Wash; site 7 is "Sever Wash," between Alice Hill and Fran Ridge in the eastern outflow of Midway Valley; site 8 is called "Knothead Gap," and is southeast of the C-well wellpad in the southern end of Midway Valley. The new stations were instrumented similarly to the previous four "remote" stations, with the addition and/or change of four measurements. The basic height for humidity and temperature was established as 2-m above ground level (m-agl) to comply with current monitoring guidance. Delta-temperature 10 m-agl, solar radiation, and vertical wind speed measurements were added as likely atmospheric stability indicators for future dispersion modeling work.

A limited amount of meteorological data from two calendar quarters were reported to the State of Nevada to fulfill monitoring conditions associated with Air Quality Permit No. 2693. Particulate matter data are also reported in the State reports. The air quality data are collected under environmental programs not included in the SCP. This activity is included for continuity, although outside the scope of the SCP.

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

Forecast: The data collection program is planned to continue throughout FY 1993. The Study Plan revision is scheduled to be completed by October 1992. Revision 0 of this Study Plan was approved by DOE on March 20, 1991. It was sent to the NRC on May 16, 1991, and was accepted on November 12, 1991, with no comments. A CAR from YMPO QA audit YMP-92-004 occurred in March 1991, with respect to variances in Study Plan format and level-of-detail requirements from administrative procedure 1.10Q (YMPO's preparation, review, approval and revision procedure for Study Plans). On March 30, 1991, YMPO directed Science Applications International Corporation (SAIC) to undertake a revision to the Study Plan to address the CAR. This revision is in preparation by SAIC. The required data will continue to be reported to the State of Nevada to maintain the air quality permit. A fourth new site (site 9), which is similar to the three new ones, is planned for the Gate-510 location along the southern border of the NTS near the community of Amargosa Valley. Work is also under way to upgrade the first five sites to the additional measurement capability of the four new sites.

2.2.8.4 Study 8.3.1.12.3 - Studies to provide data on the location of population centers relative to wind patterns in the general region of the site

This investigation on the SCP was written with no distinct studies or activities. Instead of a study plan, a Scientific Investigation Implementation Package (SIIP), which is the planning document used for investigations, was written to control work performed for this investigation. This is the first report of work on this investigation.

The SIIP entitled "Scientific Investigation Implementation Package for Characterizing Wind Patterns Relative to Population Centers" received final YMPO approval on April 1, 1992. The work in the SIIP is divided into four tasks, which can be grouped into two major efforts. Tasks 1 through 3 are planned to identify population centers and to characterize regional and local wind flow patterns relative to the centers using data from sources outside this investigation. Task 4 is planned to characterize nocturnal down-valley winds, which could be the most important wind pattern for this investigation. This task includes a special study with participation from the National Oceanic and Atmospheric Administration (NOAA) Atmospheric Turbulence and Diffusion Division (ATDD) from Oak Ridge, Tennessee.

A planning meeting for work in Task 4 was held in Las Vegas, Nevada, on September 1, 1992. It was attended by NOAA/ATDD and NOAA Weather Service office (WSNSO). WSNSO may participate in the field work in Task 4.

Forecast: During FY 1993, existing regional and local data will be compiled, and preliminary analysis will begin. Planning for the primary special field measurements will be completed and the measurements are planned for October 1993. There are no interim reports in this work.

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

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

Forecast: No activity is planned for FY 1993

2.2.9 Offsite installations and operations (SCP Section 8.3.1.13)

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

2.2.10 Surface characteristics (SCP Section 8.3.1.14)

The DOE responded on August 31, 1992, to NRC concerns about the level-of-detail in the Study Plan expressed in their Phase I review of the Study Plan. DOE also responded on August 21, 1992 to ten comments on this Study Plan from the State of Nevada.

2.2.10.1 Study 8.3.1.14.2.1 - Exploration program

This study began in October 1991 and was essentially competed in March 1992. The purpose of this reconnaissance study was to identify the locations for a series of soil test pits to be excavated.

2.2.10.2 Study 8.3.1.14.2.2 - Laboratory tests and material property measurements

All of the north ramp ESF test pits, 33, were excavated and the in-place testing was completed in May 1992. Removal of the typical 0.3-0.6 m (1-2 ft) of topsoil to the widespread caliche-cemented gravelly material is expected to provide an excellent foundation for the anticipated north ramp surface facility structures. Data from density and caliper logs and check shot data will be used to determine dynamic moduli for the rock and alluvium. Drill hole UE-25NRG#1 was completed in June 1992, and pit wall mapping of the test pits was completed. The core was received in July 1992 by the USBR laboratory in Denver, and testing of core is under way to provide data needed by RSN to complete design work and verification for pad construction. Geophysical logging of UE-25NRG#1 is scheduled for completion in November 1992. The work to clear a pavement adjacent to UE-25NRG#1 was finished, and detail line surveys were run to provide the fracture information requested for ESF design.

Laboratory investigations under this activity tested a range of soil and rock properties. This was a major effort in May-June 1992 with soil gradations, and relative and/or Proctor densities determined for seven representative locations.

Soil and rock properties (engineering data) were reviewed as acquired and submitted for use in the design process for surface facilities. Logs and laboratory test data for representative soil materials were submitted to YMPO's TDB in September 1992.

The draft reports for field testing of physical properties of the rock, for engineering geophysical evaluation, for laboratory investigation of physical and mechanical properties of samples, and for field measurements of mechanical properties of materials in the North Ramp site area were submitted to the ESF designers in June 1992. The check shot equipment was tested at the site in September 1992.

U.S. Bureau of Reclamation (USBR) participants met in September 1992 with USGS representatives and discussed adjustments to the north ramp and south ramp geotechnical drilling plans in response to DOE requests.

2.2.10.3 Study 8.3.1.14.2.3 - Field tests and characterization measurements

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

Forecast: In FY 1993, field activities, which include geologic mapping, core drilling, test pit excavation, and field soil and geophysical testing will be conducted along the proposed south ramp. Maps will be submitted at a scale of 1:500.

Laboratory tests on soils will consist of gradations (approximately 100) to assess engineering properties. For UE-25NRG#1 core, triaxial and direct shear testing (approximately 15) to determine mechanical properties such as friction angle and cohesion, one-dimensional consolidation, relative densities and/or Proctor densities (approximately 50) and compaction methods are to be done. Laboratory tests of rock samples will consist typically of uniaxial and triaxial shear and direct shear testing (approximately 30), direct tension testing, and dynamic tests including sonic velocities (approximately 50). A variety of indirect tests such as point load, Brazilian, and Schmidt Hammer type, as appropriate, will be performed to determine tensile strengths and uniaxial compressive strengths.

Depending on the final location of the south portal, exploration will consist of an extensive test pitting program. Approximately 30 test pits will be excavated, logged, and sampled. Approximately 100 soil samples will be collected for testing. Typical field soil testing will consist of determining densities (approximately 24 tests) and determining soil conditions; densities provide an indication of bearing capacity and settlement potential.

Standard penetration testing will be done if fine-grained materials are encountered to assess bearing capacity of the material. Dynamic tests include p- and s- wave velocity determination utilizing the portal drill holes. Field exploration in rock will consist of vertical (approximately two holes) and angle-holes (approximately four), and geotechnical geophysical testing. Typical in situ rock conditions will be determined using dynamic tests including p- and s-wave velocity determination. Discontinuities will be evaluated, especially in relation to stability of cutslopes and underground excavations.

2.2.11 Thermal and mechanical rock properties (SCP Section 8.3.1.15)

2.2.11.1 Study 8.3.1.15.1.1 - Laboratory thermal properties

The Study Plan, which had been approved by YMPO and sent to the NRC in January 1991, is being revised to incorporate changes to the ESF design. The NRC had informed DOE that they were deferring their acceptance review until ESF-related Study Plans were updated to the new ESF configuration. The revisions will be submitted to YMPO by November 1992.

Activity 8.3.1.15.1.1.1 - Density and porosity characterization. Review comments on the paper entitled "An Experimental Comparison of Laboratory Techniques in Determining Bulk Properties of Tuffaceous Rocks" (Boyd et al.) are being resolved.

Activity 8.3.1.15.1.1.2 - Volumetric heat capacity characterization. No progress during this reporting period; this activity was not funded in 1992.

Activity 8.3.1.15.1.1.3 - Thermal conductivity characterization. The C-Matic low temperature (LT) instrument is being prepared for the scoping study on the effects of saturation on thermal conductivity. The LT is used to measure thermal conductivity at temperatures from 20 to 100 °C. The system was overhauled because of erratic output from the heat flux transducers. Internal thermocouples were calibrated and installed in the instrument and modifications were made that simplify the procedure for calibrating the permanent thermocouples and digital voltmeter. The system, including the permanent thermocouples, reference thermocouples, electronic ice reference, and the data acquisition unit, was calibrated using approved calibration standards. Calibration and verification runs using the moisture containment cell are in process. The moisture containment cell is used to maintain sample saturation during thermal conductivity measurements. The guard differential is being adjusted to account for the interface resistance using the moisture containment cell. Heat-sink compound has not been used between the interfaces of the moisture containment cell and the samples because it may be absorbed into the rock pores after it is applied between testing cycles. A suitable medium is being sought to reduce the interface resistance.

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Calibration of the Thermal Conductivity Analyzer (TCA) using approved calibration standards was completed. Problems in verifying the calibration at 110 °C were caused by variances in sample-plate interfaces caused by inadequate application of heat-sink compound. The data acquisition software has been approved, as the successful calibration of the TCA using reference materials of known values satisfies the software verification requirements. The TCA will be used for thermal conductivity measurements made at or above 110 °C.

Calibration of the comparative instrument, which will be used in the scoping study to examine the effects of a fracture on thermal conductivity, has been completed. Several procedures were modified including "Saturation Effects on Thermal Conductivity," "Calibration of Temperature Sensors Used for Thermal Properties Testing," and "Calibration of Mechanical and Electrical Measuring Equipment Used for Thermal Properties Testing." A draft of the procedure "Calibration of Lawson Board Systems" has been written. This procedure uses an electronic ice reference to calibrate the Lawson thermocouple board and Lawson A/D board used in the TCA.

A QA audit was completed at Holometrix, Inc. The audit focused on documentation to confirm that test prerequisites are met for the scoping study on the effects of saturation on thermal conductivity. No major QA findings were reported and the audit has been closed out. SNL has contracted Holometrix, Inc. to perform thermal conductivity, heat capacity, and thermal expansion testing.

Forecast: A report "An Experimental Comparison of Laboratory Techniques in Determining Bulk Properties of Tuffaceous Rocks" (Boyd et al.) will be published during FY 1993.

The scoping study on the effects of saturation on thermal conductivity will begin after the C-Matic LT instrument is calibrated with the moisture containment cell, the data acquisition software is verified and approved, and the relevant procedures/revisions are issued. Three samples of welded devitrified tuff and three samples of nonwelded zeolitic tuff will be used for this study. The thermal conductivity of each sample will be measured at nominal temperatures of 30, 50, and 70 °C, at five different saturation states (fully saturated, oven-dry, air-dry, and two other intermediate states). The estimated completion date is February 15, 1993. The data and analysis report for this scoping study is estimated to be complete by August 1, 1993.

The scoping study on the effects of confining pressure and fractures will be completed. Two samples of welded devitrified tuff will be measured at a nominal temperature of 30 °C. Each sample will be then be cut in half perpendicular to the sample axis, the cut surfaces will be roughened, and the halves will be rejoined. The thermal conductivity will be remeasured at 30 °C as a function of stress applied normal to the artificial fractures. Confining pressures

of 0, 2.5, 5, 7.5 and 10 MPa will be used. The estimated completion date is March 15, 1993. The data and analysis report for this scoping study is estimated to be completed by September 1, 1993.

2.2.11.2 Study 8.3.1.15.1.2 - Laboratory thermal expansion testing

The Study Plan, which had been approved by YMPO and sent to the NRC in October 1990, is being revised to incorporate changes to the ESF design. The NRC had informed DOE that they were deferring their acceptance review until ESF-related Study Plans were updated to the new ESF configuration. The revisions will be submitted to the YMPO by November 1992.

Activity 8.3.1.15.1.2.1 - Thermal expansion characterization. A report entitled "Linear Thermal Expansion Data for Tuffs From the Unsaturated Zone at Yucca Mountain, Nevada" (Schwartz and Chocas, 1992) was published in July 1992.

Efforts focused on stabilizing the drift in the linear variable differential transformer (LVDT) of the dilatometer during long runs in which the temperature is held constant and the sample is allowed to dehydrate. The drift was attributed to changes in the LVDT temperature as driven by room temperature. Variations in the signal conditioner temperature were determined to have a minimal effect, if any, on the LVDT drift. The LVDT chamber was insulated and a heating element with a power supply/controller unit was integrated into the dilatometer apparatus to control the temperature of the LVDT chamber. A power supply/controller was also incorporated into the saturation test apparatus (STA) to regulate the water temperature. A series of verification runs of the dilatometer with the STA installed were completed. The temperature of the LVDT chamber has been controlled at 30 °C during these runs and the drift ($\Delta\mu$) during the isothermal segment of the run has been minimal ($<1\mu$). Also, the signal conditioner was replaced and calibration factors for this unit were established. Glitches in the data acquisition code that were identified during the verification runs were corrected. The calibration runs used a 10.16-cm (4-in.) borosilicate glass reference sample and the sample was heated and cooled at a rate of ≤ 1 °C/min. Water was drained from the STA when the sample reached about 100 °C (on heatup) and the sample then was allowed to soak at 125 °C for 10 hours. Afterwards, the sample was heated to 325 °C and then allowed to cool to ambient. The maximum difference between the expected expansion and the measured expansion was -6.82 percent. A series of calibration and verification runs using the same parameters with a 2.54-cm (1-in.) borosilicate glass sample will be conducted after a sample holder to accommodate the shorter sample length is fabricated.

The draft procedure, "Measurement of Thermal Expansion of Geologic Samples Using a Push Rod Dilatometer," is being revised and a draft procedure, "Effects of Sample Size on Thermal Expansion," has been written and is being reviewed.

Forecast: The scoping study on the effect of sample size on thermal expansion will be initiated after the accuracy and reproducibility of the test data are established, data acquisition software is verified and approved, and relevant procedures are issued. The linear thermal expansion of five samples of each of four different lithologies of two different sample sizes will be measured during this study. The samples will be heated at a controlled rate of ≤1 °C/min, and the atmosphere surrounding the sample during testing will be controlled to minimize sample dehydration at temperatures below the nominal boiling temperature of 100 °C. When this temperature is reached, temperature will be held constant and the sample allowed to dehydrate until the length stabilizes. The heating will continue until the maximum temperature planned for the experiment is reached, then the sample will be cooled at a controlled rate of ≤1 °C/min. Estimated completion date for testing is May 15, 1993. A preliminary draft of the data and analysis report for this scoping study will be completed by September 30, 1993.

The scoping study on the effects of sample saturation on thermal expansion will begin after completion of the scoping study on the sample size effects. Three initial saturation states will be examined (fully saturated, air-dry, and oven-dry). For these tests, the preconditioned samples will be heated to 100 °C, allowed to dehydrate, heated to 125 °C, then allowed to cool. The estimated date for initiation of these tests is September 15, 1993. The data and analysis reports will not be completed during FY 1993.

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

The Study Plan, which had been approved by YMPO and sent to the NRC in June 1991, is being revised to incorporate changes to the ESF design. The NRC had informed DOE that they were deferring their acceptance review until ESF-related Study Plans were updated to the new ESF configuration.

Activity 8.3.1.15.1.3.1 - Compressive mechanical properties of intact rock at baseline experiment conditions. Samples are not yet available for this testing effort; however, the prototype experiments have been completed and the technical procedures necessary for future testing at baseline conditions are being drafted in anticipation of sample availability in the next one to three years.

Testing of several rock types has been conducted at eight government and private rock mechanics laboratories in support of the American Society for Testing and Materials

(ASTM)/Institute for Standards Research (ISR)/ Steering Committee for the Interlaboratory Testing Program for Rock Properties. An SNL staff member is serving on the committee and has provided test data from contractors for the Phase I testing. The results have been analyzed and a report has been written summarizing the results. The report also suggests measures of precision for published rock-property standard ASTM test methods. The results, conclusions, and recommendations of the committee were presented during a meeting at the NAS in Washington, D.C. on July 21, 1992.

Activity 8.3.1.15.1.3.2 - Effects of variable environmental conditions on mechanical properties. New England Research, Inc. (NER) is conducting a study involving experiments on samples of welded Topopah Spring Member tuff at low strain-rate and creep (constant stress) conditions in order to investigate the time-dependent behavior of the intact rock. The series of experiments run at a nominal axial strain rate of 10^{-9} s^{-1} (inverse seconds; one over seconds) has been completed. The preparations for the series of constant stress (creep) experiments are complete and the first experiment has been initiated.

The data have been collected and reduced for the completed series of six experiments on saturated samples tested at room temperature and pressure and a nominal axial strain rate of 10^{-9} s^{-1}. This information has been reported in a document entitled "Unconfined Compression Experiments on Topopah Spring Member Tuff at 22 °C and a Strain Rate of 10^{-9} s^{-1}: Data Report" (Martin et al.). The data will be analyzed and the results published in an analysis report at a later date.

The first of six creep experiments is being performed. For each experiment, a sample is saturated and tested at a pore pressure of 4.5 MPa, a confining pressure of 5 MPa, and a constant differential (or creep) stress of 80 MPa. An experiment will have two phases: the first will be performed at room temperature for a week and, during the second phase, the sample will be tested at 250 °C for two months. With the appropriate calibrations and aluminum system calibration checks, the tests will each take approximately four months to complete and the series should be completed in 1994.

A report entitled "Anisotropy of Topopah Spring Member Welded Tuff" (Martin et al., 1992) was approved and published in July 1992. "The Influence of Strain Rate and Sample Inhomogeneity on the Moduli and Strength of Topopah Spring Member Tuff" (Price et al.) was presented at the 1992 AGU Spring meeting on May 11-16, 1992, in Montreal, Canada. The abstract was published in April 1992 in the Transactions of the AGU. "Modulus Dispersion and Attenuation in Tuff, Sandstone, and Granite" (Haupt et al.) was presented at the 33rd U.S. Symposium on Rock Mechanics, on June 8-10, 1992, in Santa Fe, New Mexico. A paper summarizing the presentation was published in the conference proceedings.

A paper entitled "Characterization of Porosity in Support of Mechanical Property Analysis" (Price et al.) has been submitted for presentation at the 1993 IHLRWM Conference.

A paper entitled "The Influence of Strain Rate and Sample Inhomogeneity on the Moduli and Strength of Topopah Spring Member Tuff" (Price et al.) has been submitted for consideration to be presented at the 34rd U.S. Symposium on Rock Mechanics. The conference will be held on June 27-30, 1993, in Madison, Wisconsin, and the paper will be published in the conference proceedings.

Two additional reports entitled "Experimental Comparison of Laboratory Techniques in Determining Bulk Properties of Tuffaceous Rocks" (Boyd et al.) and "The Effect of Frequency on Young's Modulus and Seismic Wave Attenuation in Tuff" (Martin et al.) have been written and are in internal review.

Forecast: Minor support will be given to the ASTM/ISR Steering Committee for the Interlaboratory Testing Program for Rock Properties. A few experiments will be performed at NER and an SNL staff member will continue to serve on the committee.

NER will be continuing a study involving experiments on samples of welded Topopah Spring Member tuff to investigate the time-dependent behavior of the intact rock. The results from a series of experiments run at a nominal axial strain rate of 10^{-9} s^{-1} will be interpreted and published. The first of six creep experiments at a constant differential (or creep) stress of 80 MPa is being performed. This experiment will be completed and at least three more will be initiated during the next year. In addition, several conference papers and other reports summarizing results from several aspects of this study will be drafted.

2.2.11.4 Study 8.3.1.15.1.4 - Laboratory determination of the mechanical properties of fractures

Study Plan 8.3.1.15.1.4 completed YMPO's screening review and comments were returned to SNL in May 1992.

Activity 8.3.1.15.1.4.1 - Mechanical properties of fractures at baseline experiment conditions. Samples are not yet available for this testing effort; however, studies are proceeding to define the baseline-condition test technique and the approach for future characterization of fracture topography.

Several SNL staff members comprise the Fracture Properties Working Group which met seven times during the last six months to discuss testing plans and progress. The discussions centered on the need to revise the Study Plan and planning for an investigation of the physical significance of some empirically derived fracture models.

Detailed characterization and analysis of fracture surfaces will aid in the interpretation of mechanical properties (e.g., normal stiffness, shear stiffness, and frictional shear strength)

and transport properties (e.g., fluid and solute transport). To accomplish this, a laser profilometer has been designed, built, and tested. During this six-month period, the existing profilometer system (profiler and software) has been adapted to profile circular samples, as used in rotary friction (axial compression-torsion) experiments on thin-walled cylinders with a fracture oriented perpendicular to the cylinder axis. Previous to this improvement, only linear profiles could be taken.

In an initial study to determine the variability of the roughness of natural fracture surfaces, the topographies of seventeen natural fractures from various rock types (including tuff from Yucca Mountain) were profiled. These data are being analyzed to quantify the roughness of each surface, its scaling (size-dependent) properties, and the degree of mismatch between the two opposing surfaces. A simple mathematical model of rough fractures has been developed based on these data. Using this simple model, a computer code is being developed for simulation of the frictional shear strength of rock fractures. Simulations using this code will allow some physical insight into empirically derived relationships commonly used in engineering geology for design of structures in rock. The data and analyses are being included in a report being drafted for submittal to a technical journal.

A study addressing what variables are important for inclusion into the constitutive description of fractures is continuing. Experiments will be performed on artificial (relatively smooth) and natural (rough) fractures. The analysis is continuing on a series of experiments on artificial fractures in samples of welded Topopah Spring Member tuff. These experiments were designed to study the effect of water in rate-stepping experiments. A creep experiment on a sample with an artificially produced fracture oriented approximately 35 degrees to the sample axis is continuing. The test will be completed in the next few months and the resulting data analyzed.

<u>Activity 8.3.1.15.1.4.2 - Effects of variable environmental conditions on mechanical properties of fractures.</u> Amonton's law ($\tau = \mu\sigma$, where τ is the shear stress parallel to the fracture, σ is the normal stress across the fracture, and μ is called the coefficient of friction) is the most common relationship used to describe the mechanical properties of relatively smooth (or artificial) fractures. A study is continuing that begins to address whether other variables (e.g., time of stationary contact, velocity of sliding, degree of saturation, temperature, and history) are important for inclusion into the constitutive description, or whether the simple formulation of Amonton's law is sufficient for most modeling efforts. The preliminary results indicate that these other variables produce second-order effects and may be required.

The frictional behavior of artificially produced (i.e., relatively "smooth") fractures was investigated using a range of stress paths. Following shear deformation, the subsequent behavior is highly dependent on whether the fracture remains primed (i.e., normal stress is not relieved).

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One of the major reasons for performing the majority of characterization experiments on artificially produced surfaces is that each natural fracture surface has a unique topography and individual relationship between the two surfaces. One way of studying a natural fracture in a detailed, statistical way is to create a mold of each surface and then cast multiple replicas of the original surfaces for testing. This has been done for a few natural fractures in tuff using potting rubber and gypsum cement for the mold and cast, respectively. The replicas will be tested multiple times at a single set of conditions and various sets of environmental conditions to compare with the results obtained in the artificially produced fractures in tuff.

The time-dependent mechanical properties of fractures are being investigated to address long-term stability issues within the potential repository. Experiments have been completed on artificial fractures in samples of welded Topopah Spring Member tuff to study the effect of water in rate-stepping experiments. Fracture samples were tested at room dry and saturated conditions, with rates varying form 10^{-1} to 10^{2} μm/s. A sample under constant normal stress is sheared at a constant velocity until the shear stress reaches steady state. At that time, the shearing velocity is changed by an order of magnitude. The response of the sample, in terms of the shear stress required to continue sliding at the induced velocity, is recorded and analyzed. Preliminary analysis of the data has indicated that there is very little, if any, difference in the shear behavior at these two saturation conditions.

In an additional study of time-dependent properties, a sample (right-circular cylinder, diameter of approximately 54 mm, and a length-to-diameter ratio of 3:1) with an artificially produced fracture oriented approximately 35 degrees to the sample axis is being tested under creep (constant shear stress) conditions. The confining pressure and the initial axial stress difference were both set at 10 MPa, which gives a ratio of shear-to-normal stress on the surface of about 0.36. The value for fully established sliding would be in the range of 0.6-0.7. The sample is at room temperature and vented to the atmosphere. The axial stress difference will be increased every week or so until time-dependent sliding is observed.

A presentation entitled "Shear Response of a Rock Joint Under Different Boundary Conditions: An Experimental Study" (Wibowo et al., 1992) was made at the Fractured and Jointed Rock Masses Conference on June 3-5, 1992, in Lake Tahoe, California. A paper summarizing the presentation was published in the conference proceedings. A report entitled "Effect of Boundary Conditions on the Strength and Deformability of Replicas of Natural Fractures in Welded Tuff" (Wibowo et al.) has been written and is in SNL review.

Forecast: Study Plan 8.3.1.15.1.4, "Laboratory Determination of the Mechanical Properties of Fractures" is being revised in response to YMP review comments. The plan will be returned to the YMPO in the next few months.

The characterization and analysis of fracture surfaces will continue. The initial study to determine the variability of the roughness of natural fracture surfaces is being reported in

an article to be submitted to an appropriate journal in the next few months. Three reports will be in the review process during the FY 1993. These reports detail the data, results, and analysis of a study entitled "Effect of Boundary Conditions on the Strength and Deformability of Replicas of Natural Fractures in Welded Tuff."

2.2.11.5 Study 8.3.1.15.1.5 - Excavation investigations

The Study Plan, which had been approved by YMPO and sent to the NRC in February 1989, is being revised to incorporate changes to the ESF design. The NRC had informed DOE that they were deferring their acceptance review until ESF-related Study Plans were updated to the new ESF configuration.

SNL hosted a meeting of the Rock Mechanics Review Panel on June 11-12, 1992. The Rock Mechanics Review Panel consists of six independent, objective, and highly qualified experts in rock mechanics who provide advice and technical recommendations to SNL's rock mechanics investigators. SNL's current plans for the testing in the ESF were presented to the panel and the discussions with the panel that followed helped advance the design of the ESF experiments. These design enhancements, which should result in better test measurements when the experiments are fielded, will be incorporated into revisions of the applicable Study Plans.

A technical exchange was held with staff from the Canadian Underground Research Laboratory. Fielding of a large mining test was discussed along with instrumentation problems and in situ stress measurement techniques. SNL staff benefitted greatly from the interchange. A letter report on the interchange was forwarded to DOE.

Activities 8.3.1.15.1.5.1 through 8.3.1.15.1.5.3. No progress during the reporting period; these are out-year activities.

Forecast: During FY 1993, Study Plan 8.3.1.15.1.5, "Excavation Investigations," will be revised to reflect the change in the ESF configuration from shaft access to ramp access, and to reflect the change in mining method from drill-and-blast to mechanical mining using a TBM. It is anticipated that the revised Study Plan will be submitted to YMPO before the end of FY 1993. Additionally, SNL will provide support to the LANL Test Coordination Office in developing test planning packages (TPPs) for the SNL ESF tests. This will be a minimal effort to define critical design information for the TPPs and the ESFDR Appendix B for Title II design. No activity is planned for Activities 8.3.1.15.1.1.1, 8.3.1.15.1.5.2, or 8.3.1.15.1.3.

2.2.11.6 Study 8.3.1.15.1.6 - In situ thermomechanical properties

The Study Plan for this study is being scoped by SNL.

A report on the thermal effects on instrumentation was finished. The report will support the ESF thermomechanical experiments. The report lists the instruments that will be required in the experiments, along with their required accuracy, range, and temperature capabilities. This list is matched with off-the-shelf instrumentation, where possible, and notes where this is not possible. New technologies, such as fiber optics, and advanced materials, such as graphite composites, that hold promise for use in developing those instruments that cannot be obtained as off-the-shelf items are discussed. The performance of geologic test instruments in other thermomechanical experiments is reviewed.

Written material detailing the basis for SNL's estimates of the cost of the in situ thermomechanical properties experiments was provided to the Independent Cost Estimation (ICE) Team. Detailed discussions were held with the members of the team to allow an independent estimate of the cost of the experiments to be made.

SNL provided support to the writing of a heater test duration decision paper. This paper examines alternative means of providing the information needed from the planned in situ coupled hydrothermal tests.

Activities 8.3.1.15.1.6.1 through 8.3.1.15.1.6.5. There has been no progress during the reporting period; these are out-year activities.

Forecast: During FY 1993, the writing of Study Plan 8.3.1.15.1.6 will begin. Additionally, efforts at test consolidation between the SNL ESF thermal-mechanical tests and the LLNL thermal-hydrologic tests will be supported.

2.2.11.7 Study 8.3.1.15.1.7 - In situ mechanical properties

The work to be performed under this activity is described in Study Plan 8.3.1.15.1.7. Written material detailing the basis for SNL's estimates of cost of the in situ mechanical properties experiments, as documented in the PACS system, was provided to the ICE Team. Detailed discussions were held with the members of the team to allow an independent estimate of the cost of the experiments to be made. Clarification was provided to the ICE Team to explain differences between SNL's PACS estimates and the ICE Team's estimates for this activity.

Activities 8.3.1.15.1.7.1 and 8.3.1.15.1.7. 2. No progress during the reporting period; these are out-year activities.

Forecast: During FY 1993, the writing of Study Plan 8.3.1.15.1.7 will begin. Also, SNL will provide support to the LANL Test Coordination Office in developing TPPs for the SNL ESF tests. This will be a minimal effort to define critical design information for the TPPs and the ESFDR Appendix B for Title II design. No activity is planned for Activities 8.3.1.15.1.7.1 or 8.3.1.15.1.17.2.

2.2.11.8 Study 8.3.1.15.1.8 - In situ design verification

YMPO reviewer comments on Study Plan 8.3.1.15.1.8 were reviewed and proposed resolutions to each of the comments were developed. Additionally, to be consistent with the new ESF configuration, substantial portions of this Study Plan were rewritten and incorporated into the proposed resolutions. The comment resolution meeting is planned for January 12, 1992.

Activities 8.3.1.15.1.8.1 through 8.3.1.15.1.8. 4. No progress during the reporting period; these are out-year activities.

Forecast: SNL will support the LANL Test Coordination Office in developing TPPs for the SNL ESF tests. This will be a minimal effort to define critical design information for the TPPs and the ESFDR Appendix B for Title II design. The revision of Study Plan 8.3.1.15.1.8, incorporating the change in configuration and construction method of the ESF, will be completed. No activity is planned for Activities 8.3.1.15.1.8.1, 8.3.1.15.1.8.2, 8.3.1.15.1.8.3, or 8.3.1.15.1.8.4.

2.2.11.9 Study 8.3.1.15.2.1 - Characterization of the site ambient stress conditions

The Study Plan, which had been approved by YMPO and sent to the NRC in February 1989, is being revised to incorporate changes to the ESF design. The NRC had informed DOE that they were deferring their acceptance review until ESF-related Study Plans were updated to the new ESF configuration.

Forecast: No activity is planned for FY 1993.

2.2.11.10 Study 8.3.1.15.2.2 - Characterization of the site ambient thermal conditions

The Study Plan is in internal SNL review and will be submitted to YMPO early in FY 1993.

Forecast: Existing and new temperature logs will be compiled, evaluated, and processed for inclusion in the YMP TDB.

2.2.12 Preclosure hydrology (SCP Section 8.3.1.16)

2.2.12.1 Study 8.3.1.16.1.1 - Characterization of flood potential of the Yucca Mountain site

DOE responded to two concerns expressed in NRC's Phase I review in a letter to the NRC dated September 3, 1992.

Activity 8.3.1.16.1.1.1 - Site flood and debris hazards studies. Isolated thunderstorms during the period April 1, 1992, to September 30, 1992, caused flooding and debris transport in areas of central and northern Nevada. Damage to private and public property was severe in some cases, but no injuries or deaths were reported. Data were collected and documented for further evaluation and interpretation of the mechanisms that caused debris transport to occur. Data were also collected on minor runoff which occurred along Cano Springs Wash, NTS, and along the Amargosa River at Eagle Mountain, Tecopa, and Westside Road in southern Death Valley.

Analysis and evaluation of FY 1991 flood data were completed. Interpretation of the results will take place during a multiyear analysis phase during which the FY 1991 floods will be compared and contrasted with those that occurred during the period 1983-92.

An interpretive report on the 1984 debris flows at Jake's point near Yucca Mountain is being prepared. An aerial reconnaissance of the mouth of Fortymile Wash was conducted to determine a method for deriving the flow paths of recent floods. It was determined that detailed maps could be prepared to accurately delineate the locations and paths of floodwaters that may have recently flowed through a distributary stream network which extends from Fortymile Wash Canyon to the Amargosa River.

Forecast: This study, beyond monitoring of emplaced instrumentation, will be placed on hold during FY 1993, pending a decision as to whether or not more data needs to be collected.

2.2.12.2 Study 8.3.1.16.2.1 - Location of adequate water supply for construction, operation, closure, and decommissioning of a mined geologic disposal system at Yucca Mountain, Nevada

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

Forecast: No activity is planned for FY 1993.

2.2.12.3 Study 8.3.1.16.3.1 - Determination of the preclosure hydrologic conditions of the unsaturated zone at Yucca Mountain, Nevada

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

Forecast: No activity is planned for FY 1993.

2.2.13 Preclosure tectonics (SCP Section 8.3.1.17)

2.2.13.1 Study 8.3.1.17.1.1 - Potential for ash fall at the site

Activities 8.3.1.17.1.1.1 through 8.3.1.17.1.1.3. No progress during the reporting period due to lack of funding.

Forecast: No activity is planned for FY 1993.

2.2.13.2 Study 8.3.1.17.2.1 - Faulting potential at the repository

Activities 8.3.1.17.2.1.1 and 8.3.1.17.2.1.2. No progress during the reporting period; these are out-year activities.

Forecast: No activity is planned for FY 1993.

2.2.13.3 Study 8.3.1.17.3.1 - Relevant earthquake sources

The NRC accepted the Study Plan in a Phase I review letter dated May 18, 1992.

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

Forecast: Work this year will focus on developing the methodology to be used for a seismic hazard evaluation of Yucca Mountain and to prepare documentation of DOE's proposed approach for the NRC.

2.2.13.4 Study 8.3.1.17.3.2 - Underground nuclear explosion sources

Activities 8.3.1.17.3.2.1 and 8.3.1.17.3.2.2. No progress during the reporting period; this is an out-year activity.

Forecast: No activity is planned for FY 1993.

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

The Study Plan has completed YMPO review, and resolution of comments is underway.

Activity 8.3.1.17.3.3.1 - Select or develop empirical models for earthquake ground motions. Work elements include: (1) selection and (or) development of empirical ground-motion models that are appropriate for estimating earthquake ground motions at the site, and (2) collecting and synthesizing ground-motion data from the Great Basin and other regions that are tectonically analogous and which may be useful in selecting the most appropriate model.

Activity 8.3.1.17.3.3.2 - Select or develop empirical models for ground motion from underground nuclear explosions. Data-collection efforts for this activity were halted because of reductions in funding.

A report entitled "A Statistical Analysis of Ground Motion Resulting from Underground Nuclear Explosions in the Yucca Mountain Region" (Rutherford) was submitted for internal SNL review. This report explains the results of a modeling effort designed to predict ground motion in the region and to provide details of the statistical analysis performed to construct the model. Predictions based on this model are provided that can be compared to the predictions of ground motion from other seismic sources to determine the appropriate design for the proposed repository.

Forecast: Empirical ground-motion models will be used to predict ground motion at the potential repository site as a function of earthquake magnitude and distance between the earthquake source and the site.

Finite-difference synthetic seismograms will be used to investigate the causes for observed differences between downhole and uphole UNE waveforms recorded at Yucca Mountain. The computer code used for seismic transmission studies will be adapted to allow for an input waveform. Modeling will include propagation of the known downhole waveforms up to the surface through estimated structures based on geologic information and well logs. Prior to modeling, available geologic information will be carefully reviewed, and characteristic waveforms inspected in order to form reasonable starting models. Modeling results will be documented in a report. Evaluation of old data sets as candidates for a qualification process will be completed.

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

The NRC accepted the Study Plan in a Phase I review letter dated June 8, 1992. A response to a minor concern in this letter was being prepared for transmittal to the NRC.

Forecast: During FY 1993, work will continue in the following areas: (1) determination from ground-motion records, systematic effects of the local site geology on surface and subsurface motions, (2) identification of any significant site-wide bias in ground-motion levels, as compared with average levels for the Southern Great Basin, (3) recording of ground-motion at several stations or in one or more boreholes in order to calibrate theoretical models and determine motion averages of surface facilities location, and (4) estimation of spectral amplification functions and amplification factors for peak ground-motion parameters.

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

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

Forecast: No activity is planned for FY 1993.

2.2.13.8 Study 8.3.1.17.3.6 - Probabilistic seismic hazards analyses

Activities 8.3.1.17.3.6.1 and 8.3.1.17.3.6.2. No progress during the reporting period; these are out-year activities.

Forecast: Development of a Study Plan is scheduled during FY 1993.

2.2.13.9 Study 8.3.1.17.4.1 - Historical and current seismicity

The NRC accepted Study Plan 8.3.1.17.4.1 on May 14, 1991.

Activity 8.3.1.17.4.1.1 - Compile historical earthquake record. No progress during the reporting period. Work is scheduled to begin in 1993.

Activity 8.3.1.17.4.1.2 - Monitor current seismicity. Continuous monitoring of the SGBSN enabled successful recordings of a large number of seismic events during the reporting period. Lab and field testing continued and six new stations and one node were added to the seismic network. A 1991 earthquake catalog entitled "Seismicity and Focal Mechanisms for the Southern Great Basin of Nevada and California, in 1991" (Harmsen) went through USGS review and was submitted for DOE approval.

Personnel worked very hard at short notice to deploy portable seismographs to record aftershocks of the Little Skull Mountain earthquake during the period of June 29 - July 14, 1992. Personnel were on duty 24 hours a day to keep the data collection system operational and perform routine processing of incoming data. During this period, a backlog of more than 160 data tapes was accumulated due to the high rate of incoming data from monitoring of aftershocks in the vicinity of Little Skull Mountain and throughout the network.

Considerable work has effected a relatively smooth transition of the SGBSN from management by the USGS Branch of Geologic Risk Assessment (BGRA) to the UNRSL. Cooperation between BGRA and UNRSL continued, data and preliminary results were exchanged on a regular basis and seismological recording equipment was transported to Reno, Nevada. UNRSL staff conducted numerous tasks to prepare for reception of the SGBSN.

An informational "white paper" titled "The Little Skull Mountain Earthquake of June 29, 1992" was prepared by USGS/UNRSL staff at the request of the YMPO Project Manager. The letter report contained basic information on the earthquake, including parameters measured by SGBSN instrumentation and effects of the earthquake on the immediate area. This report was sent to YMPO on August 5, 1992. DOE supplied a copy to the NRC by letter dated August 31, 1992.

Forecast: Monitoring of the SBGSN will continue during FY 1993. Work will begin in compiling a record of historical seismic events.

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

The NRC accepted Study Plan 8.3.1.17.4.2 on November 24, 1989. The NRC completed a detailed technical review (Phase II) on March 16, 1990, where 16 comments were offered.

Activity 8.3.1.17.4.2.1 - Identify appropriate trench locations in Midway Valley. Twenty-eight soil test pits were excavated for soil-stratigraphic studies in Midway Valley. Soil profiles are being described in these pits to provide correlations and temporal control of Quaternary stratigraphic units mapped in Midway Valley with units exposed in trenches. Soil descriptions are complete for approximately one half of the soil pits. Soils data were compared with age assignments estimated on the basis of surface mapping criteria. Refinement of the 1:6,000-scale Quaternary surficial map of Midway Valley continued based on soil descriptions and field checks. The report "Preliminary Mapping of Surficial Geology of Midway Valley, Yucca Mountain Project, Nye County, Nevada" (Wesling et al., 1992) was published.

Activity 8.3.1.17.4.2.2 - Conduct exploratory trenching in Midway Valley. Three trenches were excavated in June 1992 as part of continued work in Midway Valley. Trenches MWV-T5 and MWV-T6 were excavated at the site of prospective surface facilities. MWV-T5 exposes a more than 315-m-long section of Quaternary alluvium and colluvium from Exile Hill east into Midway Valley. A down-to-the-east step of brecciated bedrock at the western-most end of the trench was examined. Fractures with strikes approximately coincident with the trend of the step were also examined with particular attention to evidence of vertical or horizontal displacement of the colluvium. Similar fractures also were studied in trench MWV-T6 and in three soil test pits (NRSF-TP7, 8 & 32). Trench MWV-T4 (old USGS trench 17) was cleaned and deepened to assess the paleoseismic history of the western branch of the Paintbrush Canyon fault within southern Midway Valley. Trench mapping activities focused on surface faulting events, total vertical dip-slip displacement, and the amount of lateral displacement of Pleistocene colluvial deposits. Trench mapping and soil pit descriptions are continuing.

A draft report entitled "Geologic Interpretation of Trench A/BR-3 for Site Characterization Study 8.3.1.17.4.2, Midway Valley Area, Yucca Mountain Site, Nevada" (Swan et. al.) was completed in April 1992, and will probably be released as an Interim Data Report by SNL. In cooperation with Study 8.3.1.5.1.4.2, carbonate was obtained from selected trenches and soil test pits for uranium-series age estimates. Five geophysical lines (gravity and electromagnetic) were established across Midway Valley in cooperation with Study 8.3.1.4.2.1. The purpose of the geophysical lines is to assess the location of faults beneath the Quaternary cover of the valley. The preliminary results of trench mapping, surficial geologic mapping, soil pit descriptions and gravity and magnetic geophysical data

from the lines in Midway Valley were presented to the NRC during a site visit on September 18-19, 1992. The field trip was attended by approximately 50 people, including observers from the NWTRB, the State of Nevada, and surrounding Nevada counties.

Forecast: The report and map showing surficial geology in Midway Valley will be completed. Prepare and submit preliminary data report (with trench logs) on the exploratory trenches through the potential surface facilities locality. One or two new trenches may be necessary to further examine the features identified in Trench 6 and at the western-most end of T5. One new trench may be located above the Midway Valley fault as identified by 1992 geophysical surveys. This study will be completed in FY 1993.

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

YMPO comments on Study Plan 8.3.1.17.4.3 were addressed and the Study Plan was returned to YMPO for verification of comment resolution and approval on September 22, 1992.

Activity 8.3.1.17.4.3.1 - Conduct and evaluate deep geophysical surveys in an east-west transect crossing the Furnace Creek fault zone, Yucca Mountain, and the Walker Lane. No progress during the reporting period; this is an out-year activity.

Activity 8.3.1.17.4.3.2 - Evaluate Quaternary faults within 100 km of Yucca Mountain. Staff conducted field reconnaissance of the Furnace Creek fault zone, Bare Mountain fault, Beatty scarp, and Ash Meadows fault zone. After the June 29, 1992, earthquake near Little Skull Mountain, a search for evidence of possible surface-fault rupture was conducted. Initial compilation of data on known and suspected Quaternary faults was completed and a computerized reference data base established. A draft open-file report entitled "Preliminary Assessment of Quaternary Faults within 100 km of Yucca Mountain" (Piety et.al.) was completed in September 1992. The report outlines the small amount of data on age, amount of displacement, recurrence, and slip rate for most of the faults within the area of study.

Activity 8.3.1.17.4.3.3 - Evaluate the Cedar Mountain earthquake of 1932 and its bearing on wrench tectonics of the Walker Lane within 100 km of the site. This study was not funded in 1992. It is a planned activity scheduled to begin in FY 1994.

Activity 8.3.1.17.4.3.4 - Evaluate the Bare Mountain fault zone. This activity was not funded in 1992. Work is scheduled to begin in FY 1993.

Activity 8.3.1.17.4.3.5 - Evaluate structural domains and characterize the Yucca Mountain region with respect to regional patterns of faults and fractures. No progress during the reporting period; this is an out-year activity.

Forecast: Data collection under Activity 8.3.1.17.4.3.4 is scheduled to begin in FY 1993.

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

Study Plan 8.3.1.17.4.4 was submitted to YMPO on August 3, 1992. YMPO review comments were returned to the principal investigator on September 25, 1992. Documentation is being prepared by USGS to change the SCPB to transfer activity 3 to Study Plan 8.3.1.17.4.6 work scope.

Activity 8.3.1.17.4.4.1 - Evaluate the Rock Valley fault system. A preliminary study of the fault zones was begun by compilation and desk analysis of base maps, published maps and reports, aerial photography and satellite images. Work included creation of a reference data base of all published data relevant to Study 8.3.1.17.4.4 and analysis of 1:40,000 air photos and 1:250,000 Side-Looking Airborne Radar (SLAR) mosaics of the fault zones in preparation for field work. Reconnaissance field work was undertaken from August 26, 1992, to September 3, 1992, to evaluate the suitability of previous mapping for seismic hazards evaluation, to appraise the style and history of strike-slip faults exposed in bedrock and consolidated alluvium, and to assess possible sites for trenching. An interim report entitled "A Reconnaissance Study of Strike-Slip Faulting near Yucca Mountain, Nevada" (O'Leary) was prepared. The report summarizes the results of field examinations of the Rock Valley, Mine Mountain, and Cane Spring fault zones.

Activity 8.3.1.17.4.4.2 - Evaluate the Mine Mountain fault system. No progress during the reporting period; this is an out-year activity.

Activity 8.3.1.17.4.4.3 - Evaluate the Stagecoach Road fault zone. The Stagecoach Road fault evaluation has been transferred to Study Plan 8.3.1.17.4.6 (Quaternary faulting in the Site Area) because geologic mapping has demonstrated that the Stagecoach Road fault is an extension of the Paintbrush Canyon fault. Documentation to change the SCPB, to provide for transfer of this scope of work, is being prepared by the USGS.

Activity 8.3.1.17.4.4.4 - Evaluate the Cane Spring fault system. No progress during the reporting period; this is an out-year activity.

Forecast: Work planned for FY 1993 includes completion of Study Plan comment resolution, field mapping along the Rock Valley fault system with emphasis on fault slip indicators, and preparation of a preliminary report. Due to the Little Skull Mountain earthquake, additional field work will be conducted on the Mine Mountain fault system.

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

Study Plan 8.3.1.17.4.5 received DOE approval and was sent to NRC on August 12, 1992.

Activity 8.3.1.17.4.5.1 - Evaluate the significance of the Miocene-Paleozoic contact in the Calico Hills area to detachment faulting within the site area. Two weeks of reconnaissance field work were conducted in the second half of FY 1992. Several detachment faults along the California - Nevada border and in the Bare Mountain area were examined. Field work was conducted in CH area and a preliminary geologic map of the area was completed. A draft report entitled "Geology and Hydrothermal Alteration at the Calico Hills, Nevada" (Simonds and Scott) was prepared and is anticipated to be ready for USGS review early in FY 1993.

Activity 8.3.1.17.4.5.2 - Evaluate postulated detachment faults in the Beatty-Bare Mountain area. In addition to library research and consultations with geologists who have worked in the Beatty - Bare Mountain areas, a reconnaissance field trip to Bare Mountain was conducted to evaluate published and unpublished geologic mapping in the area of a proposed detachment fault. A scientific notebook plan was prepared so that investigators can begin a thermobarometry study of lower plate rocks as soon as the Study Plan receives NRC approval. The scientific notebook plan was submitted for USGS review.

Activities 8.3.1.17.4.5.3 through 8.3.1.17.4.5.5. No progress during the reporting period; these are out-year activities.

Forecast: During FY 1993 geologic maps will be completed for CH and Bare Mountain areas known or hypothesized to expose detachment faults. The origin of distinctive breccia masses proximal to Yucca Mountain, which appear to have formed as a consequence of tectonic activity and may have formed in conjunction with detachment faulting, will be evaluated. Work under Activity 8.3.1.17.4.5.5 will begin. Isotopic dates of geologic materials that overlap detachment faults will be determined. Studies of minerals believed to have formed during faulting will be studied to determine at what depth below the land surface detachment faulting was active in the past.

2.2.13.14 Study 8.3.1.17.4.6 - Quaternary faulting within the site area

The NRC accepted Study Plan 8.3.1.17.4.6 on October 3, 1991.

Documentation is being prepared by USGS to change the SCPB to transfer the scope of work pertaining to study of the Stagecoach Road Fault from Activity 8.3.1.17.4.4.3 to Study Plan 8.3.1.17.4.6.

Activity 8.3.1.17.4.6.1 - Evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain. Detailed fault zone mapping was obtained from previous workers for the Solitario Canyon, Fatigue Wash, Windy Wash, Sever Wash, Pagany Wash, Paintbrush Canyon, and Stagecoach Road faults. Field mapping, including fault locations and fault attributes, was compiled from aerial photos and plotted on overlays for the twelve, 1:12,000 scale orthophoto quadrangles that cover Yucca Mountain. A structure map of southern Yucca Mountain was prepared from unpublished geologic mapping. Data from previous workers will be combined with new mapping to prepare a comprehensive map showing all Quaternary faults in the vicinity of Yucca Mountain.

An open file report entitled "Photogeologic and Kinematic Analysis of Lineaments at Yucca Mountain, Nevada: Implications for Strike-Slip Faulting and Oroclinal Bending" (O'Neill, et. al.) received USGS approval. A revised version of the manuscript was prepared for submittal to an outside journal. Staff also contributed to the Electric Power Research Institute (EPRI) probabilistic seismic hazard study of future faulting within the proposed repository block.

Activity 8.3.1.17.4.6.2 - Evaluate age and recurrence of movement on suspected and known Quaternary faults. Excavation of four new trenches, re-excavation of two existing trenches, and cleaning of four natural exposures on the Solitario Canyon, Fatigue Wash, Paintbrush Canyon, and Stagecoach Road faults were completed. Preliminary investigations of the Busted Butte exposures of the Paintbrush Canyon fault focused on net vertical displacement since 700 ka, and determining the number of faulting events that affected the upper part of the exposed section. Logging has commenced on the Solitario Canyon fault trenches, and all of the other trenches have been examined and cleared by safety inspectors for mapping activities.

Along the Bow Ridge fault, trench 14C was cleaned and trench 14D was extended and modified as part of the Midway Valley activities (8.3.1.17.4.2). Trench 14C and a new section of trench 14D were logged. The surficial deposits in these trenches were correlated with the Quaternary stratigraphy developed as part of the Midway Valley activities.

Samples of pedogenic carbonate were collected from both buried and relict soils, and fault zones, in the Busted Butte exposures and trenches 14C and 14D. These samples will be processed for both U-series dating and stable isotopic analyses.

Recently exposed relationships between buried soils and fault-related fractures and veins have been examined and sampled for geochronological work at several sites. Critical cross-cutting relationships in gully walls of the sand ramps on the west side of Busted Butte are particularly important to bracketing the latest movement along the Paintbrush Canyon fault in this area, and to placing constraints on earthquake recurrence intervals and rates of displacement. In addition, similar relationships exposed in Trenches 14C and 14D on the west side of Exile Hill have been sampled and should provide geochronological constraints on Bow Ridge fault activity. Although some zones have high opal contents, initial scoping work indicates the presence of other soil horizons consisting of relatively pure carbonate which will hopefully provide accurate and unambiguous ages.

Forecast: A draft map of Quaternary faults in the vicinity of Yucca Mountain is anticipated by early FY 1993. It is expected that a probabilistic seismic hazard study of future faulting within the proposed repository block will be published by the end of calendar year 1992 by EPRI.

2.2.13.15 Study 8.3.1.17.4.7 - Subsurface geometry and concealed extensions of Quaternary faults at Yucca Mountain

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

Forecast: No activity is planned for FY 1993.

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

Activities 8.3.1.17.4.8.1 through 8.3.1.17.4.8.4. No progress during the reporting period; these are out-year activities.

Forecast: No activity is planned for FY 1993.

2.2.13.17 Study 8.3.1.17.4.9 - Tectonic geomorphology of the Yucca Mountain region

Activities 8.3.1.17.4.9.1 through 8.3.1.17.4.9.3. No progress during the reporting period; these are out-year activities.

Forecast: During FY 1993, the Study Plan will be written, reviewed internally by USGS, and submitted to YMPO.

2.2.13.18 Study 8.3.1.17.4.10 - Geodetic leveling

Activities 8.3.1.17.4.10.1 through 8.3.1.17.4.10.3. No progress during the reporting period; these are out-year activities.

Forecast: During FY 1993, a survey of about 92 km from Bare Mountain across Yucca Mountain and Rock Valley will be completed by first-order, class-one levels. This datum will be compared with that obtained in 1980. A Global Positioning Satellite (GPS) survey will also be conducted to measure the amount of horizontal movement since the original network was laid out in 1983.

2.2.13.19 Study 8.3.1.17.4.11 - Characterization of regional lateral crustal movement

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

Forecast: No activity is planned for FY 1993.

2.2.13.20 Study 8.3.1.17.4.12 - Tectonic models and synthesis

A draft version of the Study Plan was prepared, informally reviewed within USGS, and further revised.

Activity 8.3.1.17.4.12.1 - Evaluate tectonic processes and tectonic stability at the site. A request to procure enhanced Landsat thematic mapper and SPOT imagery for the Yucca Mountain region was prepared and submitted. The order is currently being processed at the Jet Propulsion Laboratory and is anticipated for delivery in early FY 1993. These enhanced images will assist in the tectonic, surficial geologic, hydrologic, and paleoclimatic interpretations of the Yucca Mountain region.

Surface deformation caused by the Landers earthquake (magnitude 7.5) of June 28, 1992, was examined in the field to determine whether similar features, indicative of paleoearthquakes, might be recognizable near Yucca Mountain. A draft report entitled "Tectonic Modeling in the Yucca Mountain Region" (Hamilton) summarizes the authors' observations to date and compares the geology of the Landers region with Yucca Mountain.

A report entitled "Tectonic Characterization of a Potential High-Level Repository at Yucca Mountain, Nevada" (Whitney and O'Leary) underwent USGS and YMPO review and was submitted to the American Society of Civil Engineers (ASCE). The report will be published in a proceedings volume of ASCE entitled Dynamic Analysis and Design Considerations for High-Level Nuclear Waste.

Activities 8.3.1.17.4.12.2 and 8.3.1.17.4.12.3. No progress during the reporting period; these are out-year activities.

Forecast: During FY 1993, complete internal USGS reviews and submit Study Plan for YMPO review. A scoping study will be initiated on the behavior of major Quaternary faults in the region of tectonic interest by using a boundary-element modeling approach.

2.3 REPOSITORY OVERVIEW

2.3.1 Geomechanical analyses (SCP Section 8.3.2.1.4.1)

The objective of this work is to develop evaluate, document, verify, and validate material models, analysis methods, and computer codes for use in preclosure performance analyses of a repository.

An important component of this work involves developing constitutive models capable of analyzing the responses of jointed rock masses. SNL's current continuum-jointed rock constitutive models represent state-of-the-art analysis capabilities. In this reporting period, there were ongoing efforts to improve both the capabilities and efficiency of the models. The two-dimensional orthogonal joint set model was reformulated to run faster and the results were verified against the results from the original formulation.

SNL continued its work in code documentation. The manual for the JAC3D finite-element code "JAC3D: A Three-Dimensional Finite-Element Computer Program for the Non-Linear Quasi-Static Response of Solids with the Conjugate Gradient Method" (Biffle) is essentially complete. In support of ESF activities, SNL has worked to obtain QA certification for the pertinent computer codes so that quality-affecting work can be performed. In this reporting period, a number of the codes used for thermal-mechanical analyses have received QA certification. These codes include FASTQ (finite-element mesh generation), BLOT (display and plotting of finite-element results), COYOTE II (finite-element thermal analyses), and JAC2D (finite-element solid mechanics analyses). This effort will continue as the codes are updated and specific modifications for application to jointed rock are made.

In addition to the work on the continuum joint models, scoping studies performed to determine boundary element and discrete element techniques would benefit the analysis effort. If modeling a large block of the repository or surrounding rock were necessary to ensure that

the boundary effects were properly accounted for, boundary-element technology coupled with finite elements could make analysis procedures economically feasible. The local nonlinearities could be handled with the finite elements, while the boundary elements would take care of the far-field effects. This finite element-boundary element work has been a joint effort between SNL and Geologic, Inc., a company specializing in boundary-element technology. To date, SNL has been able to couple finite elements and boundary elements in a single code and perform a number of successful test problems. There are some test problems that have not been successful, indicating more work is needed.

There has also been some effort to assess the applicability of discrete element technology to the classes of problems of interest at Yucca Mountain. The ability to perform detailed modeling of jointed rock structures is important when answers to questions regarding local effects, such as drift stability when subjected to seismic loading, are needed. Some effort was spent in formulating a discrete-element method that is well-suited to the types of static and dynamic loads that are expected at Yucca Mountain. This effort is viewed as essential in making discrete-element analysis economically feasible for addressing the relevant problems.

In order to have high-quality data for evaluating numerical analysis methods and joint models, an experimental study was initiated in which a stack of polycarbonate plates with a centrally located hole was axially loaded to induce sliding between the plates. Sliding displacements are measured using Moiré grid techniques. As of September 1992, the experimental and data reduction techniques had been developed and refined to a point that experiments could be performed with high confidence. After these initial series of tests are performed, more complicated joint patterns and rock, or rock simulate materials, will be used. These tests are very important for developing and validating SNL's analysis methods.

As part of the effort to assess and recommend rock mass properties for analyses to support the ESF, ACD and site characterization, SNL performed work to analyze the spacing and orientation of fractures for thermal-mechanical units down through CH. Using this information, rock quality designations for each unit were developed. Once the rock quality designations were assigned and by using intact rock properties and well-known empirical methods, it was then possible to estimate the rock mass mechanical properties such as elastic moduli and strength. These estimates of properties will be very useful for subsequent design analyses.

To better understand the properties of rock joints, SNL and the University of Colorado conducted an experimental study on the effects of nonstandard loading conditions on the frictional properties of joints. In these studies, the normal stiffness with which the rock specimens were loaded was varied. By varying the loading stiffness, the effect of joint dilation could be studied.

Forecast: During FY 1993, SNL will develop the user and theory manual for JAC2D, one of the principal thermomechanical analysis codes. Continuum joint models in two and three dimensions will be developed, documented, and verified. This work will include defining the appropriate test problems that will be needed to meet software QA requirements. FY 1993 efforts will work on the robustness of the two-dimensional models and will review, assess, and modify the three-dimensional work performed to date. This work, along with code documentation work, will allow JAC2D and a continuum joint model to be entered into SNL's QA system. Deliverables include reports and conference papers. Discrete joint and discrete block modeling capabilities will be developed for use in validation analyses along with the continuum joint models. Deliverables also include reports detailing development efforts. A coupled boundary-element/finite-element computer code will be developed for analyzing three-dimensional thermomechanical problems associated with designing a nuclear waste repository. This coupling will allow the finite elements in JAC to be used to focus on the near-field effects with the far-field boundaries accounted for properly by use of boundary elements.

SNL will conduct thermal and structural analyses which will provide verification for software, benchmark analyses (code comparisons), and validation analyses. This work will include validation analyses of laboratory experiments and will also include benchmark analyses using different codes of hypothetical (but realistic) repository structures.

2.3.2 Seismic analyses (SCP Section 8.3.2.1.4.2)

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

Forecast: No activity is planned for FY 1993.

2.3.3 Ventilation analyses (SCP Section 8.3.2.1.4.3)

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

Forecast: No activity is planned for FY 1993.

2.3.4 Safety analyses (SCP Section 8.3.2.1.4.4)

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

Forecast: No activity is planned for FY 1993.

2.4 REPOSITORY DESIGN

2.4.1 Configuration of underground facilities (postclosure) (SCP Section 8.3.2.2)

2.4.1.1 Design Activity 1.11.1.1 - Compile a comprehensive list of all the information required from site characterization to resolve this issue

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

Forecast: No activity is planned for FY 1993.

2.4.1.2 Design Activity 1.11.1.2 - Determine adequacy of existing site data

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

Forecast: No activity is planned for FY 1993.

2.4.1.3 Design Activity 1.11.1.3 - Document reference three-dimensional thermal/mechanical stratigraphy of Yucca Mountain

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

Forecast: No activity is planned for FY 1993.

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

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

Forecast: No activity is planned for FY 1993.

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

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

Forecast: No activity is planned for FY 1993.

2.4.1.6 Design Activity 1.11.3.1 - Area needed determination

SNL and other participants' staffs have been involved in an effort sponsored by YMP and the M&O to develop a coherent strategy and plan for resolving the issue of repository thermal loading. SNL will continue to support several working groups.

Forecast: Two- and three-dimensional thermal analyses will be run to evaluate thermal loading scenarios. Included in the analyses will be evaluations of waste emplacement options (drifts versus borehole), general repository layouts, and waste stream projections. Output from these analyses will be required by the repository designers as the YMP begins ACD. Deliverables include reports and briefings to repository designers.

2.4.1.7 Design Activity 1.11.3.2 - Usable area and flexibility evaluation

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

Forecast: No activity is planned for FY 1993.

2.4.1.8 Design Activity 1.11.3.3 - Vertical and horizontal emplacement orientation decision

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

Forecast: No activity is planned for FY 1993.

2.4.1.9 Design Activity 1.11.3.4 - Drainage and moisture control plan

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

Forecast: No activity is planned for FY 1993.

2.4.1.10 Design Activity 1.11.3.5 - Criteria for contingency plan

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

Forecast: No activity is planned for FY 1993.

2.4.1.11 Design Activity 1.11.4.1 - Chemical changes resulting from the use of construction materials

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

Forecast: No activity is planned for FY 1993.

2.4.1.12 Design Activity 1.11.4.2 - Material inventory criteria

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

Forecast: No activity is planned for FY 1993.

2.4.1.13 Design Activity 1.11.4.3 - Water management criteria

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

Forecast: No activity is planned for FY 1993.

2.4.1.14 Design Activity 1.11.5.1 - Excavation methods criteria

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

Forecast: During FY 1993, development of design constraints to limit the extent and magnitude of excavation-induced changes in rock mass permeability will be initiated. Realistic criteria for establishing the suitability of proposed construction methods (e.g., blasting techniques, TBMs, etc.) will be developed based on PA requirements. For example, such criteria include not changing the extent of the disturbed zone or unnecessarily complicating seal evaluations or emplacement.

2.4.1.15 Design Activity 1.11.5.2 - Long-term subsidence control strategy

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

Forecast: During FY 1993, the development of a long-term subsidence control strategy will be initiated. This work will be tailored to help clarify YMP's position regarding

the potential for surface subsidence and the impact of postclosure ground movement on waste containment and isolation. Included in the evaluation will be an assessment of current SCP goals as well as backfill requirements.

2.4.1.16 Design Activity 1.11.6.1 - Thermal loading for underground facility

A report entitled "Equivalent Energy Density Concept: A Preliminary Reexamination of a Technique for Equating Thermal Loads" (Ryder, 1992) has been published. The report documents the results of a study that addresses the thermal design problem of bounding-induced thermomechanical responses over expected ranges of waste stream characteristics (age and burnup). Generic scaling results based on 5,000 mega-Watt day per metric ton of uranium (MWd/MTU) burnup bins are presented in addition to results for the extreme yearly average characteristics of an oldest-fuel-first receipt schedule.

Initial design analyses to address a range of thermal loading for both in-drift and in-borehole emplacement schemes have been completed and will be consolidated with the M&O waste-stream studies. SNL and the M&O will review these results and will designate several cases for further study.

Forecast: During FY 1993, two- and three-dimensional thermal analyses will be run (as stated in Design Activity 1.11.3.1 forecast) to evaluate thermal loading scenarios. Included in the analyses will be evaluations of waste emplacement options (drifts vs. borehole), general repository layouts, and waste stream projections. Outputs from these analyses will be required by the repository designers as the YMP begins ACD.

2.4.1.17 Design Activity 1.11.6.2 - Borehole spacing strategy

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

Forecast: No activity is planned for FY 1993.

2.4.1.18 Design Activity 1.11.6.3 - Sensitivity studies

An extended summary of the results of a far-field thermal study (abstract) was submitted by Eric Ryder, SNL, for presentation at the 1993 IHLRWM Conference. The title of the paper will be "Comparison of Predicted Far-Field Temperatures for Discrete and Smeared Heat Sources." The study focuses on an evaluation of a range of design-basis areal

power densities (APDs) given a consistent set of modeling assumptions. Captured in the three-dimensional model are an accounting for variations in yearly average waste characteristics and the use of a detailed repository geometry.

Forecast: No activity is planned for FY 1993.

2.4.1.19 Design Activity 1.11.6.4 - Strategy for containment enhancement

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

Forecast: During FY 1993, SNL will develop a strategy to enhance containment for ACD. This task will examine and document alternative approaches that can be used to enhance postclosure performance. Included in the analyses will be examinations of the impacts of tailored waste streams, altered edge geometries, waste emplacement orientations, and panel aspect ratios.

2.4.1.20 Design Activity 1.11.6.5 - Reference calculations

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

Forecast: No activity is planned for FY 1993.

2.4.1.21 Design Activity 1.11.7.1 - Reference postclosure repository design

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

Forecast: No activity is planned for FY 1993.

2.4.1.22 Design Activity 1.11.7.2 - Documentation of compliance

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

Forecast: No activity is planned for FY 1993.

2.4.2 Repository design criteria for radiological safety (SCP 8.3.2.3)

2.4.2.1 Design Activity 2.7.1.1 - Design evaluation for compliance with radiological safety design safety design criteria and performance goals

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

Forecast: No activity is planned for FY 1993.

2.4.3 Nonradiological health and safety (SCP Section 8.3.2.4)

2.4.3.1 Design Activity 8.3.2.4.1.1 - Design activity to verify access and drift usability

A series of calculations have been completed that examine the temperature and stress changes at all exploratory access and drift locations planned for construction during site characterization. Results were obtained using a three-dimensional, semi-analytic model assuming a conceptual layout that has been proposed for development using TBMs. Initial design-basis APDs of 57 and 80 kW/acre (141 and 198 kW/ha) were examined, and the models run to 10,000 years following emplacement. The results of this study are being documented in a report ["Drift Design Methodology and Preliminary Application for the Yucca Mountain Site Characterization Project (Hardy et al., 1991)].

A series of two-dimensional thermal analyses were run in support of the M&O's systems study on the thermal management of the potential repository. The analyses examined the near-field thermal effects of two emplacement options, two waste package concepts, two drift shapes and sizes, and five design-basis APDs [20, 57, 80, 100, and 114 kW/acre (49, 124, 198, 247 and 282 kW/ha)]. Thermal profiles generated in this study are currently being analyzed structurally using the compliant joint model ["Two-Dimensional Continuum Model for Jointed Media with Orthogonal Sets of Joints," (Chen, 1986)] and rock-quality designations of one, three, and five (Hardy and Bauer, 1991).

Forecast: During FY 1993, thermal and mechanical analyses will be conducted to assess the impacts of various thermal loading scenarios on the ESF accesses and drifts. These analyses will be conducted as part of SNL's implementation of the drift design methodology in support of the ESF design. Thermal and mechanical analyses will be done to assess the impacts of various thermal loading scenarios on waste containment and isolation. Included in the analyses will be evaluations of drift, borehole, and access stability. Specific analyses to be conducted during FY 1993 will depend on the needs of the ESF or repository design team.

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

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

Forecast: No activity is planned for FY 1993.

2.4.4 Preclosure design and technical feasibility (SCP Section 8.3.2.5)

Several integration processes took place during the reporting period. Working with LLNL and LANL, SNL developed a plan to consolidate thermal tests in the ESF. Working with LLNL and the M&O, SNL began revising the thermal-design goals for the repository. Working with the M&O, SNL transferred design information from its previous work and identified issues to be resolved by the new design contractors during ACD.

As part of the integration efforts, SNL completed a set of initial design analyses to address the range of thermal loading that would be appropriate for both in-drift and in-borehole emplacement schemes. The results of these and other studies were transmitted to the M&O for use in current design studies.

Forecast: During FY 1993, management support will be provided to assemble thermal, mechanical, hydrologic, and other data to support the design of the repository and to evaluate repository subsystem design options.

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

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

Forecast: No activity is planned for FY 1993.

2.4.4.2 Design Activity 4.4.3.2 - Operations plan to accompany the license application design

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

Forecast: No activity is planned for FY 1993.

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

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

Forecast: No activity is planned for FY 1993.

2.5 SEALS SYSTEM DESIGN

2.5.1 Shaft and borehole seals characteristics (SCP Section 8.3.3.2)

2.5.1.1 Study 1.12.2.1 - Seal material properties development

Activities 1.12.2.1.1 and 1.12.2.1.2. No progress during the reporting period; these are out-year activities.

Forecast: During FY 1993, a plan for laboratory testing to be performed in support of the sealing program will be written, reviewed at SNL, and submitted to the YMP. Study Plan 8.3.3.2.2.1 will address materials properties as emplaced and as altered in anticipated geologic environments. Both cementitious and earthen materials will be addressed and important properties of the materials will be determined.

Evaluations of backfill performance will be documented. Evaluations will address the areas of hydrologic, structural, mechanical, thermal, and geochemical behavior, as well as integration with relevant information concerning the site and waste package. The primary focus of the document will be crushed rock, i.e., rockfill created by the TBM. The rockfill, as modified by the extraction, handling, and placement will also be considered. From the evaluations, a strategy for backfilling the repository will be developed, including how and when to backfill the repository.

Due to funding constraints, the number of numerical analyses to be performed in this summary account has been reduced. The analyses to be performed here will support laboratory and field testing efforts. Some of the analyses will provide direction in the testing program. For example, geochemical analyses would be performed to predict end products which should be analyzed for during the experimental program. Other calculations will be performed to determine how seals will respond during the field test.

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

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

Forecast: No activity is planned for FY 1993.

2.5.1.3 Study 1.12.2.3 - In situ testing of seal components

The final version of the report "Initial Field Testing Definition of Subsurface Sealing and Backfilling Tests in Unsaturated Tuff" (Fernandez et al.) was submitted to YMPO for review at the end of FY 1992. This report discusses the field testing program, and technical rationale for it for YMPO to consider in adopting a sealing strategy for site characterization boreholes and underground access ways. Two papers corresponding to this field testing effort were presented at the IHLRWM Conference in April 1992. The first paper was entitled "Proposed Sealing Field Tests for a Potential High-Level Radioactive Waste Repository" (Fernandez et al., 1992). The second paper was entitled "Supporting Hydration Calculations for Small- to Large-Scale Seal Tests in Unsaturated Tuff" (Case et al., 1992).

To support the field test planning effort, the program SHAFT.SEAL was completed, including review of the applicable SNL procedures associated with software development and use and generation of verification problems to evaluate the effectiveness and correctness of the software code. A draft user's manual was also prepared.

Forecast: Comment resolution on the Fernandez report will take place, otherwise no activity is planned for FY 1993.

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

Design Subactivity 1.12.4.1.1 - Define subsystem design requirements. The development of a strategy to seal exploratory boreholes continued at a low level of effort during this period. The primary activities completed were: portions of Chapter 3 dealing with the work strength and the in situ conditions; a draft of Chapter 4, Design Evaluations of Borehole Seals, including considerations when emplacing cementitious seals, corrosion of casing, and grout bulb effectiveness; and a draft of Chapter 5, Feasibility in Emplacing Borehole Seals.

Analyses were performed on the seismic evaluation of sealing components. This work involves (1) definition of the equivalent static and dynamic loads, (2) evaluation of dynamic

amplification as a function of frequency, (3) Universal Distinct Element Code (UDEC) analyses of rigid sealing components, and (4) pseudostatic analysis to establish critical angle of incidence and peak loads.

The results of the analysis were reported in "Seismic Considerations for Sealing a Repository in Unsaturated Fractured Tuff" (Fernandez et al.) which was presented at the Symposium on Dynamic Analysis and Design Considerations for High-Level Nuclear Waste Repositories. The symposium was held August 19-20, 1992, in San Francisco, California. The report concludes by recommending several strategies that can potentially enhance the performance of the sealing components.

A review of technologies to seal underground openings continued. This review included case histories prepared for a number of mining and civil operations, the preparation of the available technologies report, and the initiation of the review of Defense Nuclear Agency (DNA) sealing activities.

Design Subactivity 1.12.4.1.2 - Perform trade-off studies to support advanced design development. The primary area of effort involved performing numerical analysis to support the backfilling strategy development. Hydrologic, gaseous, geochemical, and in situ temperature and stress analyses were performed.

The hydrologic analyses are intended to determine the lateral extent of water flow in a drift from a discrete, water-producing zone. All water flow scenarios involved water entering a drift through a saturated fault zone. The drift was assumed to be backfilled with a variety of backfill materials. Additionally, the drift was inclined. Other variables in the analysis included the hydraulic conductivity of the fractured, bulk rock, the fault zone hydraulic conductivities, two steady-state water flow boundary conditions, and two transient water flow boundary conditions. To enhance the understanding of the water flow in the backfill, simple analytical solutions were performed.

The objective of the gaseous flow analyses is to determine the lateral migration of gaseous flow through backfill. The effort focused on development of an analytical solution evaluating the effectiveness in limiting gas flow along drifts of backfill (or seals) occupying the entire drift cross section. The analytical solution indicates that if seals can be constructed such that their gas permeability is on the same order as the gas permeability of the host rock, they can be very effective in limiting the flow of gas along the drifts. These preliminary results are independent of the driving pressure gradient and assume that the driving pressure gradient for gas flow is parallel to the axis of the drifts.

The geochemistry analyses evaluations considered alterations of the mineralogy of the Topopah Spring tuff and CH tuff. Several areas were investigated, including the effects of

temperature, water composition, and moisture content, through the use of numerical analysis. Other areas investigated included the thermal and chemical stability of clays and the optimum clay ratio.

Finally, preliminary temperature and stress change histories were developed assuming various loading conditions. For example, 20 kW/acre (49 kW/ha) 30-year-old waste, 20 kW/acre 60-year-old waste, 57 kW/acre (141 kW/ha) 30-year-old waste, and 80 kW/acre (198 kW/ha) 30-year-old waste.

Forecast: The primary effort for FY 1993 will include a strategy to seal exploratory boreholes and a review of available technologies to seal underground openings including a review of the DNA activities. Two SNL reports summarizing the work will be submitted to YMPO. An SNL report on the available technologies to seal underground openings will be completed during FY 1993. It will include discussions of backfilling, grouting, and bulkhead installation technologies. Specifically, a historical perspective on each of these technologies will be presented. Material usage, emplacement methods, and specific issues to each technology will also be addressed. This effort also includes responding to peer review comments and publishing the report.

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

Activities 1.12.4.2.1 through 1.12.4.2.3. No progress during the reporting period; these are out-year activities..

Forecast: No activity is planned for FY 1993.

2.6 WASTE PACKAGE DESIGN

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

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

The Preliminary Near Field Environment Report was sent to YMPO for review on April 27, 1992. Following YMPO review and comment resolution, LLNL will prepare a submission to the Reference Information Base (RIB).

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

Conceptual design began for a large-block (3-5 m sides) laboratory test of coupled thermal-hydrological-mechanical-geochemical-corrosion phenomena. A proposal for this test was submitted to YMPO.

LLNL comments on the PNL report entitled "Incentives for Selection of Spent Fuel for Delivery to the Federal Radioactive Waste Management System - A Preliminary Analysis" were discussed and clarified with staff at the Battelle Washington office. This draft report is currently under revision at PNL in preparation for a peer review. A draft paper entitled "Systems Implications of Repository Thermal Loading, Phase I Analysis Methodology" (Gottlieb) was reviewed by LLNL staff.

LLNL is supporting the M&O by conducting repository-heat-driven hydrothermal calculations and by providing technical assistance to support drafting the report "Systems Implications of Repository Thermal Loading, Phase I Analysis Methodology." LLNL staff provided input to and reviewed the Phase I draft of the thermal loading study being prepared by M&O-Vienna and attended a meeting of the report authors in Las Vegas, Nevada on August 19, 1992.

Forecast: During FY 1993, consideration will be given to redrafting Study Plan 8.3.4.2.4.1 (originally prepared in 1988) to more accurately reflect current plans for work in this task. As part of Activity 1.10.4.1.7, runs using EQ3/6 geochemical modeling code to consider precipitation and dissolution effects on pore and fracture properties will continue.

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

The review comments for Study Plan 8.3.4.2.4.1, "Characterization of the Chemical and Mineralogical Changes in the Post-Emplacement Environment" were fully incorporated in the text of the Study Plan. Although a draft of the revised Study Plan is near completion, consideration is being given to preparing a revised version that more accurately reflects the current plans for the work in this task, because the draft Study Plan currently under review was prepared originally in 1988.

LLNL staff attended the joint meeting of the Geochemistry and Hydrology Integration Team in Denver, Colorado, June 9-11, 1992. The meeting focused on detecting and characterizing fast pathways for fluid transport at Yucca Mountain and on integrating geochemistry and hydrology. Of particular interest was the influence of man-made materials (e.g., cement, grout) on the hydrological and geochemical properties of the environment in the

repository, and how excavation could modify the site properties. Reports from working groups and recommendations are being compiled and will be distributed later this year.

Activity 1.10.4.1.1 - Rock-water interactions at elevated temperatures. LLNL staff participated in the Oklo Working Group meeting in Brussels, Belgium, and meetings in Paris, France, with Agence Nationale pour la Gestion des Dechets Radioactifs (ANDRA) representatives, April 4-11, 1992. These meetings were called for to explore possible sites for analog studies that may be useful for radionuclide and code validation activities.

A paper entitled "Water-Rock Interactions in New Zealand Hydrothermal Systems: Comparison of Some Simulated and Observed Geochemical Processes" (Glassley and Christenson, 1992) was presented at the 1992 IHLRWM Conference held in Las Vegas, Nevada.

Activity 1.10.4.1.2 - Effect of grout, concrete, and other repository materials on water composition. The SCPB Revision 8, necessary to incorporate Man-Made Materials activities into the Waste Package Environment Testing area and create a Study Plan, completed technical review and was approved by YMPO.

Activity 1.10.4.1.3 - Composition of vadose water from the waste package environment. No progress during the reporting period; this is an out-year activity.

Activity 1.10.4.1.4 - Dissolution of phases in the waste package environment. The paper entitled "Free Energy Dependence of Albite Dissolution Kinetics at 80 °C, pH 8.8" (Burch et al.,) was approved by YMPO on June 29, 1992, and submitted to Chemical Geology, July 1992.

Activity 1.10.4.1.5 - Effects of radiation on water chemistry. No progress during the reporting period; this is an out-year activity.

Activity 1.10.4.1.6 - Effects of container and borehole liner corrosion products on water chemistry. No progress during the reporting period; this is an out-year activity.

Activity 1.10.4.1.7 - Numerical analysis and modeling of rock-water interaction. Attempts to model the coupling of fluid-rock interaction with hydrological properties continued, with emphasis on identifying specific regimes within which particular equilibrium conditions could be recognized. These early calculations suggest that chemical equilibrium will be approached in regions near the waste package. Initial runs with EQ3/6 to consider precipitation and dissolution effects on pore and fracture properties were started.

The paper entitled "Modeling Fluid-Rock Interaction at Yucca Mountain, Nevada: A Progress Report" (Viani and Bruton, 1992a) was approved by YMPO on July 30, 1992, and was published in September 1992.

The paper entitled "Modeling Ion Exchange in Clinoptilolite Using EQ3/6 Geochemical Modeling Code" (Viani and Bruton, 1992b) was approved by YMPO on May 8, 1992, and was presented at the 7th International Symposium, Water Rock Interaction Conference held at Park City, Utah, July 13-18, 1992.

2.6.1.3 Study 1.10.4.2 - Hydrologic Properties of waste package environment

Work continues at LLNL to resolve YMPO comments on Study Plan 8.3.4.2.4.2, "Hydrologic Properties of the Waste Package Environment."

Activity 1.10.4.2.1 - Single-phase fluid system properties. Most of the LLNL hydrology work in this period was in the two-phase fluid system properties activity.

Activity 1.10.4.2.2 - Two-phase fluid system properties. The feasibility study of using a resonant cavity to measure relative humidity in laboratory rock samples continued. Calibration was completed of the prototype resonant cavity at 85 °C and a range of relative humidity levels from 50 percent to almost 100 percent. Work was completed to redesign the resonant cavity. Work has been temporarily discontinued due to problems with the network analyzer.

The determination of the characteristic curves of the eight disc-type Topopah Spring Tuff samples from U3hg-1 hole, at a depth of 400 m (1,312 ft) continue to be studied. The discs are 2.54 cm in diameter and about 0.6 cm thick. Imbibition studies have been done on this rock before. The characteristic curve information will be added to the results of the previous imbibition study for the estimation of relative permeability of this rock. Although the sample is from Area 3, far from Yucca Mountain, the relative permeability and other hydrologic properties of this rock can be used for model validation. The porosities of these samples have been determined. During the test, the discs were saturated with water and put into a constant-humidity chamber which was set at a constant temperature and various relative humidity levels. Measurements have been completed at 50, 60, 70, 80, 90, and 98 percent relative humidity levels at 20 °C. The samples are in the draining phase at a relative humidity of 75 percent.

A suite of fracture-matrix flow calculations was conducted to compare primary retardation mechanisms affecting radionuclide transport in fractures. Transport of radionuclides can occur under locally fracture-dominated or matrix-dominated flow conditions. The type of flow has a major impact on the relative amount of hydrological and geochemical interaction between the infiltration pulse and the mineralogy of the fractures and

matrix. In general, three primary categories of retardation have been identified which retard aqueous species transport in fracture-matrix systems, two of them involving physical retardation of the wetting front and one involving chemical retardation.

Radionuclide transport under matrix-dominated flow conditions is retarded by the chemical sorption properties of the matrix. Transport under fracture-dominated flow conditions, on the other hand, is retarded by chemsorption onto fracture surfaces which, because of geochemical alteration from previous episodic events (or from repository-heat-generated condensate drainage), could be considerably different from the matrix. Additional retarding mechanisms for fracture-dominated transport are liquid advection and diffusion, resulting in transport of the species from the fracture into the matrix.

Radionuclides moving through fractures will be advected into the matrix by matrix imbibition. The concentration of radionuclides in the fracture is not reduced by matrix imbibition, but the movement of the advective liquid front down the fracture is retarded. This type of retardation could be termed "physical-advective retardation" as opposed to "chemical retardation".

Molecular diffusion from the fracture to the matrix is an important retarding process only when it is comparable to or stronger than the imbibition flux. Diffusion into the matrix dominates if the matrix imbibition diffusivity constant, D_m, is much smaller than the apparent molecular diffusivity constant of the solute. Because of the small storativity of the fracture, molecular diffusion from fracture to matrix may be an important retarding mechanism for fracture-dominated transport, even though it is a relatively slow process. Diffusion, unlike advection, retards transport by reducing the solute concentration in the fracture stream. This type of retardation could be termed "physical-diffusive retardation."

"Back-diffusion" occurs when a clean pulse of water flowing down a fracture is contaminated by radionuclides diffusing out of the matrix. This process occurs if the apparent molecular diffusivity constant of the solute is comparable to or larger than the matrix imbibition diffusivity constant, D_m. On the other hand, if D_m is large relative to the apparent molecular diffusivity constant, advection by imbibition from fracture to matrix will dominate molecular diffusion from matrix to fracture, limiting the entrainment of radionuclides in the fracture pulse.

An important release and transport scenario pertains to the situation in which the emplacement drift is backfilled with a high k_m (matrix permeability) material. For high-k_m backfill, flow conditions in the emplacement drift (surrounding the waste package) are matrix-dominated, which will attenuate any potential fracture-dominated pulse of water reaching the emplacement drift. Consequently, any release and transport of radionuclides is controlled by molecular diffusion, resulting in a slowly expanding plume of radionuclides through the backfill and into the surrounding Welded Topopah Spring (TSw2) host rock. Radionuclides

will diffuse from the contaminated matrix into any flowing fractures each time a liquid fracture pulse passes through the contaminated plume domain. Depending on the relative magnitude of D_m and the molecular diffusivity constant, the mass of entrained radionuclides may be quite limited.

Scoping calculations of in situ heater tests were conducted in support of the decisional analysis for the proposed Yucca Mountain Test Facility (YMTF) at Busted Butte. A major objective of this study is to look at the trade-offs between test duration (and heating rate) and the primary hydrological, geochemical and geomechanical objectives of in situ heater tests. Because of the range of considered testing options, calculations were designed to address in situ heater tests which range from an 18-month duration (with a 12-month full-power heating stage) to a 5-7 year duration (with a 3-5 year full-power heating stage). During the latter stage of the test the heating rate will be ramped down to observe cool-down and re-wetting behavior. Work also began on investigating the impact of heater test size by considering three cases: (1) six 5.5-kW heaters in two parallel heater drifts with 8.23-m center-to-center drift spacing; (2) twenty-one 5.5-kW heaters in three parallel heater drifts with 12.8-m center-to-center drift spacing; (3) sixty-five 5.5-kW heaters in five heater drifts with 14.26-m center-to-center drift spacing.

Hydrologic and thermal properties and hydrostratigraphy used to model the reference case of previous modeling studies of repository-heat-driven hydrothermal flow were applied. Because of the presumed similarity in hydrostratigraphy between Busted Butte and the repository block at Yucca Mountain, these preliminary calculations are considered to be equally applicable to potential prototype tests at Busted Butte and to the ESF tests at Yucca Mountain.

The in situ heater tests are represented with two kinds of models. The drift-scale model is a two-dimensional cross-sectional model which explicitly represents the details of the heaters and heater drifts in the plane orthogonal to the drift axes. A 21-heater configuration is composed of three parallel 4.6 x 4.6-m heater drifts, with 12.8-m center-to-center drift spacing. Each drift contains seven 1.5 x 1.5 x 4.57-m drift-emplaced heaters with 5.49-m center-to-center spacing between heaters. The heated length of each drift is 38.4 m. Because it is two-dimensional, the drift-scale model effectively assumes that the heater drifts are infinitely long, effectively neglecting the heat loss which occurs due to heat flow parallel to the drift axes.

Also represented is the 21-heater test configuration as a disk-shaped "homogenized" heat source with a diameter of 21.665 m and a height of 1.5 m, yielding the same bulk-heated volume as the actual configuration. The radial "test-scale" model smears temperature effects between the heater drifts at very early time, but is representative after the dry-out zones have coalesced and has the advantage of accurately accounting for the overall heat balance. Comparisons between the drift-scale and test-scale models show outstanding agreement in

rock temperature at the center of the heater array for the first four years of full-power heating for twenty-one 5.5-kW heaters. The dry-out performance also agrees well between the two kinds of models.

Because of the limited time frame available for testing, all heater testing must be conducted at accelerated heating rates relative to actual repository thermal conditions. Therefore, the major challenge is to determine how much the heating rate can be accelerated without distorting the critical coupling between hydrothermal flow, geochemistry and geomechanics. For sizing the temporal and spatial extent of the heater tests, the following criteria were considered: (1) the velocity of the dry-out front; (2) the spatial extent and duration of the hydrothermal perching of condensate; (3) the peak rock temperatures; (4) the time rate of change of temperature; and (5) the volume of the dry-out zone.

The first and second criteria primarily relate to hydrothermal-geochemical coupling at the re-fluxing front which may result in the geochemical alteration of fracture and matrix properties. If the dry-out front is driven too quickly, there will be inadequate time for geochemical effects to occur. The third and fourth criteria relate to the potential for geomechanical and geochemical effects to significantly alter the thermo-hydrological properties in a way that is not representative of repository thermal loading conditions. The fifth criterion relates to the scale of the dry-out zone relative to the scale of the heterogeneity of the fracture properties (particularly the fracture spacing). If the dry-out zone is small relative to the scale of heterogeneity, dry-out and condensate drainage may be completely dominated by the local heterogeneity. Moreover, the validation of models which incorporate bulk-averages of matrix and fracture properties require tests where bulk averages are statistically meaningful. To hydrothermally perch condensate, it is necessary to coalesce the boiling zones, thereby precluding condensate from being easily shed off the sides of the individual boiling zones surrounding each heater.

Heating rates from 2.25 to 22 kW per heater were considered. With respect to the second criterion, it was determined that adequate coalescence of the dry-out zones occurs when dry-out extends approximately 14 m vertically. For 5.5-kW heaters, 14 m of vertical dry-out is achieved in four years with a peak rock temperature of 214 °C. For 6.3, 8.25, 12.38, and 22-kW heaters, 14 m of vertical dry-out is achieved in 3.4. 2.5, 1.7 and 1.1 years, respectively, with peak rock temperatures of 230, 264, 335, and 485 °C, respectively. Therefore, to achieve coalescence between heater drifts during an 18 month test, it is necessary to drive peak rock temperatures to nearly 500 °C. Moreover, the velocity of the dry-out front associated with the 22-kW accelerated-rate test is on the order of 10 m/yr which is much greater than the dry-out front velocities typical of repository conditions ($\leq$ 1.0 m/yr).

The impact of test size was investigated by considering the following three cases: (1) six 5.5-kW heaters in two parallel heater drifts with 8.23-m center-to-center drift spacing; (2) twenty-one 5.5-kW heaters in three parallel heater drifts with 12.8-m center-to center-drift

spacing; (3) sixty-five 55.5-kW heaters in five heater drifts with 14.26-m center-to center-drift spacing. At the center of the heater array, the rock temperatures at the end of four years of full-power heating are 147, 214, and 231 °C for the 6, 21, and 65 heater arrays, respectively, while the vertical thickness of the dry-out zone is 5.6 m, 14.3 m, and 16.6 m for these three arrays. Effectively, the center of the 21-heater array performs as though the test were infinite in areal extent during the first four years of full-power heating.

Also investigated was the ability to discriminate between conduction-dominated heatflow and heatflow which is significantly influenced by far-field convection (called convection-influenced heatflow). Two general conditions are required for convection-influenced heatflow: (1) thermal loading conditions which are sufficiently high to drive UZ-scale buoyancy flow and (2) sufficiently large bulk permeability, k_b, of the fractured rock mass. Because far-field convection occurs on the UZ-scale, fracture pathways which give rise to the large k_b must be contiguous throughout the UZ. In addition to the reference case of 2.8×10^{-13} m^2 (3.3 100-μm fractures per meter), also considered was 8.3×10^{-11} m^2 (1-1000-μm fractures per meter), and 1.9×10^{-18} m^2 (no fractures).

When heat conduction dominates heat flow, vapor flow is driven both vertically upwards and downwards from the boiling zone. Local boiling pressure gradients (which drive water vapor away from the boiling zone) tend to be more dominant than the buoyancy-driven pressure gradients which drive UZ-scale convection cells. Because the boiling pressure gradients are symmetric about the heated zone, roughly equal quantities of water vapor are driven above and below the dry-out zone, resulting in a vertically symmetric distribution of condensate generation. Superimposed on this vertically symmetric distribution of condensate generation is the effect of condensate shedding off the sides of the boiling zone. Because of the relatively small size of the heater tests, it was found that condensate shedding quickly results in a greater proportion of the condensate lying below the boiling zone for the reference case, causing an apparent asymmetry in condensate distribution. However, because heat flow is conduction-dominated, the temperature distribution is vertically symmetric about the heater horizon.

When far-field heat convection significantly influences far-field heat flow, the UZ-scale buoyancy-driven pressure gradients dominate the local boiling pressure gradients. Therefore, although local boiling pressure gradients below the dry-out zone tend to drive vapor downwards, UZ-scale convection cells dominate vapor flow, resulting in water vapor being driven upwards. Consequently, in the high-k_b case, all of the water vapor is driven upwards where it condenses above the dry-out zone. Therefore, for convection-influenced heatflow, the expectation would be to see nearly all of the condensation occurring above the dry-out zone. This asymmetry in condensate distribution results in a much larger vertical upward component of latent heat convection in the high-k_b case, manifested by a very pronounced vertical asymmetry in the temperature distribution and reduced temperatures near the heaters. The upper heat-pipe (or condensate) zone is more than twice the vertical extent

of the reference case. The uppermost extent of boiling temperatures is significantly higher in the high-k_b case, and the lowermost extent is considerably less. The resultant vertical upward shift in the upper boiling temperature front is 2.5 m after one year, 5.5 m after two years, and 9.0 m after four years of full-power heating in the twenty-one 5.5-kW heater array. Therefore, the vertical temperature distribution is a very clear discriminator as to whether far-field convection significantly affects heat flow.

A linear ramp-down to zero power in the one year period following four years of full power heater testing has also been modeled for both the reference and high-k_b cases for the twenty-one 5.5-kW heater array. Although the heaters were turned off after five years, boiling conditions at the center of the heater array persisted until 6.54 years for the reference case. The cooling effect of far-field convection resulted in boiling conditions persisting only until 5.8 years for the high-k_b case. Re-wetting of the heater horizon back to ambient saturation takes much longer than cooling to sub-boiling temperatures. For the reference case, it takes 533 years for the center of the heater array to re-wet back to one-half ambient saturation (34 percent). Although the high-k_b case dried out 13 percent less rock, it takes 16.5 percent longer (621 years) to re-wet back to one-half ambient saturation. The longer re-wetting time is due to the enhanced vertical movement of gas carrying away moisture from the condensate zone above the dry-out zone. Hence, "breathing" of the UZ is facilitated by a large k_b. Both cases require nearly 5,000 years to re-wet back to ambient saturation.

Repository thermal calculations using heat conduction models have been conducted by three groups (LLNL-Hydrology, LLNL-Engineering and SNL). The LLNL-Engineering and SNL groups have assumed that the thermal conductivity (K_{th}) for TSw2 can be applied to the entire UZ. However, K_{th} (both wet and dry values) for TSw2, are twice as large as the wet K_{th} value for the nonwelded Paintbrush Tuff (PTn) and CHnv units and the welded CHnz, and nearly four times larger than the dry K_{th} value of the CHnz. Therefore, assuming the TSw2 K_{th} can be applied to the entire UZ substantially under-represents the insulating effect of the lower K_{th} values of the far-field units. LLNL-Hydrology calculations (assuming that the TSw2 K_{th} values apply to the entire UZ) found that the duration of boiling decreases by 50 percent relative to the case with the RIB Version 4 K_{th} distribution. For 30-year-old fuel and an APD of 114 kW/acre (282 kW/ha), the duration of boiling decreases from 6,500 to 3,200 years. The three most similar calculations [114, 102 and 100 kW/acre (282, 252, and 247 kW/ha)] by the three groups agreed within about 10 percent for both peak temperature and boiling duration when the temperature rise was scaled to the heat load. For long-term boiling performance, the depth of the repository appears to be optimally located with the highest K_{th} being in the near-field (providing for limiting peak temperatures), and the lowest K_{th} being in the far-field (insulating the repository, thereby extending the duration of boiling).

Several suites of scoping calculations were conducted that systematically examined the sensitivity of the hydrothermal performance of the UZ to four drivers: thermal conductivity

(K_{th}), bulk permeability (k_b), recharge flux, and the treatment of hydrothermal flow in the SZ. APDs of 20-114 kW/acre (49-282 kW/ha) were used with 30- and 60-year-old fuel.

In past calculations, the thermal conductivity values were used from the RIB version 3. In the latest calculations, a suite of cases was run using RIB version 4 values of K_{th}. Because version 4 values are generally lower, all of the version 4 cases have longer boiling periods. For example, the calculated duration of the boiling period (t_{bp}) for 30-year old fuel with an APD of 57 kW/acre (141 kW/ha) increases from 1,800 to 2,100 years. For 30-year-old fuel and an APD of 114 kW/acre (282 kW/ha), t_{bp} increases from 5,000 to 6,500 years and for 60-year-old fuel and an APD of 114 kW/acre, t_{bp} increased from 10,000 to 13,000 years. While the duration of boiling increases, the peak temperatures for the version 4 cases do not increase. Although K_{th} for many of the units (the nonwelded units in particular) are smaller in version 4, the dry K_{th} of the TSw2 (the repository horizon), is significantly greater than in version 3. Therefore, the relative changes in K_{th} (version 4 vs. version 3) tend to reduce the far-field heat loss outside of the boiling zone (thereby prolonging the duration of boiling), but allowing for greater heat dissipation within the dry-out zone (thereby reducing the peak temperatures in the near-field).

The sensitivity of hydrothermal performance was examined at a range in bulk permeability from $1.9 \times 10^{-18} m^2$ (no fractures) to $2.8 \times 10^{-13} m^2$ (3-100-μm fractures per meter). When no fractures are present, there is no significant boiling because the small matrix permeability results in very large gas-phase pressure gradients, resulting in an elevated boiling point. Therefore, matrix-only flow is associated with completely conduction-dominated flow with no boiling effects, resulting in somewhat higher peak temperatures than the case with fracture flow and significant boiling effects. In contrast, if buoyancy does not significantly affect the mass flow of vapor, the duration of boiling is insensitive to the presence or absence of fractures. When buoyancy dominates vapor flow, both peak temperatures and the duration of boiling conditions are somewhat reduced. For $k_b = 2.8 \times 10^{-13} m^2$, the local boiling pressure gradients dominate far-field buoyancy, resulting in conduction-dominated heat flow for both 57 and 114 kW/acre (141 and 282 kW/ha) of 30-year-old fuel using RIB version 4 values of K_{th}.

The sensitivity of hydrothermal performance was examined at a range of net recharge flux from 0 mm/yr (resulting in an initial repository saturation of 68 percent) to 0.132 mm/yr (95 percent initial saturation) using the RIB version 4 values of K_{th}. In spite of the much wetter initial saturation distribution in the high net recharge case, the duration of boiling is the same as the zero net recharge case. The high net recharge case is associated with lower peak repository temperatures due to the higher initial heat capacity of the partially saturated rock.

In all of the calculations to date, the water table has been treated as being at a fixed depth and at a constant temperature. This assumption causes the SZ to act both as a heat sink

and a reservoir of liquid for re-wetting the dry-out zone. The impact of this assumption was examined by including the upper 1000 m of the SZ in the model. Heat conduction as well as convection, including buoyancy flow, are modeled in the SZ. For all of the cases considered [20-114 kW/acre (49-282 kW/ha), 30- and 60-year-old fuel], the treatment of the water table and SZ has very little impact on peak repository temperatures. Beyond 1,000 years (after temperatures have peaked), the SZ begins to heat up, thereby becoming less of a heat sink. Consequently, the duration of boiling substantially increases, particularly for higher thermal loading conditions. For 30-year-old fuel and an APD of 57 kW/acre (141 kW/ha), t_{bp} increases from 2,100 to 3,500 years. For 30-year-old fuel and an APD of 114 kW/acre (282 kW/ha), t_{bp} increases from 6,500 years to 11,500 years.

Calculations for low thermal loads which do not result in boiling are also affected by the treatment of the SZ. For 30-year-old fuel and an APD of 20 kW/acre (49 kW/ha), hydrothermal flow in the SZ extends the duration of time the repository is above 50 °C from 2,200 to 3,600 years and extends the duration of time the repository is above 40 °C from 5,060 to 14,150 years.

The impact of low thermal loads (resulting in sub-boiling conditions) on repository-heat-drive re-fluxing was examined. Even for sub-boiling conditions, repository-heat-driven re-fluxing will be significant for tens of thousands of years. Under ambient conditions, the geothermal gradient drives ambient re-fluxing even if the net flow of moisture is zero. Depending on what is assumed for naturally-occurring net recharge flux, repository-heat-driven condensate drainage (and the ambient re-fluxing) will probably be the dominant sources of liquid flux in the UZ.

For 30-year-old fuel and an APD of 36 kW/acre (89 kW/ha) (the same waste package spacing as the reference SCP case of 57 kW/acre (141 kW/ha) with 10-year old fuel), the average temperature at the center of the repository peaks at 90 °C. Although boiling temperatures never occur, repository-heat-driven re-fluxing results in as much as 1 mm/yr of liquid flux at the repository horizon (90 times the ambient re-fluxing). For 30-year-old fuel and an APD of 20 kW/acre (49 kW/ha), repository-heat-driven re-fluxing is at least five times larger than ambient re-fluxing. Therefore, boiling conditions are not required to generate significant vapor-phase and liquid-phase flux due to repository heating. Because sub-boiling conditions will also not mitigate the occurrence of episodic meteoric sources of deep nonequilibrium fracture flow, hydrologic assessments of low thermal loading conditions must account for the superposition of naturally occurring episodic fracture flow and repository-heat-driven re-fluxing for essentially all the time of regulatory concern.

Work began to examine the impact of repository-heat-driven hydrothermal flow on the hydrology and geochemistry of the SZ. It was found that there is a significant temperature rise in the upper SZ even for the lowest thermal loads. For 30-year-old fuel and an APD of 20 kW/acre (49 kW/ha), the upper SZ peaks at 46.9 °C (16.5 °C above ambient) at 6,900

years and remains above 40 °C for 26,350 years. Therefore, there is the potential for repository-heat-driven hydrothermal-geochemical alteration of the upper SZ even for low thermal loads. Work will soon begin to conduct preliminary scoping calculations of the potential of such alteration. For 30-year-old fuel and 114 kW/acre (282 kW/ha), the upper SZ peaks at 90 °C at 830 years, remains above 90 °C for 670 years, and remains above 70 °C for 12,400 years.

Several enhancements were made to EXTOOL including a new capability that maps the duration of time for which certain threshold conditions are exceeded. Data are examined between successive snapshots at a location to determine if a specified threshold is exceeded, and the time of threshold crossing is calculated. When the value at that location drops below the threshold, the second crossing time is calculated. For instance, if one is interested in the duration of fracture flow conditions which are generated by condensate drainage during repository-heat-driven boiling and dry-out, the duration of fracture flow conditions throughout the UZ can be contoured to indicate the potential for hydrothermal-geochemical alteration of fracture pathways.

Minor modifications were made to the output routine in V-TOUGH and was ported to the code to the Open Computing Facility (OCF) IBM workstations as well as to the National Energy Research and Supercomputing Center (NERSC) Crays which are now running UNICOS. Minor changes were also made to V-TOUGH to make it compatible with the most recent FORTRAN compiler on the IBMs. These changes resulted in version 5.4 of V-TOUGH. Several cases were benchmarked on the NERSC Crays, and it was found that the turn-around time was unsatisfactory for LLNL applications. Presently, it has been decided to emphasize running on the OCF IBMs.

An Individual Software Plan (ISP) has been completed to qualify the V-TOUGH code for quality affecting activities. The ISP was modified to reflect recent changes in the SQAP. The ISP has been signed by the LLNL Software QA manager and is now being processed by the LLNL QA manager.

A Flow and Transport Workshop was held in Las Vegas, Nevada on May 5-6, 1992. Presentations were given entitled "The Impact of Repository-Heat-Generated Hydrothermal Flow on Repository Performance" (Buscheck) and "The Impact of Physical and Chemical Retardation on Radionuclide Transport in Fractures" (Nitao).

UNR staff members visited LLNL on April 23, 1992, and July 16, 1992, to discuss possible collaboration efforts on modeling. M&O staff visited LLNL on June 24, 1992, to discuss hydrothermal-geomechanical coupling issues. YMPO and M&O staff visited LLNL on July 27, 1992, to discuss YMTF issues with the LLNL staff.

The following papers were presented at the 1992 IHLRWM Conference: "Characterizing the Altered Zone at Yucca Mountain: The Beginning of a Testing Strategy" (Chesnut, 1992); "The Impact of Thermal Loading on Repository Performance at Yucca Mountain" (Buscheck and Nitao, 1992); and "The Implications of Episodic Nonequilibrium Fracture-Matrix Flow on Site Suitability and Total System Performance"(Nitao, 1992).

Activity 1.10.4.2.3 - Numerical analysis of flow and transport in laboratory systems.

Liquid and gas velocity fields were extracted from the long-term hydrothermal calculations of the repository to calculate Damkohler numbers that indicate whether the assumption of local geochemical equilibrium is valid.

Work has begun on the development of the prototype version of the NUFT code, focusing on the three-dimensional gridblock generator. This version will handle aqueous species transport. Heatflow has been added and runs have been set up to run the NUFT code for imbibition calculations.

LLNL staff attended an INTRAVAL meeting at the HRF of the NTS on April 7, 1992, to discuss the Yucca Mountain model test case of the transect between neutron boreholes USW N-54 and USW N-55. Plans are to develop several alternative conceptual models of the hydrologic system in the vicinity of the transect, including the welded Tiva Canyon (TCw) unit, the various subunits of the nonwelded vitric PTn, and the upper welded Topopah Spring (TSw) unit. The related numerical modeling study will include various combinations of nonequilibrium fracture-matrix models and equivalent continuum models in order to analyze the impact of episodic nonequilibrium flow and steady-state matrix-dominated flow. The impact of the geothermal gradient and vapor movement will be investigated with nonisothermal models. Because the critical dimensionality of the system does not coincide with the transect between USW N-54 and USW N-55, the site-specific models will be augmented with an analysis of the mechanisms affecting the moisture balance in the vicinity of the transect.

LLNL staff attended the INTRAVAL meeting at LBL on August 24, 1992, to discuss the model validation test case using data from neutron boreholes USW N-54 and USW N-55.

Forecast: During FY 1993, a revised Study Plan will be prepared.

2.6.1.4 Study 1.10.4.3 - Mechanical attributes of the waste package environment

A final draft was prepared for Study Plan 8.3.4.2.4.3, "Characterization of the Geomechanical Attributes of the Waste Package Environment" with all comments being

resolved. The SCPB Section 8.3.4.2.4.3 was revised in Revision 8 to remain consistent with the structure of this Study Plan. This draft was submitted to YMPO.

Activity 1.10.4.3.1 - Waste package environment stress field analysis. Input was prepared for the thermal loading studies and for the proposed large block facility study. LLNL staff attended the Workshop on Fractured Rock Masses in Lake Tahoe, California, on June 3-5, 1992, and the Rock Mechanics Symposium in Santa Fe, New Mexico, on June 8-11, 1992.

Forecast: During FY 1993, Study Plan 8.3.4.2.4.3 will be issued.

2.6.1.5 Study 1.10.4.4 - Engineered barrier system field tests

Activity 1.10.4.4.1 - Repository horizon near-field hydrologic properties. The first draft of Study Plan 8.3.4.2.4.4 "Engineered Barrier System Field Tests" has been completed. The internal review process will soon be started.

LLNL chaired the Probabilistic Risk Assessment in Waste Processing session at the 1992 IHLRWM Conference held in Las Vegas.

LLNL staff attended the Sample Overview Committee (SOC) meetings on May 1, June 3, and July 7, 1992, in Las Vegas, Nevada and on September 10, 1992, at the NTS, the ESFTC design review meetings in Las Vegas, Nevada on May 12 and June 1, 1992, and participated in the ESFTC meeting in Las Vegas, Nevada on August 18, 1992.

LLNL staff met with an M&O group to kickoff the heater test duration decision analysis on June 19, 1992, and attended a meeting on thermal testing in Las Vegas, Nevada with the M&O group leader on June 24, 1992. Calculations were conducted at LLNL for several heater tests scenarios. These calculations were incorporated in the M&O group report in early July 1992. LLNL staff participated in the Heater Test Duration task force meetings in Las Vegas, Nevada on July 6, 10, and 13, 1992.

Activity 1.10.4.4.2 - Repository horizon rock-water interaction. No progress during the reporting period; this is an out-year activity.

Activity 1.10.4.4.3 - Numerical analysis of fluid flow and transport in repository horizon near-field environment. No progress during the reporting period due to lack of funding.

Forecast: A new Study Plan, 8.3.4.2.4.5 "Characterization of the Effects of Man-Made Materials on the Chemical & Mineral Changes in the Post-Emplacement Environment"

was created in Revision 8 of the SCPB. It will be written to address the portions of the SCP Issues 1.4 and 1.5 that pertain to the impacts of man-made materials on the local water chemistry. At the time LLNL is authorized to proceed with each of the Study Plans, the workscope will be assessed and a forecast for completion of these activities will be projected.

2.6.2 Characteristics and behavior of the waste form (SCP Section 8.3.5.10)

2.6.2.1 Activity 1.5.1.1 - Integrate waste form data and waste package design data

Subactivity 1.5.1.1.1 - Integrate spent fuel information. Review comments for the Waste Form Characterization Report have been received and are being addressed.

PNL received approval for their program-specific SQAP. Their QA Plan was revised to incorporate this new information.

A combined meeting was held on September 17-18, 1992, in Winnipeg, Canada, with LLNL, PNL and the AECL staff to discuss progress on the spent fuel dissolution task (SA-2 US/Canada collaboration agreement). AECL and LLNL representatives gave brief overview presentations of the spent fuel activities at this meeting.

A report entitled "Spent Fuel Acquisition Plan" has been reviewed by LLNL and comments are being incorporated into the final draft. In this report, recommendations are made for fuels to be acquired for characterization as testing materials. The five fuel types suggested for the testing program are: (1) high burnup fuel (>60 MWd/kgM) with strong rim effect; (2) low fission-gas release (<10%), high burnup fuel; (3) low fission-gas release (<10%), low burnup fuel; (4) burnable poison fuel (5 to 8 wt% Gd_2O_3) with relatively high burnup; and (5) high-fission gas release BWR fuel. The report has been delayed as there has been some difficulty defining what constitutes a high burnup fuel. The data suggest that burnup has little effect on the oxidation processes of spent fuel, but this has not been confirmed for a high-burnup fuel (>60 MWd/kgM).

It might be thought that one only needs to obtain a fuel of this burnup level and then test it. However, when fuels are allowed to achieve higher burnups, microstructure reorientation (rim effect) can occur. This restructuring may effect oxidation kinetics. However, it may not be possible to identify any fuels that would have sufficient restructuring to allow systematic evaluation of this effect. Also, a review of the current literature data has not shown that there is a correlation between burnup and the amount of restructuring that may occur. This is contrary to the assumption that higher burnup will equate to more restructuring.

Subactivities 1.5.1.1.2 and 1.5.1.1.3. No progress during the reporting period; these are out-year activities.

Forecast: During FY 1993, LLNL will complete the review process of the preliminary waste form characterization report.

2.6.2.2 Activity 1.5.2.1 - Characterization of the spent fuel waste form

Subactivity 1.5.2.1.1.1 - Dissolution and leaching of spent fuel. A series of UO_2 dissolution measurements on UO_2 pellets at room-temperature and 20 percent oxygen (O_2) experiments were completed. The dissolution rates were much higher than the first series reported last fall. An explanation for this difference is being sought. The only planned difference was the higher dissolved O_2 levels of the recently finished runs, which was the reason for the repeated runs. The O_2 content is not likely to be a significant factor here. The buffer compositions were the same as before and have no measurable impurities. One cell from the last series was disassembled so that the surface of the pellet could be examined with X-ray Photoelectron Spectroscopy (XPS) to look for impurities or other anomalies that might explain the higher dissolution rates. No unexpected chemical species were seen; however, the cell interior and filters contained dark powder that presumably spalled from the UO_2 dissolution test sample. This spall would increase the surface area above the nominal area value used in evaluating the intrinsic dissolution rate. The origin of this irregularity is being pursued. The increase in surface area would account for the high dissolution rate.

To further investigate the uncertainties in surface area changes during the tests, four UO_2 pellets were analyzed by using Electron Spectroscopy for Chemical Analysis (ESCA) and Scanning Electron Microscopy (SEM). These pellets included one from the last series of runs showing high dissolution rates of U, one from the low dissolution-rate runs last fall, and two unused pellets from batches that were hydrogen-reduced at different times. The latest series had buffers saturated with 20 percent O_2 in Ar. The similar runs last fall lost some O_2 via permeation through the plastic tubing during the tests. Although there were differences in the surface chemistry, all pellets showed U at a higher oxidation state than UO_2. The SEM analyses showed that the two pellets used in the dissolution runs experienced significant grain-boundary and pore etching via dissolution of UO_2. The buffer solutions before and after leaching, as well as the high-purity water used in their preparation, were analyzed via Inductively Coupled Plasma (ICP) MS. This highly sensitive technique for aqueous solutions can detect impurities in the part-per-trillion range. No unexpected chemical species were found. Dissolved O_2 concentration in the buffers is a possible cause of the high dissolution rates, although the reason for such a large effect is unclear. Experiments using single-crystal UO_2 and stainless steel systems with integral O monitors were performed. These experiments eliminate the surface area and O_2 concentration uncertainties.

Because of the surface area uncertainties, a follow-up series of uranium-dissolution experiments using single-crystal UO_2 were completed at room temperature in buffer solutions saturated with 20 percent O_2 in Ar. These experiments minimized the surface area uncertainties that were seen in the last series. The results showed good agreement and compared well with spent fuel dissolution data obtained by PNL and with the UO_2 powder experiments performed at both LLNL and PNL.

At PNL, flow-through testing of spent fuel specimens at reduced O_2 fugacities is in progress according to the approved test matrix. The inconsistent spent fuel test results reported by PNL were caused by loose-end fittings on the flow-through columns. This apparently resulted from reuse of columns that had been used in previous tests. The end fittings were not sufficiently tightened in the hot cell after new spent-fuel specimens were installed. Use of new columns that allow pretightening of the end fittings outside the hot cell should eliminate the problem. New spent-fuel specimens will be installed in new columns, and testing at reduced O_2 fugacities will be restarted.

Tests with partially oxidized (U_4O_9 lattice that is smaller than the UO_2 lattice) spent fuel fragments 1 mm in size are in progress. Results obtained to date (total of 21 days of testing) indicate little difference between the oxidized fragments and similar fragments of unoxidized fuel. The U and the ^{137}Cs dissolution rates from the oxidized specimens were less than a factor of two greater than from the unoxidized specimen). These results are similar to those obtained earlier when partially oxidized (U_4O_9 lattice) spent-fuel grains approximately 15 μm in size were found to dissolve at about the same rate as unoxidized grains of the same fuel. The fuel in both sets of tests was the same (ATM-105, a BWR fuel with 31 MWd/kgM burnup and 0.6-percent fission gas release). The partially oxidized fuel had been oxidized in air at 175 °C for about two years resulting in specimens with stoichiometries of $UO_{2.38}$ and U_4O_9 crystal lattice structures. Both oxidized and unoxidized specimens of fragments (~1 mm) and grains (~15 μm) were prepared using identical procedures, and identical methods were used to determine the surface areas of the oxidized and unoxidized specimens. Test conditions were the same for all four specimens (2×10^{-3} M carbonate/bicarbonate, pH = 9, atmospheric O_2 fugacity, 50 °C).

The absence of a substantial difference in dissolution rates between these oxidized and unoxidized specimens under the given conditions is an important preliminary result for the spent fuel characterization activities. Results obtained with the fuel grain specimens show that prior oxidation by air had little effect on the chemical dissolution rate per unit surface area. Results obtained with fragment (~1 mm) specimens show that the oxidation did not crack open the grain boundaries wide enough to make them more accessible to water as was thought possible, i.e., oxidation did not increase the effective surface area of the fuel. Thus, these preliminary results indicate that air oxidation to a U_4O_9 lattice structure would not increase the potential rate of release of radionuclides from a waste package should the spent fuel ever be contacted by water.

To show that these favorable results are generally applicable to spent fuel for the lifetime of a Yucca Mountain repository, two additional pieces of information are required: (1) additional tests must be performed to determine whether the reported results can be shown to be generally applicable to other fuels and other water chemistry test conditions that are relevant to the Yucca Mountain potential repository site; (2) further testing must be performed to determine whether air oxidation of spent fuel can progress past the U_4O_9 stage under expected Yucca Mountain conditions (the next oxidation phase beyond U_4O_9 is expected to be U_3O_8 which will have a significant volume increase).

The paper "Dissolution Rates of As-Received and Partially Oxidized Spent Fuel" (Gray et al., 1992) was presented at the 1992 IHLRWM Conference held in Las Vegas, Nevada.

An Argonne National Laboratory (ANL) paper entitled "Uranium Release and Secondary Phase Formation During Unsaturated Testing of UO_2 at 90°C" (Wronkiewicz et al.), (previously entitled "Leaching Patterns and Secondary Phase Formation During Unsaturated Leaching of UO_2 at 90°C") was approved by YMPO on May 8, 1992, and was submitted to the Journal of Nuclear Materials. A collaborative PNL/LLNL paper entitled "Parametric Study of LWR Spent Fuel Dissolution Kinetics" (Gray et al., 1992) was approved by YMPO on June 3, 1992, and was submitted to the Journal of Nuclear Materials. It was also published as an LLNL report in June 1992.

Subactivity 1.5.2.1.2 - Oxidation of spent fuel. An interim examination of the spent fuel in the dry baths at PNL was conducted. There were no unusual results. There was no indication of excessive weight gain indicating formation of the next phase change above U_4O_9. The next interim examination is scheduled in August 1992. Weight gain data had indicated that moisture level has no effect on the oxidation rate. This was confirmed by ceramographically examining two samples oxidized to O_2/M~2.4 at -55 and +80 °C dewpoints. No difference in appearance was found. X-ray diffraction analyses are being conducted on the samples.

As part of the oxidation investigations, issues were being considered that might have been overlooked and which would affect the data interpretation. There is a possibility that higher oxides might have been forming on the surface of the fuel grains, and the new phase might be falling off the grains in powder form. Since only individual spent fuel grains from each dry bath crucible are examined, any powders falling off the grains into the bottom of the crucibles would be missed and the data interpretation would be incorrect. The entire contents of one of the crucibles containing fragments with O_2/M-2.4 was examined. No powder was observed in the crucible, putting this concern to rest.

A series of short-term oxidation scoping experiments on Gd-doped unirradiated UO_2 and spent fuel were performed to determine the parameters for next year's dry bath tests.

The Gd-bearing fuel oxidized to U_4O_9 similar to spent fuel oxidation (not to U_3O_7 like unirradiated UO_2). The rate of oxidation decreased with increasing Gd content. The amount of Gd used in these experiments ranged from the amount of fission products in current spent fuel to the higher values expected from future high-burnup fuels that use burnable poisons. These scoping experiments support the earlier evidence that suggests fission products may be responsible for the stabilization of the UO_2 matrix against oxidation.

Very short-term, one day or less, Thermogravimetric Apparatus (TGA) ramp tests are being conducted to approximately determine the temperature and time domains for which the phase of oxidation beyond U_4O_9 will occur. This scoping work will be used to complete test plans for O_2 drybath and future TGA oxidation activities during FY 1993.

For high-burnup spent fuels, spatial variation may occur in oxidation and dissolution response across the diameter of a pellet. A marker to identify the original diametrical position of a fragment within a pellet is conjectured to be the distribution of "epsilon" particles (aggregation of fission product metals). An empirical relationship to relate "epsilon" distribution and fragment spatial position is being investigated, but efforts to date have not been successful. Such a relationship would be useful in spent fuel characterization of test matrix samples.

The paper "Oxidation of Spent Fuel in Air at 175°C to 195°C" (Einziger et al., 1992), (previously entitled "Ceramographic Determination of Spent Fuel Oxidation Rate") was presented at the 1992 IHLRWM Conference held in Las Vegas, Nevada.

Subactivities 1.5.2.1.3 through 1.5.2.1.6 . No progress during the reporting period due to lack of funding.

Forecast: The oven dry-bath oxidation testing of spent fuel at PNL will continue and will provide oxidized spent fuel samples for spent fuel dissolution activities. TGA oxidation testing at PNL will be planned and initiated to characterize the U_4O_9 to U_3O_8 oxidation phase transformation. The spent fuel (PNL) and UO_2 (LLNL) dissolution activities will continue; an oxidized spent fuel dissolution test matrix will be initiated and a repository nominal water chemistry dissolution test matrix will be planned and initiated. Available spent fuel waste form information will be incorporated into the Waste Form Characteristics Report for design and Performance Assessment use.

2.6.2.3 Activity 1.5.2.2 - Characterization of the glass waste form

Subactivity 1.5.2.2.1 - Leach testing of glass. This activity has received limited funding in FY 1992. These funds are being used to maintain the N2 and N3 tests at ANL. The N2 tests (SRL actinide-doped glass) continue, with no sampling occurring during this

reporting period. These tests have been in progress for 340 weeks. The N3 tests (ATM-10, a West Valley actinide-doped glass) continue and have been in progress for 258 weeks. A readiness review and QA Grading were completed at ANL to upgrade the status of the N2 and N3 tests. On September 15, 1992, a draft of "High-Level Nuclear Waste Borosilicate Glass: A Compendium of Characteristics" was released for review. An international team of independent reviewers currently is reviewing the document. A DOE management review is planned for January 1993.

Work continued on the analyses of glasses that have been reacted in water vapor (100 percent relative humidity) at 75 °C for time periods up to three years.

A series of parametric tests are still ongoing. Because of limited volume in the test vessels, a number of the tests were sampled to avoid allowing the standing water level to contact the glass. Solutions were collected for 11 tests and will be saved for later analysis when free time becomes available on the ICP/MS. The solutions were analyzed for pH, C, and anion content as these analyses are performed in-house at ANL. Samples were taken for colloid analysis to be done on the Transmission Electron Microscope (TEM).

Subactivities 1.5.2.2.2 and 1.5.2.2.3. No progress during the reporting period due to lack of funding.

Forecast: The long-term glass waste form alteration testing at ANL will be maintained but no characterization activities will be done at existing funding allocations. Available glass waste form information will be incorporated into the Waste Form Characteristics Report for design and Performance Assessment use.

2.6.2.4 Activity 1.5.3.1 - Integrate scenarios for release from waste packages

Subactivity 1.5.3.1.1 - Develop scenario identifications. Staff attended the NRC Technical Exchange on Scenario Development meeting in Albuquerque, New Mexico, on April 28-29, 1992.

Subactivity 1.5.3.1.2 - Separate scenarios into anticipated and unanticipated categories. No progress during the reporting period due to lack of funding.

Subactivity 1.5.3.1.3 - Development of parameters describing the scenarios. Development continued of the Yucca Mountain Integrating model (YMIM) to analyze scenario inputs.

Subactivity 1.5.3.1.4 - Determine adequacy of design envelope of waste package. The YMIM model began preliminary design analyses. First results were presented at the PA Support to Design and Testing Meeting, July 14-15, 1992, in Las Vegas.

Forecast: The primary effort will be continued development of the Yucca Mountain Integrating model (YMIM) simple integrating Engineered Barrier/Near Field (EBVS/NFE) model and applications to scenario analyses and sensitivity studies. When the next TSPA iteration begins, EBS/NFE scenarios will be proposed for analysis.

2.6.2.5 Activity 1.5.3.2 - Develop geochemical speciation and reaction model

Subactivity 1.5.3.2.1 - Develop data base for geochemical modeling. GEMBOCHS programs DBAPP and D0OUT were used to generate three revised suites of thermodynamic datafiles (DATA0 suites R14-R16) that support the EQ3/6 geochemical modeling package (version 7.0). These new datafiles together with the corresponding DATA1 suites were transferred to the Alliant FX/80 where they can be accessed by local EQ3/6 users.

The GEMBOCHS data base was restructured and all data transferred into the new table structure; associated modifications to DBAPP and D0OUT were completed. This update facilitated significantly improved performance of DBAPP and D0OUT. A separate DBAPP update expanded the capabilities of this software to facilitate interactive review of all GEMBOCHS data, tightened access controls on user modification of these data, and broadened the range of information that can be included in the data base.

The GEMBOCHS staff completed development (including extensive beta testing) of the CNGBOCHS software system and submitted a paper entitled "CNGBOCHS: an Integrated Ingres-Email-Interleaf System for Processing Change Requests Associated with the GEMBOCHS Thermodynamic Database and EQ3/6 Software Package" (Daveler et al.). This paper is now in internal review.

The GEMBOCHS staff began transferring the GEMBOCHS data base and software library from the local sun 3/260 server to a dedicated sun SPARCstation 2. Completion of this transfer will result in dramatically improved performance for each data base and software module in the GEMBOCHS system.

ISPs for three GEMBOCHS programs (CNGBOCHS, DBAPP and D0OUT) were generated, reviewed, revised, and accepted by the LLNL-YMP software QA program.

"The LLNL GEMBOCHS Database" document was submitted to YMPO. The "Software Library: YMP-TDB Quarterly Report: [First, Second] Quarter, 1992" document was submitted to YMPO.

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The requested set of GEMBOCHS parameter screens was generated and submitted to YMPO for inclusion in the YMP-TDB Parameter Dictionary. The GEMBOCHS chapter of the YMP-TDB handbook, to be published this fall, was generated and submitted to YMPO. A Technical Data Workshop, intended to familiarize project investigators with recent developments in the technical data management system was held at LLNL on July 27, 1992.

The R14 datafiles were used with the EQ3/6 test case library. A few problems were detected and were reported to the GEMBOCHS Administrator. The R15 datafiles were partially checked by running them through the test library.

An OCRWM audit of LLNL on August 10-14, 1992, reviewed EQ3/6 code maintenance and GEMBOCHS maintenance/development. The audit evaluated a variety of activities related to record management of changes and developments. No findings were issued in this area.

LLNL staff presented a talk entitled "Reverse/Re-Engineering an Existing Database" at the INGRES World '92 Conference held in Tarpon Spring, Florida, on May 17-21, 1992. This presentation has been submitted to YMPO for approval and after approval will be submitted as a journal article to INGRES. LLNL staff presented a talk entitled "The GEMBOCHS Database and Software Library: Overview of Contents, Components, and Applications" at the quarterly meeting of the YMP-TDB Administrators Working Group (Las Vegas, Nevada, June 30, 1992), at the YMP-TDB meeting " Overview of Technical Data Management" (LLNL, July 27, 1992), and during the OCRWM audit (LLNL, August 10, 1992).

Subactivity 1.5.3.2.2 - Develop geochemical modeling code. Planning for development of version 8.0 of EQ3/6 continued. Several major new capabilities are being planned, including pressure corrections, redox disequilibrium, and redox kinetics. In addition, incorporation of surface chemistry models and their linkage to rate law models, as for redox processes and mineral dissolution and growth is also being addressed. However, these may have to be put off to version 9.0.

The pressure corrections may be of considerable importance in the near future in order to deal with analyses of deep ground waters and samples of waters from proposed natural analog studies. Currently, the effect of pressure on thermodynamic properties is fixed as a function of temperature; 1.013 bar (1 atm) up to 100 °C and the steam/liquid water equilibrium pressure up to 300 °C. Actual pressures in systems of interest may be higher by as much as 300 to 500 bars (hydrostatic pressure alone corresponds to a gradient of 100 bars/km). Pressure corrections require additional thermodynamic data for volume functions. Much of this data is presently in the GEMBOCHS relational data base, but is not passed on to EQ3/6.

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A guideline was prepared documenting the rationale for the organization of chemical species and reactions in future versions of the EQ3/6 data files. The organization of the data file is very important to code usage, as the code utilizes reaction coefficients to define mass balance relations. Depending on how these reactions are written, the mass balance totals for chemical components may or may not correspond to the quantities reported by chemical analysts.

The restructuring of the sets of basis and auxiliary basis aqueous species used in EQ3/6 calculations was completed. This resulted in significantly improved flexibility with regard to the range of geochemical problems that can be addressed using the EQ3/6 package.

Version 7.0 of EQ3/6 was submitted to the Energy Science and Technology Software Center (ESTSC) at Oak Ridge, Tennessee. As part of the submittal, an abstract was prepared in the ESTSC-required format. This abstract will replace the old FIPS abstract. This software transmittal to the ESTSC fulfills a requirement under DOE Order 1360.4B. Version 7.1 was subsequently also submitted.

New data files were run through the EQ3/6 test case library to catch any errors associated with the recent rewrite of a significant subset of reactions. This testing was necessary to facilitate proper use of the software. EQ3/6 was ported to a Silicon Graphics workstation and test cases were run. Problems were identified which appeared to be associated with the Fortran compiler. After further examination, the problems were resolved.

At the direction of YMPO, the most recent version of the EQ3/6 software package and a set of the pre-release code manuals was transmitted to NAGRA under the provisions of the DOE/NAGRA bilateral agreement. In addition, the most recent version of the EQ3/6 software package and a set of the pre-release code manuals were transmitted by LLNL to representatives of LANL, PNL, and the technical staff of the NWTRB.

An ISP was completed and approved for Maintenance, Code Release and Documentation of EQ3/6 version 7. A separate ISP was completed and approved for Initial Qualification of EQ3/6 version 7. An ISP will next be prepared for all activities pertaining to version 8. If the necessary funding is received, development of version 8.0 will begin at the start of FY 1993.

A YMPO QA surveillance was conducted on EQ3/6 on June 15-17, 1992. Corrective action in response to a CAR was completed by incorporating all known bug fixes regarding EQ3/6 version 7.0 into a version 7.1, using the approved configuration management system. A letter concerning this matter and a set of floppy disks containing version 7.1 have been transmitted to all YMP parties who earlier received version 7.0 or version 7.0x. Version 7.0x was the major focus of the CAR. Version 7.1 also contains the new set of data files (R15).

Corrective action in response to a second CAR was completed by inventorying records and submitting all inactive records to the LRC. Active records not submitted are less than one year old.

The first of the four geochemical code user manuals entitled "EQ3/6, A Software Package for Geochemical Modeling of Aqueous Systems: Package Overview and Installation Guide, Version 7.0, Part I" (Wolery) was approved by YMPO on September 2, 1992, and will be published as an LLNL report. The second geochemical code user manual entitled "EQPT, A Data File Preprocessor for the EQ3/6 Software Package: User's Guide and Related Documentation, Version 7.0, Part II" (Daveler and Wolery) completed the technical review process. Comments made by the reviewer have been addressed by the author and the draft has been returned to the reviewer for re-review. The third geochemical code user manual entitled "EQ3NR, A Computer Program for Geochemical Aqueous Speciation-Solubility Calculations: Theoretical Manual, User's Guide and Related Documentation, Version 7.0, Part III" (Wolery) was sent to YMPO for programmatic review on September 30, 1992. The fourth geochemical code user manual entitled "EQ6, A Computer Program for Reaction Path Modeling of Aqueous Geochemical Systems: Theoretical Manual, User's Guide and Related Documentation, Version 7.0, Part IV" (Wolery and Daveler) is in internal review.

LLNL participated in the September 30, 1992, dry run in Las Vegas, Nevada for the October 14, 1992, NWTRB full board meeting.

A paper entitled "Hydrolysis and Carbonate Complexation of Dioxoplutonium (V)" (Bennett et al.) was approved by YMPO and was submitted to Radiochimica Acta. A paper entitled "Chemical Thermodynamics of Technetium V" (Rard) was approved by YMPO on April 27, 1992, and submitted for inclusion in the book "Chemical Thermodynamics of Technetium." An LBL/LLNL collaborative paper entitled "Photoacoustic Spectroscopy and the Effect of Amplified Spontaneous Emission (ASE)" (Klunder et al.) was approved by YMPO on April 6 and submitted to Journal of Analytical Chemistry.

Forecast: During FY 1993, the paper "CNGBOCHS: an Integrated Ingres-Email-Interleaf System for Processing Change Requests Associated with the GEMBOCHS Thermodynamic Database and EQ3/6 Software Package" (Daveler et al.) will complete internal review; the GEMBOCHS chapter of the YMP-TDB handbook will be published; development of version 8 of EQ3/6 will begin; and LLNL will participate in the October 1992 NWTRB full board meeting.

GEMBOCHS activities will include maintenance of the GEMBOCHS thermodynamic data base and associated software library (which includes CNGBOCHS, DAPP, D0OUT, etc.) for use with EQ3/6 and other geochemical modeling packages. As needed, support will be provided to revise thermodynamic datafiles for use with the EQ3/6 geochemical modeling

package. New and revised thermodynamic data and extrapolation algorithms will be incorporated into GEMBOCHS and D0OUT. Development of a windows/4GL version of DBAPP will begin.

2.6.2.6 Activity 1.5.3.3 - Generate models for release from spent fuel

Subactivity 1.5.3.3.1 - Generate release models for spent fuel models. No progress during the reporting period due to lack of funding.

Forecast: No activity is planned for FY 1993.

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

Subactivity 1.5.3.4.1 - Generate release models for glass waste forms. No progress during the reporting period due to lack of funding.

Forecast: No activity is planned for FY 1993.

2.6.2.8 Activity 1.5.3.5 - Waste package performance assessment model development

Subactivity 1.5.3.5.1 - Development of system model. The ISP for PANDORA version 1.1 development was released as an LLNL controlled document. The user's manual entitled "PANDORA 1.1 User's Manual" (Lewis and Hardenbrook) and a report entitled "Post-Closure Performance Assessment of Waste Packages for the Yucca Mountain Project" (O'Connell et al.) were completed and are now in internal review.

Version 1.1 includes expanded treatment of the flow-through and bathtub water contact modes and gaseous release mode to accommodate a wide range of input values. Additional external data files, new program control of time stepping, program control of solubility-based and alteration-based limiting factors on release rate, and a check on exhaustion of inventory of solubility-limited radionuclides were implemented. PANDORA 1.1 was tested extensively during and after implementation.

The waste form alteration and release submodels of the YMIM of the EBS, near field and PANDORA were compared. The differences between the base-case models were large and are due to different model assumptions and base-case parameter values. The differences are within the range of possible system performances, and arise from differing intent. PANDORA intends to show presently supportable bounds on system performance, using conservatism to compensate for present uncertainties and for nonmodeled features. YMIM is intended for sensitivity analysis or "what-if" analysis, exploring the implications of possible

assumptions or parameter values. The main subject for YMIM's hypothesis analysis is the coupling among the many processes linking the EBS and the near field. Either program could be changed to substantially match the waste form alteration and release assumptions of the other, by data changes and a few model changes.

LLNL participated in the Source Term/Near Source Effects meeting held at Berkeley, California, on May 27, 1992. Discussions were held on source term, waste package, temperature effects and hydrological flow.

As requested at the May 27, 1992, DOE-EPRI PA meeting, representatives of LLNL and Ohio State University (EPRI support) met on June 26, 1992, to discuss implementation of LLNL hydrothermal calculations into the EPRI total system PA model.

A paper entitled "Diffusion Releases Through One and Two Finite Planar Zones" (Ueng and O'Connell) was approved by YMPO on June 15, 1992, and was published as a LLNL report in July 1992. A paper entitled "Simplified Source Term Model for Total System Performance Assessment" (O'Connell) is in internal review.

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

Forecast: The LLNL EBS system model (PANDORA 1.1) will be used internally to support sensitivity studies and development of the EBS source term for the TSPA. Work will resume on a controlled sampling system to describe a heterogeneous ensemble of waste packages.

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

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

Forecast: No activity is planned for FY 1993.

2.6.2.10 Activity 1.5.4.2 - Probabilistic calculation of releases from the waste package

This activity in currently in the prototype and planning stage. The revised SIP for waste package PA has been approved for interim use and has been submitted to YMPO.

Forecast: During FY 1993, LLNL will prepare an individual software plan for upgrade of PANDORA 1.1 to 1.5.

2.6.2.11 Activity 1.5.5.1 - Determine radionuclide transport parameters

Subactivity 1.5.5.1.1 - Radionuclide distribution in tuff wafers.

Work in this area that is also pertinent to determining the radionuclide distribution in tuff cores is reported under subactivity 1.5.5.1.2. No significant activity occurred pertaining exclusively to distributions of radionuclides in tuff wafers due to reduced funding levels in FY 1992.

Subactivity 1.5.5.1.2 - Radionuclide distribution in tuff cores. LLNL staff attended a meeting on August 24, 1992, in Las Vegas and presented a summary of work related to characterization of natural colloids in NTS waters. Other presentations by Technical University of Munich, Germany, LANL, UNM, and USGS also focused on colloids and their role in radionuclide transport. Other attendees were LBL, USGS, and YMPO.

On August 26, 1992, LLNL, LANL, YMPO, SNL, USGS staff met to plan and organize a workshop to focus on the role of colloids in the transport of radionuclides in a potential repository at Yucca Mountain. A tentative agenda was developed, and prospective speakers are being invited.

Microscopic examination of autoradiography film that was exposed to tuff core wafers and a sample of Climax Stock granite revealed the presence of alpha tracks. Samples had been exposed for 11 days to three weeks. Additional autoradiography on tuffs has not shown any observable radiographic patterns. Because of the low level of alpha activity in the tuff core wafers, it has been difficult optimizing exposure and development times. An alpha sample with sufficient activity (lantern mantel) was obtained and its alpha emission measured. This sample will be used to optimize the autoradiography technique.

The testing and calibration of the flow-through system continued. This system is designed to study the adsorption and hydrology of pore fluid with radionuclide tracers. The calibration of the transducers along with the pressure-transmitting diaphragm was completed. A water cooling system has been constructed to cool the water flowed through the heated sample. The flow-through apparatus was tested at room temperature using a core with a "saw cut" fracture. A two-order-of-magnitude decrease in permeability occurred. Samples were taken of the outflow fluid to look for evidence of bacterial growth. Based on particle morphology, outflow solutions collected at two flow rates at room temperature, contained both inorganic and organic particles. The organic particles were all similar and appeared to be bacteria. Their concentration was significantly greater at the higher flow rate. Thus, the

reduction in permeability in the core is apparently due to plugging caused by microbial growth. Samples of the outflow solution from the apparatus run at 150 °C were also examined. In addition to particles with bacterial morphology, other particles indicative of pieces of organic material were also present. The inorganic particles present in all the outflow solutions were similar in morphology to the particles identified previously in J-13 and other NTS waters. The core will be disassembled, and further examination will continue. The upstream and downstream Teflon valves proved to be too pliable to maintain a steady flow rate in the system. Gold-plated stainless steel valves will be used in the next test. The tests will be continued at elevated temperatures.

TEM and optical microscopic analysis of colloids separated from UO_2 leach solutions was conducted. Results indicate that some of these particles may be contaminants. After further examination, colloidal C particles were identified from the holey C film used to coat the TEM sample support grids as the major source of this contamination. The potential for contamination of fluids by particles used in the "finishing" of plastic sample bottles is also being investigated.

The photon correlation spectrometer was repaired and analysis of the particle size distribution of colloids in spent fuel leach fluids continued.

The adsorption of uranyl ion onto goethite at 70 °C has been completed over the pH range of 4 to 9. Preliminary analysis of the data suggests that adsorption is enhanced relative to adsorption at 25 °C.

A paper entitled "Colloid Formation During Waste Form Reaction: Implications for Nuclear Waste Disposal" (Bates et al.) was approved by YMPO and submitted to Science.

Forecast: The diffusion profiles of Cs, Sr, and U will be measured in single crystals of clinoptilolite at various temperatures. The transport of non-radioactive elements through fractured and saw-cut cores will be studied at elevated temperatures.

2.6.3 Characteristics and configurations of the waste packages (SCP Section 8.3.4.3)

Various concepts were evaluated during the ACD phase of waste package development. Seven concepts were selected for detailed evaluation during ACD. These concepts include: large, metallic multibarrier (partially shielded); metallic multibarrier (totally shielded); small, metallic multibarrier (borehole); nonmetallic multibarrier; overpacked, multi-element sealed canister; universal cask waste package; and the reference SCP single-wall design. The evaluation will include thermal, structural, criticality, and shielding calculations.

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The initial thermal evaluation of the 21-PWR, in-drift waste package design concept was completed. Three configurations were evaluated: the first assumed that heat is transferred directly to the fuel basket; the second included an air gap between the assemblies and the basket; and the third assumed that the package was lying in the drift with half of the package contents in contact with the package and half with an air gap. The results indicated that the aluminum-boron fuel basket with a stainless steel cylinder provided the best thermal performance of the three options, not exceeding internal temperatures of 350 °C .

Preliminary waste page criticality and shielding analyses were performed. The analysis consisted of an initial parametric evaluation of a 21 PWR waste package. The criticality results indicated that burn-up credit will be required or additional poison elements will need to be installed in the waste package. In highly enriched fuel with high burn-up, burn-up credit and additional poison material will be required to meet 10 CFR 60 criticality requirements. The results of the parametric review indicate that the large multibarrier waste package is possible within standard engineering processes.

A major finding of the shielding evaluation was that a waste package that holds 12 or more PWR assemblies will not require anymore shielding because of fuel assembly self-shielding. The evaluation was performed using metallic shielding materials. The shielding materials perform two functions: first and foremost, they are the corrosion barriers for waste containment; secondly, they provide the nuclear shielding. The evaluation indicated that a thickness of 30.5 cm (12 in.) of iron would be required for 33 GWD/MTU, 10-year-old fuel.

All preparations were concluded for starting the waste package ACD phase of the program. The readiness review team reviewed the documentation, training records, facilities, equipment, etc. All material was found to be in order.

Forecast: The ACD phase of the waste package/EBS design will be initiated early in FY 1993. This will permit the initiation of detailed thermal, structural, shielding, and criticality evaluation of the seven design concepts. Performance analysis of these concepts will also be initiated.

2.6.4 Waste package production technologies (SCP Section 8.3.4.4)

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

Forecast: No activity is planned for FY 1993.

2.6.5 Waste package performance (SCP Section 8.3.5.9)

2.6.5.1 Activity 1.4.1.1 - Integrate design and materials information (metal container)

Subactivities 1.4.1.1.1 and 1.4.1.1.2. No progress during the reporting period due to lack of funding.

Subactivity 1.4.1.1.3 - Physical properties. Repository scale thermal conduction calculations for drift emplaced robust waste packages with APDs up to 125 kW/acre (309 kW/ha) with 60-year-old fuel are ongoing to address the temperature profiles throughout the repository, as a function of time, out to 10,000 years. The TOPAZ calculations are done using two different models, a three-dimensional model for the far field, and a two-dimensional model to evaluate temperature profiles in the waste package. The first twenty runs have produced enough data to derive parametric relationships for quantifying additional mass loading scenarios. The maximum drift wall temperatures have varied between 35 °C and 390 °C depending on the mass loading and the age of the fuel. These temperatures correspond to 13.6 MTUs/acre with 30-year old fuel to 284.7 MTUs/acre with 10-year-old fuel. To date, only 33 GWD/MTU burnup spent fuel has been used in the calculations. The calculations determine the maximum temperatures around the drift as a function of time, plot temperature isotherms at various time steps out to 10,000 years, and determine the effect of backfilling at any specified time.

A code-to-code verification exercise was completed. One run from SNL, one run using the LLNL-Engineering code TOPAZ, and one run using the LLNL-Hydrology V-TOUGH code were compared. The runs used 30-year-old spent fuel, thermal loadings of 100 and 114 kW/acre (247 and 282 kW/ha), and homogenous rock properties (the entire mountain at TSw2 properties). After the results were scaled to a common thermal loading of 100 kW/acre (247 kW/ha), the temperature was plotted as a function of time, and the results were within a 10-percent band. The agreement is even closer at late times.

A draft summary of the corrosion of weathering steels was prepared and provided to the M&O design team. LLNL is leading a task team on corrosion; the team is one of several discipline-oriented teams summarizing issues needing to be resolved in order to make a thermal loading decision.

LLNL staff attended a meeting in April 1992 with YMPO and M&O representatives to discuss waste package strategy and LLNL responsibilities.

LLNL attended a meeting at the M&O office in Las Vegas, Nevada on July 8-9, 1992, to review and compare thermal calculations with representatives of SNL and the M&O. There is close agreement between the LLNL and SNL results even though the thermal models are quite different.

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LLNL staff attended the YMPO Thermal meeting in Las Vegas, Nevada on August 20-21, 1992, to define the method and time table to settle thermal issues. Many of the issues addressed tie very closely with the thermal calculations being done at LLNL. Several task teams were formed to summarize issues needing resolution prior to specifying repository thermal loading.

Subactivities 1.4.1.1.4 through 1.4.1.1.6. No progress during the reporting period due to lack of funding.

Forecast: During FY 1993, LLNL will continue the degradation mode survey of corrosion allowance materials.

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

Subactivities 1.4.1.2.1 through 1.4.1.2.5. No progress during the reporting period due to lack of funding.

Forecast: No activity is planned for FY 1993.

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

Subactivity 1.4.2.1.1 - Establishment of selection criteria and their weighting factors. No progress during the reporting period due to lack of funding.

Subactivity 1.4.2.1.2 - Material selection. A paper entitled "Selection of Candidate Container Materials for the Conceptual Waste Package Design for a Potential High Package Design for a Potential High Level Waste Repository at Yucca Mountain" (Van Konynenburg et al.) is in internal review.

Forecast: During FY 1993, the paper "Selection of Candidate Container Materials for the Conceptual Waste Package Design for a Potential High Level Waste Repository at Yucca Mountain" (Van Konynenburg et al.) will be published. No other activity is planned for FY 1993.

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

Subactivities 1.4.2.2.1 through 1.4.2.2.8. No progress during the reporting period due to lack of funding.

Forecast: No activity is planned for FY 1993.

2.6.5.5 Activity 1.4.2.3 - Degradation modes affecting candidate austenitic materials

Subactivities 1.4.2.3.1 through 1.4.2.3.9. No progress during the reporting period due to lack of funding.

Forecast: No activity is planned for FY 1993.

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

Subactivities 1.4.2.4.1 through 1.4.2.4.6. No progress during the reporting period due to lack of funding.

Forecast: No activity is planned for FY 1993.

2.6.5.7 Activity 1.4.3.1 - Models for copper and copper-alloy degradation

Subactivities 1.4.3.1.1 through 1.4.3.1.7. No progress during the reporting period due to lack of funding.

Forecast: No activity is planned for FY 1993.

2.6.5.8 Activity 1.4.3.2 - Models for austenitic material degradation

Subactivities 1.4.3.2.1 through 1.4.3.2.8. No progress during the reporting period due to lack of funding.

Forecast: No activity is planned for FY 1993.

2.6.5.9 Activity 1.4.3.3 - Models for degradation of ceramic-metal, bi-metallic/single metal, and coatings and filler alternative systems

Subactivities 1.4.3.3.1 through 1.4.3.3.3. No progress during the reporting period due to lack of funding.

Forecast: No activity is planned for FY 1993.

2.6.5.10 Activity 1.4.4.1 - Estimates of the rates and mechanisms of container degradation in the repository environment for anticipated and unanticipated processes and events, and calculation of container failure rate as a function of time

Subactivities 1.4.4.1.1 and 1.4.4.1.2. No progress during the reporting period; these are out-year activities.

Forecast: No activity is planned for FY 1993.

2.6.5.11 Activity 1.4.5.1 - Determination of whether the substantially complete containment requirement is satisfied

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

Forecast: No activity is planned for FY 1993.

2.6.5.12 Activity 1.5.5.2 - Radionuclide transport modeling in the near-field waste package environment

Subactivities 1.5.5.2.1 and 1.5.5.2.2. No progress during the reporting period; these are out-year activities.

Forecast: No activity is planned for FY 1993.

2.7 PERFORMANCE ASSESSMENT

2.7.1 Waste retrievability (SCP Section 8.3.5.2) No progress during the reporting period; this is an out-year activity.

Forecast: No activity is planned for FY 1993.

2.7.2 Public radiological exposure - normal conditions (SCP Section 8.3.5.3) Throughout this reporting period, SNL staff met regularly with DOE and T&MSS staff to discuss the development and application of methodologies for evaluating Items Important to Safety (IITS) and Waste Isolation, work which is being performed. Before commencing work on IITS, several meetings were held with M&O contractor reviewers to resolve comments on "Identification of Structures, Systems, and Components Important to Safety at the Potential Repository at Yucca Mountain" (Hartman and Miller). A presentation on the methodology proposed for evaluating Items Important to Waste Isolation (IITWI) and the results of its application to unconsolidated surficial deposits was made in September 1992.

A report entitled "Disturbance Criteria for Items Important to Waste Isolation: A Methodology and an Application to Unconsolidated Surficial Deposits" (Schelling et al.) has been completed and provided to the YMP Assessment Team.

Efforts continue to apply standard probabilistic risk assessment methods to the ESF design, with the objective of determining the impact of ESF design changes (from the original vertical shaft configuration to the current dual ramp configuration) on previous radiological risk evaluations, and to evaluate the level of uncertainty in the assessment. The results of this work will be used by the Assessment Team to identify the IITS for the ESF, if any.

Forecast: Activity in FY 1993 will focus on compiling and evaluating available information regarding the waste isolation characteristics and performance of natural barriers. This information will be reported to the Assessment Team for use in establishing an IITWI component of the Q-List and for defining necessary controls on impact activities. A report on ESF IITS, tentatively entitled "Preclosure Radiological Safety Evaluation - Exploratory Studies Facility" will be completed, reviewed, and provided to the Assessment Team. Additional safety analysis work will be performed primarily by the M&O. SNL will work with the M&O to ensure a continuous transition of this work.

Upon completion of the natural barrier report, SNL will continue to provide PA support for addressing concerns regarding waste isolation impacts of specific barrier-impacting activities. SNL work in the design area of assessing radiological safety risks is

expected to be complete with release of the ESF IITS report. Future IITS work will be done by the M&O design team, but is not expected to be a significant project priority until a more definitive repository design basis is established.

2.7.3 Worker radiological safety - normal conditions (SCP Section 8.3.5.4)

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

Forecast: No activity is planned for FY 1993.

2.7.4 Accidental radiological release (SCP Section 8.3.5.5)

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

Forecast: No activity is planned for FY 1993.

2.7.5 Groundwater travel time (SCP Section 8.3.5.12)

2.7.5.1 Activity 1.6.2.1 - Model development

Subactivity 1.6.2.1.1 - Development of a theoretical framework for calculational models. The development of a mathematical framework for the modeling of ground-water flow and contaminant transport, as well as for other purposes, currently depends heavily on the acquisition of experimental data. The SCP activity under which such data are acquired is Activity 1.6.2.2.2, and the current work is summarized there.

Subactivity 1.6.2.1.2 - Development of calculational models.

Forecast: The forecast for Activity 1.6.2.2 also applies to Activity 1.6.2.1.

2.7.5.2 Activity 1.6.2.2 - Verification and validation

Subactivity 1.6.2.2.1 - Verification of codes. Performance Assessment - Software development progressed through a number of activities important to the future computational needs of PA. The TOUGH2 code, which will be used in the near future in support of validation activities, was installed for use on the YMP local-area network at SNL. The NORIA-SP code, which models flow and transport, was debugged and corrected to produce a certified version for quality-assurance purposes; this code was placed under a source-code

control system that will also be useful for QA. Several steps were taken in improving visualization capabilities that are essential to the complex analyses underway in PA and its support to design and validation. An applications-visualization system (AVS) became part of the use of certain codes. For example, the interface between TOUGH2 and the AVS was developed during the past six months. Several three-dimensional test problems were acquired for testing the AVS on the hardware and software that were developed during this reporting period. A demonstration of the AVS was given for officials of DOE and the M&O. A related effort was the development of a visual-interface system that links performance-assessment calculations closely to the data bases on which they rest. As part of this effort, SNL evaluated the use of a particular data base, INFORMIX, and its embedded query language for this purpose.

SNL staff have been analyzing field data obtained from boreholes UZ-1 and UE-25a for the purpose of backing out pore pressure as a function of altitude. These pressures may prove beneficial as boundary conditions for numerical calculations. One set of these pressures were used at the left boundary of a Yucca Mountain model, with 1.0 mm/yr infiltration applied to the top boundary. A steady-state solution was obtained using LLUVIA-II on the SUN machine. The boundary pressures result in the mix of positive and negative vertical velocities that smooth into exclusively downward flow approximately 100 m from the boundary. These results will be compared with the numerical solutions.

A report entitled "Boundary Integral Method for Steady Unsaturated Flow in Homogeneous Media" (Martinez, 1992) completed internal SNL technical and management review and YMP policy review. The paper was presented at the 7th International Conference on Boundary Element Technology, June 3-5, 1992, in Albuquerque, New Mexico.

SNL staff attended the PA Flow and Transport meeting in Las Vegas, Nevada, on May 5-6, 1992. A number of presentations were given, including "Some Aspects of Modeling Liquid Flow in Fractures" (Martinez) and "Boundary Integral Methods for Unsaturated Flow in Nonhomogeneous Media" (Martinez, 1992), and "Application of Unit-Boundary Conditions" (Eaton).

Results of one- and two-dimensional benchmarking problems have previously been reported as part of the evaluation of JACQ3D and COYOTE-II. These codes are being investigated to determine whether modern, state-of-the-art numerical methods can efficiently solve flow problems of interest to the YMP. The next step in this process is to apply these codes to a problem in three dimensions. The problem to be solved is similar to the earlier two-dimensional problem with the domain extended to three dimensions. The input infiltration will not be fully extended in the third dimension to ensure a three-dimensional flow field. Both codes have been readied to solve this problem and the mesh is being defined. A large (~20,000 unknowns) three-dimensional problem of flow through an unsaturated, heterogeneous domain was defined to test the applicability of JACQ3D and

COYOTE-II to this class of problem. The performance results for JACQ3D indicate a fairly efficient algorithm for large problems. However, experience indicated that the solver loses efficiency or even fails to converge when the conductivity varies over more than five to six orders of magnitude. This condition can occur when applying infiltration into an initially very dry medium. The solver in COYOTE-II is very efficient and capable of handling drier problems than JACQ3D, but the matrix assembly requires substantial central processing unit time. These results were documented in a memo and distributed.

A Picard solver was added to the DUAL code, which incorporates a dual-porosity model for solving flow problems. This direct solver provides an initial guess for the Newton solver, and, for the test case run, appears to eliminate the large number of iterations in the Newton solver and results in much faster execution times.

A paper entitled "Some Modeling Issues in Nuclear Waste Isolation" (Martinez and McTigue) was presented at the Environmental Studies workshop, University of Minnesota, July 5-10, 1992. The meeting was sponsored by the Institute for Mathematics and its Applications with the objective of providing an interdisciplinary forum for joint exploration of recent advances in environment studies. The talk discussed mathematical challenges associated with modeling transport in unsaturated fractured porous materials and presented some modeling examples.

Staff participated in a scoping meeting to outline studies to be incorporated into the 1993 Total Systems Performance Analysis report (Barnard et al., 1992). The contributions proposed include results of matrix/fracture vapor flow studies and a summary of the importance of dimensionality.

SNL staff met with members of the M&O in August 1992 to discuss code development as part of the M&O role in coordinating PA. The areas of interest included methods for modeling flow in fractures, boundary integrals, method-of-lines procedures, and parallel processing.

Subactivity 1.6.2.2.2 - Validation of models. A tour of the SNL Flow and Contaminant Transport Model Validation Laboratory was given to OCRWM, YMP, and M&0 management staff on May 29, 1992. During the tour, the approach to model development and validation was discussed and the integrated physical and numerical experimental efforts were demonstrated for flow and transport through single fractures, fracture/matrix interaction, and development of scaling laws for heterogeneous media.

The YMP Flow and Contaminant Transport Model Validation Laboratory supported research and educational opportunities for four doctoral students, four masters candidates, and

nine undergraduates during the past six months. All students were supported through a variety of DOE and SNL Fellowship programs designed to promote interest in science and engineering related to waste management issues.

Unsaturated Flow Through Single Fractures - Gravity-driven fingering occurs in nonhorizontal fractures supplied with water along the top edge. A systematic experimental approach for studying gravity-driven fingering in unsaturated fractures was presented at the 1992 IHLRWM Conference, "Gravity-Driven Fingering in Unsaturated Fractures" (Nicholl et al., 1992). As a first step toward understanding this system, experiments were performed in an analog fracture consisting of two roughened glass plates held in close contact. Results imply that increasing the volume of fluid contained in the front leads to increases in both finger width and velocity. Finger velocity was also found to increase with gravitational gradient. Further experiments conducted to complete the data set are being incorporated into a second paper for submittal to a scientific journal. Experiments to support two additional studies of gravity-driven fingering in nonhorizontal fractures have also been completed. Extended summaries of these studies, "Small-Scale Behavior of Single Gravity-Driven Fingers in an Initially Dry Fracture" (Nicholl et al.), and "Wetting Front Instability in an Initially Wet Unsaturated Fracture" (Nicholl et al.), have been prepared and submitted for presentation at the 1993 IHLRWM Conference.

Percolation theory modified to include gravity and multiple-neck pore filling facilitation was applied to gravity-driven fingering in porous media (Glass and Yarrington). SNL staff are in the process of extending this work to analyze gravity-driven fingering in rough walled fractures at angles between 0 and 90 degrees with respect to vertical. The purpose of this analysis is to better understand the aperture-scale mechanics of gravity-driven fingering, including: (1) influence of aperture distribution in random spatial field, (2) influence of correlated spatial aperture field, and (3) influence of gravity versus aperture field spatial structure in determining the wetted structure within a fracture. An extended summary of this work, "Modeling Gravity-Driven Fingering Using Modified Percolation Theory" (Glass), has been prepared and submitted for presentation at the 1993 IHLRWM Conference.

In a collaborative effort with LANL, a preliminary validation study of flow models for saturated flow in fractures performed in an analog rough-walled fracture was extended to a natural fracture in welded tuff. Aperture fields were characterized by surface profiling using a laser profilometer. The Reynolds equation was solved numerically for both statistically generated and measured aperture fields at several spatial resolutions. Permeabilities calculated from numerical simulations were compared to those obtained in the laboratory. An extended summary of this validation study, "Surface and Aperture Characteristics for Saturated Fluid Flow in a Natural Fracture" (Reimus et al.), was prepared and submitted for presentation at the 1993 IHLRWM Conference.

Fracture Matrix Interaction - A paper entitled "Wetted-Region Structure in Horizontal Unsaturated Fractures: Water Entry Through the Surrounding Porous Matrix" (Glass and Norton, 1992) was presented at the 1992 IHLRWM Conference. In the presentation, SNL staff reported the research investigating small-scale processes that influence wetted structure within the plane of a horizontal fracture as the fracture wets or drains through the matrix. The research approach integrates both aperture-scale modeling and physical experimentation. Several types of aperture-scale models have been defined and implemented. A series of physical experimental systems have been designed that allow the measurement of wetted-region structure as a function of system parameters and water pressure head in analog fractures. In the preliminary proof-of-concept experiment, hysteresis is clearly evident in the measured saturation/pressure relation, as is the process of air entrapment, which causes a reduction in the connected areas between blocks and the wetted region available for flow in the plane of the fracture. A percolation threshold where the system is quickly spanned, allowing fluid conduction in the fracture plane, is observed that is analogous to that found in the aperture-scale models. A fractal wetted and entrapped-region structure is suggested by both experiment and modeling. This structure implies that flow tortuosity for both flow in the fracture and for interblock fluid transfer is a scale-dependent function of pressure head. SNL staff extended this preliminary study in the past six months to include systematic experiments performed on five analog fractures. Measurements were made to define hysteretic saturation/pressure relations including primary, secondary and tertiary wetting and drying curves. Similarities between these curves and those of generic porous media are clearly identified. An extended summary detailing the results of these recent experiments, "Wetted Structure Development in Analog Horizontal Unsaturated Rock Fractures" (Glass and Norton), has been prepared and submitted for presentation at the 1993 IHLRWM Conference.

Studies aimed at understanding the influence of matrix imbibition on fracture flow in thin, two-dimensional systems cut normal to the plane of the fracture continued. As part of this program, a collaborative effort has been established between SNL and the University of New Mexico Medical Center to allow access to a Sieman's Polytron real-time x-ray device. This equipment allows x-ray imaging to be performed at a much higher temporal resolution than that available with film-based x-ray imaging. Preliminary experiments were planned and initiated. These studies have been documented in an abstract entitled "An Experimental Investigation of Matrix Interaction on Fracture Flow," submitted for the 1993 AGU Fall Meeting, and an extended summary, "An Experimental Investigation of Fracture-Matrix Interaction with Comparison to Numerical Simulation" (Foltz et al.), submitted for presentation at the 1993 IHLRWM Conference.

Field, Lab, and Numerical Experimentation to Determine Scaling Laws for Effective Media Properties in Heterogeneous Media. A paper entitled "Field Research Program for Unsaturated Flow and Transport Experimentation" (Tidwell et al., 1992) was presented at the 1992 IHLRWM Conference. The presentation described the field research program aimed at

refining and validating models for flow and transport through unsaturated fractured rock. This field program emphasizes natural analogs and compliments the fully developed laboratory research program.

Work has continued on the gas permeameter that is to be used to collect data for challenging effective media property models and the development of their scaling laws. To facilitate data acquisition, an automated gas permeameter test system has been designed for use in the laboratory. The system is composed of a computer-driven x-y positioning system, electronic gas permeameter integrated with data acquisition and analysis capabilities. Construction of the permeameter will begin when the system components have arrived (by early October 1992). An extended summary entitled "Influence of Measurement Scale on Gas Permeability Data" (Tidwell et al., 1991) was submitted for presentation at the 1993 IHLRWM Conference. This summary outlines a preliminary suite of experiments aimed at refining the automated permeameter test system and challenging basic property scaling concepts.

As part of the effort to develop scaling laws for saturated and unsaturated systems containing micro-layering and cross-bedding heterogeneities, several preliminary experiments were conducted. Such heterogeneities are found in all the alluvial sediments at and around Yucca Mountain and in the bedded tuffs units within Yucca Mountain. Incomplete knowledge of the effect of these heterogeneities within a larger scale geologic "layer" raises important questions about the validity of current calculations for TSPA and in support of the ESF. The preliminary experiments, conducted in conjunction with the LANL intermediate-scale caisson experiment, were presented at the 1992 IHLRWM Conference. Subsequent experiments have been included in an extended summary, "Testing Models of Flow and Transport in Unsaturated Porous Media" (Springer et al.), which has been submitted for presentation at the 1993 IHLRWM Conference. In the experiments, micro-layering and cross-bedding heterogeneities are created in thin slabs of sand that will compose the LANL caisson. Using a full-field moisture-content technique based on light transmission, a sequence of infiltration and drainage experiments will be monitored. The experimental sequence allows the measurement of chamber-scale hysteretic moisture-characteristic curves, saturated and relative permeabilities, and solute dispersion coefficients. These effective chamber-scale properties will be measured in a series of experiments with the type and intensity of the heterogeneity varied systematically. In addition, measured transient moisture content and solute concentration fields will be compared with numerical simulations.

Development of Experimental Capabilities - SNL staff continued to develop x-ray absorption and transmitted light as techniques for measuring moisture content in porous media. Each is a high-resolution, rapid, full-field moisture-sensing technique that has been developed for use in two-dimensional, thin-slab experimental systems. Current activities have focused on evaluation of measurement precision and accuracy as well as the reporting of results. A report entitled "X-Ray and Visible Light Transmission as Two-Dimensional,

Full-Field Moisture-Sensing Techniques: A Preliminary Presentation" (Tidwell and Glass, 1992) was presented at the IHLRWM Conference in April 1992. The additional evaluation of precision and accuracy is being incorporated into a journal article covering this work.

To enhance the imaging capabilities of the SNL laboratory, efforts to purchase a dedicated x-ray generator and tube head were initiated. Available equipment was researched and a Phillips 160 System was selected. Acquisition of the unit is currently under way.

Scoping Sorption Studies - To reduce the confounding influence of disequilibrium with atmospheric CO_2 on pH measurements, methods to carry out batch experiments under CO_2-free conditions were developed. These included a low-flow Ar purge system with a two-stage scrubber and draft protocols for preparing nominally CO_2-free 0.01 M NaCl electrolyte and tracer solutions. A computer-driven autotitrator for acidimetric and alkalimetric determination of mineral surface hydrolysis constants was acquired from Stanford University. Problems encountered in mineral surface titrations due to slow dissolution and diffusion reactions and the exchange of CO_2 with the atmosphere were partially solved with the autotitrator.

The sensitivity, accuracy and precision of the technique used for nickel (Ni) analysis were improved. Methods to correct for black body radiation and carry-over of Ni from one sample to the next were developed. Optimization of the measurement protocol has reduced measurement time by one-third and extended the usable dynamic range to 0.3-100 parts per billion (ppb) without sacrificing precision or accuracy.

Caisson Experiment - An intermediate-scale experiment is being carried out by SNL and LANL to demonstrate a strategy to validate key geochemical and hydrological assumptions in PA models. The experiment involves the detection and prediction of the migration of fluid and tracers through a 6-m-high x 3-m-diameter caisson filled with a porous medium.

Materials Characterization - The caisson is being filled with Wedron 510 sand, a commercially available silica sand (Wedron Silica, Wedron III. 60557). According to bulk chemistry and mineralogy, Wedron 510 sand is nearly pure quartz, but characterization of some of its surface properties as described below suggests that it contains at least four components: quartz, carbonate, Fe, oxyhydroxide, and kaolinite. Estimates of the amount of carbonate coating the surfaces of grains in the quartz sand were made by three methods: pH shifts during equilibration with 0.01 M NaCl in CO_2-free batch systems; leaching of soluble Ca and Mg with 6 N HCl; and petrographic analysis of polished grain mounts. The first two methods indicated that the grains contained approximately 0.8 micrograms/carbonate per gram of sand. This agrees well with the visual observations that the coatings account for less than 0.1 percent of the mode.

Significant Fe (0.575 μmol/g) was leached during treatment of an aliquot of Wedron 510 with 6 N HCl. Studies of thin-sections under an optical microscope reveal that the sand grains are coated with a yellowish material; thus the majority of the Fe is likely to be present as a thin coating of hematite and/or goethite on the sand grains. Dispersed colloidal material associated with the sand comprises 0.05 percent of the original mass of the sand and appears by x-ray diffraction to be essentially pure kaolinite. A few sand grains were examined by SEM with energy-dispersive spectroscopy. Flakes of high-alumina material (kaolinite) were common, but no Fe-rich coatings on the well-rounded quartz grains were observed.

The initial design of the caisson experiment included a limonite-rich layer sandwich between two layers of pure Wedron 510 sand. Chemical and x-ray analysis of samples from candidate limonite showed it to be very heterogeneous. In addition to goethite, many of the sampled splits contain abundant quartz, clays, and sulfates. Analysis of splits taken from the bulk of the material that was delivered to the caisson site at LANL showed it contains a strong acidic component as indicated by the low pH of deionized water placed in contact with them. Because of the uncertainty in adsorption behavior that the pH change would cause in the caisson, the final caisson design did not include the limonite component.

A suite of reactive tracers that spans a variety of chemical behaviors was considered for the caisson experiment. The tracers that were chosen for the final design include: Ni (Ni), a transition metal that forms strong surface complexes with geologic materials and is representative of waste elements released from the structural materials in the high-level waste; Li, a tracer that forms relatively weak surface complexes; bromide, a conservative tracer that can be used to track the movement of water in the caisson; and B, a tracer that forms the anionic complexes that adsorb weakly to geologic materials under alkaline pH.

Ni sorption has been measured in batch experiments equilibrated for at least 48 hours at solid: solution ratios of 1:1 over the pH range 5 to 9.5. Initial Ni concentration was 50 ng/ml, and final Ni concentrations were measured by graphite-furnace atomic absorption spectroscopy. The pH-sorption curve shows a distinct sorption edge at pH ~6.5, reaching maximum sorbance at pH 8.0, followed by slowly declining sorbance with further increases in pH. Preliminary measurements of sorption of Li and B by Wedron 510 sand as a function of pH have been carried out. The results suggest that Li adsorption is low and dependent on pH; B sorption by sand was negligible over the pH range studied.

Batch and flow-through tests were initiated to determine the equilibrium pH and the extent of sorption of tracers by samplers that will be used in the caisson (ceramic cups and electrodialysis tubing). The preliminary results indicate that the electrodialysis tubing contains an acidic component (equilibrated pH = 5.8), and that sorption at the equilibrium pH was negligible. The pH of solutions in contact with the ceramic cups samplers was alkaline (8.4 - 10.6). Sorption ratios of approximately 70, 0 and 0 mL/g were measured for Ni, bromide, and B respectively in batch experiments. The initial results of the flow experiments

were consistent with the batch sorption studies. Ni sorption on four plastics used for sample collection, storage and sorption experiments was investigated as a function of solution head space and pH to guide the choice of sample storage vials of the caisson and to estimate the stability of collected solutions that are stored for later chemical analysis. Initial results suggest that moderate sorption occurs at neutral pH over 2-9 day periods in containers with large headspace. Sorption studies at lower headspace under the more acidic conditions are currently underway.

Transient Chemical Conditions in the Caisson - Ni sorption by the Wedron 510 is very sensitive to pH under near neutral conditions. Surface titration curves indicate that the sand contains several minerals that affect the solution pH. The pH profile in the caisson will be controlled by dissolution of carbonate cement, diffusion of atmospheric CO_2 into pore fluids, hydrolysis of silanol (SiOH) groups and hydrolysis of FeOOH surface groups. It is anticipated that chemical conditions within the caisson will initially be transient but that a steady-state chemical profile may eventually develop. The flow velocity, dissolution rate of carbonate cement and the CO_2 diffusion rate will control the approach to steady-state concentration profiles in the caisson; the amount of carbonate cement will determine the duration of the steady-state profile. A computer model that calculates the pH as a function of these processes is currently under development. Data from small-scale column experiments will be used to validate the code. Small-scale column experiments to study the changes in column pH as functions of time and saturation state are being carried out. A 0.01 M NaCl solution (pH $\cong$ 6) is pumped through columns (7 cm I.D. x 24 cm) filled with Wedron 510 sand at several degrees of saturation (50-100 percent). The pH of the influent and effluent solutions are measured in flow-through cells. In preliminary saturated-condition experiments, the pH of the initial effluent was neutral and rose to an alkaline steady-state pH (> 8.7) after six pore volumes had been eluted from the column. Under unsaturated conditions (50 -70 percent saturation) the effluent pH dropped to a steady-state range of 7.2 to 8.0 after elution of approximately two to five pore volumes. The differences between the pH measured by electrodes placed in in-line flow-through cells and those measured in open containers were evaluated as a function of eluted pore volumes, in order to determine if in-line pH monitors are required in the caisson experiment. Under unsaturated conditions, the pH of the in-line and open vessel samplers differed only by 0.1 - 0.15 pH units after two pore volumes had been eluted from the column.

Reactive Transport Model Development/Experimentation - A first draft of a User's Manual for the LEHGC code was completed by G. T. Yeh of the Pennsylvania State University. Efforts have been initiated to implement the LEHGC coupled reaction-transport computer code on the Computational and Computer Sciences and Mathematics Center's nCUBE, which has 1024 processors. In the initial modifications to the code, the geochemical equilibrium calculations will be performed in parallel and the transport calculations will be

carried out on a single node. The potential benefits of this effort include lower costs for CPU time, less real time spent per simulation and increasing the size and complexity of acceptable problems.

Development of an Adsorption Model for Mineral Mixtures - Experiments to determine the effect that trace surface coatings and admixed grains have on the surface properties of natural materials were initiated. The properties of the Wedron 510 sand and the limonite sample are being investigated to develop an approach to the formulation of an adsorption model for mineral mixtures. The properties of the pure quartz component of the Wedron sand are being estimated by potentiometric characterization of reference quartz samples. Data has been collected for the titration of a reference silica (untreated Min-U-Sil) in batch experiments under CO_2-free conditions. The batch systems contained a Min-U-Sil surface area similar to that of the Wedron 510 sand systems but had much less pH buffering capacity than the 510 sand. Li and B sorption experiments were carried out with a mixture of limonite (3 percent by weight) and Wedron 510 sand. Both elements exhibit low but measurable amounts of sorption in both the mixture and pure sand over the neutral pH range. Isotherm experiments to determine the linear range of sorption are currently being conducted.

Reports and Presentations:

A paper entitled "Design of an Intermediate-Scale Experiment to Validate Unsaturated-Zone Transport Models" (Siegel et al., 1992) was presented at the 1992 IHLRWM Conference, Las Vegas, Nevada, April 12-16, 1992.

A poster session entitled "Measurement and Modeling of Ni Adsorption in Mixtures of Sand and Limonite for a Large-Scale Column Test" (Ward and Siegel) was presented at the Spring 1992 meeting of the AGU in Montreal, Canada, May 11-15, 1992.

"Efforts to Verify and Validate the Lagrangian-Eulerian Model of Hydrogeochemical Transport (LEHGC)" (Hopkins et al.) was submitted for presentation at the 1992 Fall Annual Meeting of the AGU.

A summary entitled "Characterization of Materials for a Reactive Transport Model Validation Experiment" (Siegel et al.) was submitted for presentation at the 1993 IHLRWM Conference.

Forecast: During FY 1993, enhancement of pre- and post-processing will investigate the use of standardized input and binary output data base files for use in SNL's two- and three-dimensional partial differential equation codes. Routines will also be written to convert the output files to be compatible with visualization packages. A memo reporting the results and recommendations for implementation will be completed. The activity entitled "Enhancement of Computational Efficiency for Codes" will evaluate candidate flow and

transport codes on the basis of performance in solving three-dimensional flow calculations. Massive parallelization of codes will be explored to simulate flow and transport processes in partially saturated porous media. The first deliverable, due early in FY 1993, will be a memo outlining the strategy developed in this work.

Other activities planned for FY 1993 are continuation of surface chemistry of natural and analog materials characterization for caisson experiment and obtaining ion exchange and surface complexation constants describing potential sorption of tracers (B, I, Ni, Li); formulation of model for chemical evolution of water in caisson under steady and transient unsaturated and saturated flow and model reactive transport in caisson using the LEHGC code; development of model for sorption of Ni onto mixtures of minerals and develop a method for measurements of K_d in unsaturated media to assess applicability of sorption partition coefficients measured under saturated conditions to unsaturated conditions; completion of publication of User's Manual for LEGHC and initiate modifications of the LEHGC code to run the code on a massively parallel computer.

2.7.5.3 Activity 1.6.3.1 - Analysis of unsaturated flow system

Subactivity 1.6.3.1.1 - Unsaturated zone flow analysis. Staff attended a meeting to discuss the INTRAVAL test case involving large-scale flow and transport experiments at Yucca Mountain on May 9, 1992. Site data obtained from Yucca Mountain will be used to model infiltration of water into the tuffaceous units. The SNL effort will be focused on developing two-dimensional geometric and numerical models of the UZ that will be evaluated during the calibration and prediction phases of the project. Emphasis will be placed on incorporating data describing physical properties, hydrologic parameters, boundary conditions, and other state variables in a currently uninvestigated part of the system. An analysis of the reliability and the uncertainties in the site data will also be conducted as part of the exercise.

Staff at LBL constructed a grid design for an east-west cross section from 800 meters west of the Solitario Canyon fault to the Ghost Dance fault. The grid will be used, along with boundary conditions for infiltration along the ridges and slopes of Yucca Mountain and sample data from 26 vertical transects, in a study to analyze the modeling effects of boundary conditions. The data set from the transect and information from USGS neutron holes N-54 and N-55 are also being proposed as part of the data set to be included in the INTRAVAL studies. Preliminary numerical simulations were conducted under the boundary condition study ongoing at LBL to test grid problems. Only minor potential distortions were noted. A two-dimensional model of Solitario Canyon was run by workers at LBL. The model uses layers having different porosity and permeability values. The run was used to learn whether rock property contrast would affect the performance of the model. An outline of the report to document the boundary-condition study was submitted.

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As part of the continuing analysis of site data, the geometry was set up for two cross sections, one perpendicular and one parallel to the wash where boreholes N54 and N55 are located. The data received from the INTRAVAL study will be incorporated into the cross sections for analyses that will be run in the next few months. An adaptive mesh generator was written to accept output from a geostatistical program. It was also designed to generate a grid for flow codes that allows each individual block to be as homogeneous as possible. Future work will be done to formulate the interfaces for all programs. In preparation for continued efforts in the analysis of site and analog data, a request was made to install ARCVIEW. ARCVIEW is a software package that allows easy access and interactive graphical manipulation of data that have been formatted for ARCINFO. The ARCVIEW installation was successful. Efforts are now underway to tailor the installation specific needs and to add as much information to the data base as possible.

SNL hosted the organizational meeting on July 10, 1992, for the INTRAVAL study group. A proposed outline for integrating the INTRAVAL data, geostatistical simulator, and the two-dimensional flow codes was presented to the participants in the study group.

Geostatistical simulation of porosity between USW-N54 and USW-N55 for the Yucca Mountain INTRAVAL Test Case has been successfully demonstrated. In addition, an adaptive grid routine has been written to adjust to each geostatistical simulation in preparation for modeling the flow field between the two holes. Current efforts are centered on generating a model for the characteristic curves for the INTRAVAL Test Case. The geostatistical-simulation program and documentation were obtained, and a two-dimensional cross section of the first INTRAVAL problem was generated. The geostatistical adaptive grid generator (GAG) was written to take output from the geostatistical simulator and produce grids and input files for the flow simulator. The basic idea of this algorithm is to minimize the standard deviation within each element of the grid by adapting the grid. This modification makes GAG much more robust and produces better grids. Subroutines are being added to GAG to produce the input files for both flow codes (NORIA and DUAL). The geostatistical simulator produces simulated values for porosity. The other variables have to be automatically generated by GAG. More analysis of correlations between porosity and the other material properties was required to implement the statistical generation of these properties in GAG. Statistical evaluation of the INTRAVAL data is nearing completion. Results are being written up for internal distribution to solicit suggestions and comments before being incorporated into GAG and the flow codes.

A newer version of the geostatistical simulator from Stanford's GLIB was implemented along with an increase of the anisotropy from 5:1 to 10:1. The two-dimensional variogram program has also been implemented. By the end of September 1992, modifications should be completed to allow them to run using a common input file.

The incomplete gamma function was added to DUAL for use in saturation curves. Use of the gamma function allows for upscaling of saturation curves from a local scale to an element scale. Three realizations were generated by the geostatistical simulator and run through the system of codes to test the system and produce preliminary results. Graphical images were also produced to assist in interpretation and for use in outside presentations. There still remains detailed checking of input and cleaning up and debugging codes.

SNL staff attended the July 14, 1992, meeting on future directions in PA and contributed some input regarding the INTRAVAL studies relation to future PA. Staff also attended the annual Society for Industrial and Applied Mathematicians (SIAM) meeting July 20-23, 1992, to obtain information on recent research in nonsymmetric preconditioners for linear-equation solvers.

SNL staff made a short presentation on the fundamental unsaturated flow issues at a technical exchange sponsored by the YMP in Albuquerque, New Mexico, on April 1, 1992, and also made a presentation on "Unsaturated Zone Hydrologic Data Base and Elicitation of Expert Opinion" (Kaplan) at the NWTRB meeting in Dallas, Texas, on April 7, 1992.

A number of SNL staff attended the 1992 IHLRWM Conference in Las Vegas. Among the papers presented by SNL was "Comparison of Two Conceptual Models of Flow Using the TSA" (Wilson, 1992).

A report entitled "Conceptual, Experimental and Computational Approaches to Support Performance Assessment of Hydrology and Chemical Transport at Yucca Mountain" (Narasimhan and Wang, 1992) was printed and distributed.

The authors of "Processes, Mechanisms, Parameters and Modeling Approaches for Partially Saturated Flow in Soil and Rock Media" (Wang and Narasimhan) are addressing review comments and have submitted a camera-ready draft for publication.

A summary of a forthcoming paper, "The Most Likely Groundwater Flux through the Unsaturated Tuff Matrix at USW H-1" (Gauthier), was submitted for presentation at the 1993 IHLRWM Conference.

SNL staff attended the joint meeting of the Geochemistry and Hydrology Integration Teams in Denver, Colorado, on June 9-10, 1992.

Subactivity 1.6.3.1.2 - Saturated zone flow analysis. A cross-sectional model for the saturated-flow model was constructed during the reporting period. The cross-sectional and areal models of the portion of Yucca Mountain being analyzed for flow in the SZ has been simulated in two dimensions using the code ISOQUAD. The next step will be to attempt duplication of the two-dimensional results in three dimensions using STAFF3D simulations.

The simulations that have been run use alternative boundary conditions and material properties through a cross section of Yucca Mountain that includes a "drain" in the vicinity of the high hydraulic gradient northwest of the potential repository block. Preliminary results indicate that the drain postulated by the USGS could produce gradients similar to those observed. The results of the modeling were presented at the Hydrology Integration Team meeting hosted by SNL on July 28, 1992. Staff from LANL, LLNL, the USGS, YMPO, and the M&O were present to discuss, among other topics, the results of the saturated-zone modeling effort underway at SNL.

Forecast: Work to be accomplished in the analysis of the unsaturated and saturated flow systems is described in the forecast for Activity 1.6.4.1.

2.7.5.4 Activity 1.6.4.1 - Calculation of pre-waste-emplacement groundwater travel time

Subactivity 1.6.4.1.1 - Performance allocation for Issue 1.6. Analysis material that might be used in reallocation of PA activities is discussed under Subactivity 1.6.4.1.3.

Subactivity 1.6.4.1.2 - Sensitivity and uncertainty analyses of groundwater travel time. Work performed under this topic is discussed in Subactivity 1.6.4.1.3.

Subactivity 1.6.4.1.3 - Determination of the pre-waste-emplacement groundwater travel time. "Pre-Waste-Emplacement Groundwater Travel Time Sensitivity and Uncertainty Analyses For Yucca Mountain, Nevada" (Kaplan) completed SNL management and technical review and was sent to the YMP for policy review. The document has been reviewed by the YMP and returned with minor comments that will be addressed.

A paper entitled "Model Domains and Hydrologic Data Base to Support Early Site Suitability and Total-System Performance Assessment Models" (Gainer et al.) is being prepared for internal technical review. This report documents the sources of the data used in both ESSE and TSPA analyses, as well as the logic used to develop the probability distribution functions for all of the parameters.

Simulations of GWTT are using the two-dimensional flow code LLUVIA2D. Graphical interpretations of the simulations are being investigated using PV-WAVE.

SNL staff investigated the origin of value of 970 years for GWTT in the UZ claimed by the State of Nevada. The investigation showed that the number was derived from a review of the Draft Environmental Assessment conducted by the Desert Research Institute (DRI) at

the request of the State and published with the State's review comments in 1985. A draft letter was submitted to the Project Office reviewing both the comments by DRI and the State of Nevada.

A three-day short course entitled "Reliability-Based Design in Civil Engineering" was held August 3-5, 1992 and attended by SNL staff. The course was taught by Dr. M. Harr of Purdue University. The course stressed probabilistic approaches to estimates of system reliability. Application of some of the course material to PA of the Yucca Mountain site--in particular, to the estimation of GWTT--was demonstrated by SNL staff.

A presentation entitled "Preliminary Uncertainty and Sensitivity Results for Pre-Waste-Emplacement Groundwater Travel Time" (Kaplan, 1992) was given at the 1992 IHLRWM Conference in Las Vegas.

On August 6, 1992, SNL staff met with representatives of the YMPO in Las Vegas, Nevada, to discuss realistic estimates of system reliability for the Yucca Mountain site. SNL staff was requested to prepare a short white paper on uncertainty that can be used to explain the concept to the public.

SNL staff met with a member of the Harry Reid Environmental Center at UNLV on August 26, 1992, to discuss the Center's chemical analysis of selected springs in southern Nevada.

Forecast: Planning for a workshop on GWTT, to be held in 1994, will be completed in FY 1993. Simulations using available data to predict GWTT, including some uncertainty and sensitivity studies, will be documented in a report in May 1993. In addition, memos on the adaptation of the code LLUVIA to desktop computers and workstations will be distributed in September 1993. Model development will include work on probability models used to quantify uncertainties in the site data base, the conceptual process models, and the prediction of compliance with the regulatory criteria. A report on the conceptual basis for estimating compliance with the regulatory criteria is scheduled for July 1993. Geohydrologic data development is continuing, and the status and evaluation of current data in support of GWTT will be discussed in a report in June 1993.

2.7.5.5 Activity 1.6.5.1 - Groundwater travel time after repository construction and waste emplacement

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

Forecast: No activity is planned for FY 1993.

2.7.5.6 Activity 1.6.5.2 - Definition of the disturbed zone

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

Forecast: No activity is planned for FY 1993.

2.7.6 Total system performance (SCP Section 8.3.5.13)

2.7.6.1 Performance Assessment Activity 1.1.2.1 - Preliminary identification of potentially significant release scenario classes

Subactivity 1.1.2.1.1 - Preliminary identification of potentially significant sequences of events and processes at the Yucca Mountain repository site. A paper entitled "Progress Report on the Construction of Event Trees in Support of Scenario Development: Tectonics" (Barnard et al.) has completed internal technical review and the authors are responding to comments generated during management review. This document was revised to reflect general tectonic models of importance identified during the EPRI expert elicitation on seismic risk in the Yucca Mountain region.

Subactivity 1.1.2.1.2 - Preliminary identification of potentially significant release scenario classes. Staff attended and supported the NRC Technical Exchange on Scenario Development and CCDF Construction in Albuquerque, New Mexico, on April 28-29, 1992. Presentations related to scenario development given by SNL staff were "Definition of Terms" (Bingham) and "Construction of Scenarios" (Barr). A dry run for all presenters held prior to the meeting was hosted by SNL on April 21, 1992.

A paper entitled "Scenarios Constructed for Basaltic Igneous Activity at Yucca Mountain and Vicinity" (Barr et al.) was submitted for internal SNL technical review. Resolution of review comments has required a major reorganization of one of the branches of the tree. Upon completion of this reorganization, the document will be reviewed by the LANL coauthors and SNL management. Much of the work accomplished during this reporting period was on the artwork/graphics used to depict the complex scenarios related in the text. The artwork is essential for visualizing and constructing many of the numerical and analytical models related to basaltic igneous activity. The authors intend to use similar representations for the remaining scenario construction documents.

Work has resumed on a document on the construction of scenarios for nominal ground- water flow. Work is being done on the nominal-flow scenarios to better describe the interactions of groundwater with thermal, mechanical, and radiation-induced alterations to the

near field. The nominal-flow scenario report has undergone a major revision as a branch has been added to the tree describing scenarios assuming there is no net influx of water into the mountain.

Forecast: The development and selection of scenarios for modeling will continue during FY 1993. Deliverables will include completion of the report for basaltic volcanism in January 1993, for tectonic phenomena in January 1993, and for nominal flow in September 1993. Any progress on scenarios for human intrusion will be reported in a memo due September 1993.

2.7.6.2 Performance Assessment Activity 1.1.2.2 - Final selection of significant release scenario classes to be used in licensing assessments

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

Forecast: No activity is planned for FY 1993.

2.7.6.3 Performance Assessment Activity 1.1.3.1 - Development of mathematical models of the scenario classes

Subactivity 1.1.3.1.1 - Development of models for release along the water pathways. Work related to this subactivity is described under Activity 1.6.3.1 and PA Activity 1.1.5.1.

Subactivity 1.1.3.1.2 - Development of a model for gas-phase releases. A number of papers on various aspects of gas flow in Yucca Mountain have been submitted or completed by workers at Disposal Safety, Inc. (DSI). These reports include: "Numerical Studies of Rock-Gas Flow in Yucca Mountain" (Amter et al., 1992) which was printed and distributed; "Predicted Gas-Phase Movement of C-14 from a Radioactive Waste Repository" (Ross et al.) which is in internal SNL technical review and will ultimately be submitted to Science; "A Semianalytical Method of Path Line Computation for Transient Finite-Difference Models" (Lu) which is currently in technical review at SNL and will be submitted to Water Resources Research; "A Coupled Model of Gas Flow and Heat Transport in Porous Media" (Ross et al.) which was submitted to the AGU Spring Meeting in Montreal, Canada; and "Implications of Stability Analysis for Heat Transfer at Yucca Mountain" (Ross et al.) which was submitted for presentation at the 1993 IHLRWM Conference.

Subactivity 1.1.3.1.3 - Development of a model of releases through basaltic volcanism. SNL staff met with staff from M&O/Woodward-Clyde to discuss how the work reported in

"Scenarios Constructed for Basaltic Ingeneous Activity at Yucca Mountain and Vicinity" (Barr et al.) might be used to help resolve NRC comments on the Study Plan related to basaltic-volcanism issues.

Subactivity 1.1.3.1.4 - Development of a model of releases through human intrusion. No progress during the reporting period; this is an out-year activity.

Forecast: During FY 1993, a gas-flow model for total-system analysis will be extended to include the effects of barometric pumping, capability for handling higher temperatures, and other improvements. The code that includes the gas-flow model, TGIF2, will be benchmarked. The deliverable for this activity includes a report describing the code and the results obtained with it in September 1993.

2.7.6.4 Performance Assessment Activity 1.1.4.1 - The screening of potentially significant scenario classes against the criterion of relative consequences

Reported under Activity 1.1.2.1.

2.7.6.5 Performance Assessment Activity 1.1.4.2 - The provision of simplified, computationally efficient models of the final scenario classes representing the significant processes and events mentioned in proposed 10 CFR 112 and 60.115

Reported in under Activity 1.1.5.1.

2.7.6.6 Performance Assessment Activity 1.1.5.1 - Calculation of an empirical complementary cumulative distribution function

Total System Performance Assessment - Results of the TSPA - 1991 (Barnard et al., 1992) were presented to the NWTRB. Presentations included: "Total-System Performance Assessment (TSPA-1991) Problem Definition" (Dockery), "Unsaturated-Zone Hydrologic Data Set and Elicitation of Expert Opinion" (Kaplan), "TSPA Aqueous and Gaseous Release Calculations" (Wilson), and Human Intrusion, Basaltic Igneous Activity, and Combining CCDFs" (Barnard). Results of the TSPA-1991 were also presented (Barnard and Dockery) to visiting members of the Svensk Karna Vranslehantring (SKB) at a technical interchange held in Las Vegas, Nevada, on April 9, 1992.

A large effort was expended to revise and finalize the final version of "TSPA 1991: An Initial Total-System Performance Assessment for Yucca Mountain" (Barnard et al., 1992). Response to YMP review comments and the final figures were incorporated into the text in

preparation for printing. The TSPA-91 document was printed and distributed in July 1992. The final document is substantially the same as preliminary versions released in April prior to the NWTRB presentations. However, a number of editorial revisions resulting from YMP review were incorporated into the final version. A paper based on this report was solicited for submission to Radioactive Waste Management and the Nuclear Fuel Cycle. "A Preliminary Total-System Performance Assessment for the Potential Repository Site at Yucca Mountain" (Wilson et al.) completed SNL's internal reviews and has been sent to YMPO for policy review.

SNL staff attended a second-cycle TSPA planning meeting July 21, 1992, in Vienna, Virginia. Representatives of INTERA, TRW, and YMPO were also present. Members of SNL's TSPA team have begun planning the next cycle of SNL's TSPA. The areas that have been identified for study include sensitivity studies on parameters used in aqueous flow; thermal loading effects; effects of geochemistry, enhanced source term, and tectonic activity; improvement on current gas flow models and infiltration models; and a number of other problems.

SNL staff attended the ANS annual meeting in Boston, Massachusetts, on June 10, 1992, to present three papers, including: "A Six-Step Method for Systematic Performance Assessment" (Barnard, 1992), "Approach to Geologic Repository Postclosure System Performance Assessment" (Pahwa et al., 1992), and "Total-System Performance Assessment for the Yucca Mountain Project" (Wilson, 1992). Summaries of the presentations were published in Transactions of the American Nuclear Society.

On June 25, 1992, SNL hosted a meeting stimulated by EPRI to provide input on the development of enhancements to the source term/near field component of their total-system model. Representatives from EPRI, INTERA, DOE, Risk Engineering Inc., DSI, TRW, and SNL were present. The list of items recommended for inclusion into their model in the near term included modeling the distribution of container failures (by various processes), thermal effects (such as thermally accelerated geochemical processes), and hydrologic effects (such as near-field flow processes) Although the meeting was mainly concerned with discussions of waste-package and near-field issues, some far-field flow and transport issues were discussed as well.

Staff have been developing source-term inventories (using the ORIGEN data base) that reflect the changes in isotopic compositions due to reactor type, amount of burnup, and length of decay since discharge from the reactors. These data will be used to evaluate the importance of using such detailed source terms in TSPA calculations, compared with the averaged source term of 60-percent PWR (at 33,000-MWd burnup) and 40-percent BWR (at 27,500-MWd burnup). Analyses are being run on inventory as a function of burnup and decay to investigate whether the typical model using a lumped source inventory is a

reasonable representation. The lumped source model ignores several potentially important radionuclides. Therefore, it may be important to represent the source term using a more realistic inventory.

SNL staff prepared recommendations for DOE to provide EPA revisions that would address human intrusion in the environmental standards governing repositories based on the "three-bucket approach" proposed by the NRC staff. The human-intrusion work used results of the TSPA as a basis for its recommendations. Additional calculations were prepared for the analysis of the three-bucket approach. These calculations showed that in some simulations the three-bucket approach is more restrictive than the original standard. In other simulations, it is less restrictive. A report entitled "A Comparison of the 1985 EPA Standard with the Three-Bucket Approach" (Wilson) was completed and attached to the material sent by the YMP to the EPA.

Further effort in support of YMPO assistance to the EPA took the form of presentations to a special board of the NAS. This board was formed at the request of the EPA to review the material that the YMPO had sent as technical assistance. SNL staff presented the YMPO material on human intrusion and participated in the board's inquiries. The board did not examine the YMPO material on the three-bucket approach.

The calculations evaluating the three-bucket approach were the basis for a technical exchange with the NRC on July 22, 1992. At that exchange, "An Analysis of the Three-Bucket Approach" (Wilson) was presented. Other SNL staff also participated.

SNL staff attended a meeting with members of the Geochemistry Integration Team for the purpose of setting up a workshop on colloids and their implications for Yucca Mountain PA.

The WINGZ effort was redirected to use INFORMIX software and will be referred to as the Visual Integrated Data Base (VIDB). The INFORMIX software has been received and the data base system is now being constructed. (See Activity 1.6.2.2.)

SNL staff attended a meeting hosted by EPRI on the use of expert elicitation in PA in Palo Alto, California, on April 30, 1992.

A class on Expert Judgment, taught by Dr. S. Hora of the University of Hawaii, was presented in Albuquerque, New Mexico, on July 6, 1992. In addition to SNL staff, attendees included staff from YMPO, SAIC, and the M&O.

Forecast: During FY 1993, the second cycle of TSPA will proceed through analyses to enhance the first cycle, completed in FY 1992. These analyses will cover the topics listed above as areas identified for study. A report containing the results of these analyses will be

completed in September 1993. A memo describing the performance of the VIDB data base will be delivered in September 1993. A memo on the planning status of a generic methodology for using expert judgement and a report on the elicitation of probability distributions will be completed by September 1993.

2.7.7 Individual protection (SCP Section 8.3.5.14)

2.7.7.1 Activity 1.2.1.1 - Calculation of doses through the groundwater pathway

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

Forecast: No activity is planned for FY 1993.

2.7.7.2 Activity 1.2.2.1 - Calculation of transport of gaseous carbon-14 dioxide through the overburden

Reported under Subactivity 1.1.3.1.2.

2.7.7.3 Activity 1.2.2.2 - Calculation of land-surface dose and dose to the public in the accessible environment through the gaseous pathway of carbon-14

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

Forecast: No activity is planned for FY 1993.

2.7.8 Groundwater protection (SCP Section 8.3.5.15)

2.7.8.1 Analysis 1.3.1.1 - Determine whether any aquifers near the site meet the Class I or special source criteria

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

Forecast: No activity is planned for FY 1993.

2.7.8.2 Analysis 1.3.2.1 - Determine the concentrations of waste products in any special source of groundwater during the first 1,000 years after disposal

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

Forecast: No activity is planned for FY 1993.

2.7.9 Performance confirmation (SCP Section 8.3.5.16)

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

Forecast: No activity is planned for FY 1993.

2.7.10 NRC siting criteria (SCP Section 8.3.5.17)

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

Forecast: No activity is planned for FY 1993.

2.7.11 Higher-level findings--postclosure system and technical guidelines (SCP Section 8.3.5.18)

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

Forecast: No activity is planned for FY 1993.

3.0 SCHEDULE

In late November 1989, a new proposed program schedule was announced in the Secretary's report to Congress (DOE, 1989). The new schedule was based on consideration of the duration required to obtain Yucca Mountain site access from the NRC, the State of Nevada, and others; and the work scope described in the SCP and the more-detailed Study Plans. In January 1990, the schedule presented in the Secretary's report to Congress was finalized by OCRWM in the Program Cost and Schedule Baseline (DOE, 1990). This Program Cost and Schedule Baseline was revised in March 1991, in November 1991, and again in September 1992. Factors external to the program, including uncertainties associated with obtaining future environmental permits, program funding levels, and Study Plan review, may continue to affect the program schedule.

This section presents the schedule baseline for the YMP as of the end of this reporting period (September 30, 1992). More detailed schedules are maintained at the YMPO, in combination with work scopes and the dollars needed to accomplish this work. The schedule focuses on the early evaluation of site suitability of the Yucca Mountain site.

Table 3.1 presents the summary milestones for the YMP. Figure 3.1 shows the relationship of the summary milestones to the major activities.

Table 3.1 Summary Milestones [1]

	Baseline Date	Actual Date
Surface-Based Testing		
Obtain Permits	12/91	7/91
Start New Surface-Based Testing	1/92	7/91
Complete Deep Unsaturated Zone Hydrologic Hole Drilling	6/95	
ESF		
Start Final ESF Title II Design	10/91	10/91
Start ESF Site Preparation	11/92	
Start ESF In Situ Test Phase	6/96	
Complete ESF Development Drifting	11/97	
Provide Engineering Barrier System Data to Waste Package License Application Design	7/98	
Waste Package/Repository Design		
Complete Repository Program Plan	3/91	9/91
Start Waste Package/Repository Advanced Conceptual Design	10/92	10/92
Start Waste Package/Repository License Application Design	6/96	
Environmental Impact Statement		
Issue EIS Notice of Intent	5/97	
Issue EIS Implementation Plan	2/98	
Notify State of Proposed Site Selection	10/99	
Issue Draft EIS	10/99	
Issue Final EIS	3/01	
Notify State of Site Selection	3/01	
Issue Record of Decision	4/01	
Issue Site Recommendation Report to the President	4/01	
License Application		
Provide Recommendation to the Director, OCRWM, on Alternative License Application Strategies for Review	8/91	8/91
Submit License Application to the NRC	10/01	

[1]Table shows approved Program Schedule Baseline and actual completion dates as of September 30, 1992

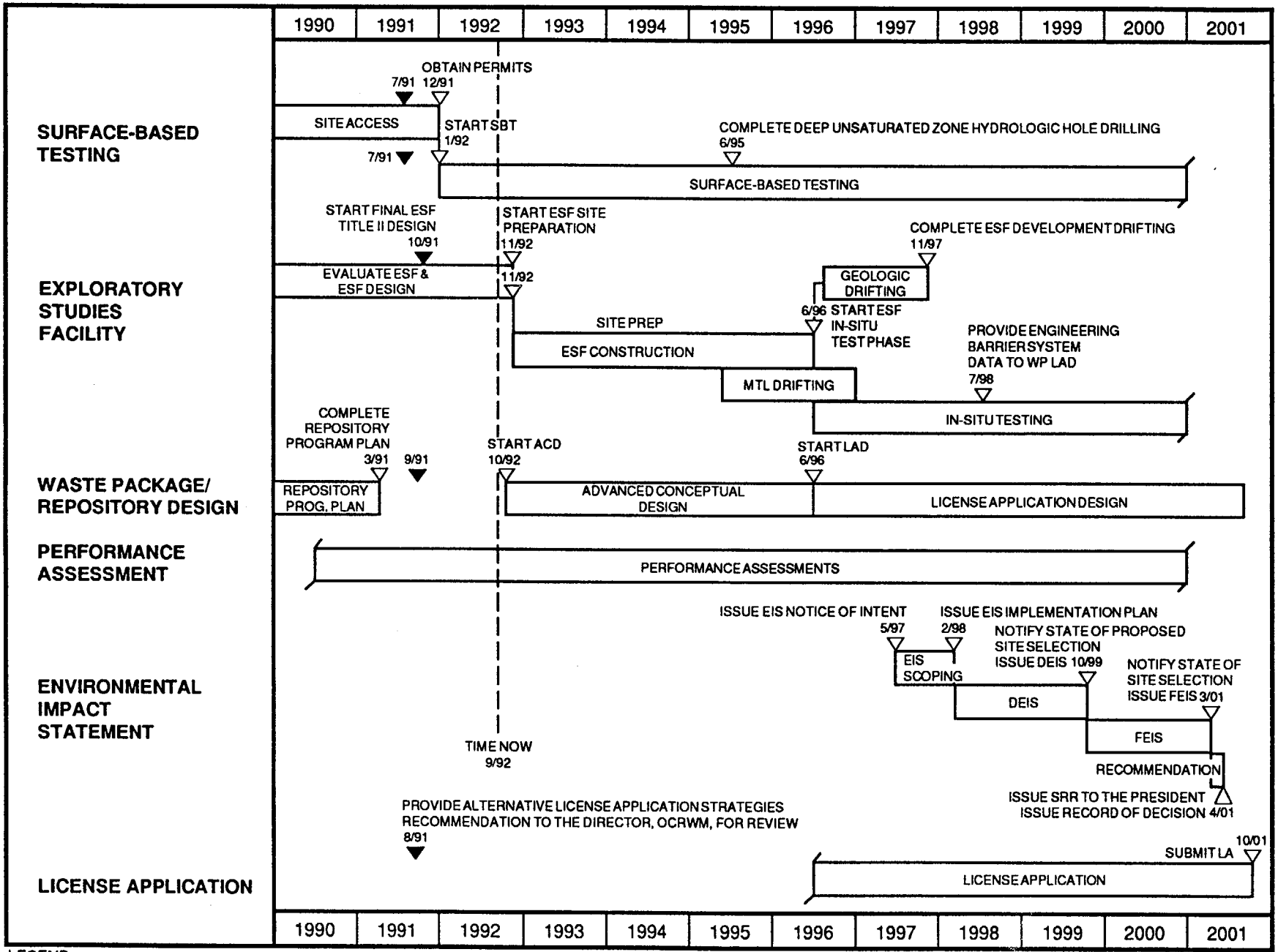

Figure 3.1. Site Characterization Summary Schedule.

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4.0 EPILOGUE

This section provides a brief summary of key events that occurred after the close of the reporting period on September 30, 1992.

Congress passed the Comprehensive National Energy Policy Act of 1992 and the President signed it into law (Public Law 102-486) on October 24, 1992. Section 801 of the law directs the EPA to "...prescribe the maximum annual effective doses equivalent to individual members of the public from releases to the accessible environment from radioactive materials stored or disposed of in the repository (at Yucca Mountain)." The law also directs the EPA to consult the National Academy of Sciences on, among other topics, whether institutional controls would prevent humans from breaching the repository's engineered and natural barriers.

Section 803 of the Act requires the Secretary to report to the Congress and the President within one year on the adequacy of current waste management disposal plans to accommodate additional volumes of spent fuel and high-level waste from an expanded nuclear industry.

In October 1992, the State of Nevada issued to DOE a point source permit for dust control for the Cone Gravel Screening Plant which will be used during ESF site preparation and construction activities.

The draft ESF ramp size study was issued to DOE by RSN in October 1992. All comments from the ESF Design Package 1A Technical and Management Design Review have been resolved. The RSN Design Verification Review, and the design specifications and drawings were completed and submitted to YMPO for acceptance and review. YMPO reviewed and accepted these documents in November 1992. Also in November, DOE received the ESAAB approval to commence ESF excavation, and site preparation was initiated.

By letter dated November 2, 1992, the NRC notified DOE that based on the NRC staff's review of information provided by DOE in relevant portions of the ESFAS and CHRBA reports, NRC considers Objection 1 lifted and SCA Comments 12, 16, 35, 57, 72, 127, 128, 132, and SCA Question 61 resolved.

In November 1992, PNL issued the report, "Preliminary Total System Analysis of a Potential High-Level Nuclear Waste Repository at Yucca Mountain" (Eslinger et al., 1992). This document describes the work that was performed by PNL as part of DOE's 1991 TSPA.

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The draft Erosion Topical Report was completed and submitted to YMPO in November 1992 and YMPO completed the review in December. The draft Report will next be reviewed by the program Headquarters office.

The Request for Proposals for a Tunnel Boring Machine to be used in the excavation of the Exploratory Studies Facility at Yucca Mountain was released on December 16, 1992.

REFERENCES

All technical reports and research products published by participating organizations on the YMP are generally available through the Office of Scientific and Technical Information (OSTI) at Oak Ridge, Tennessee. OSTI is the national center for dissemination of non-classified scientific and technical information prepared from research sponsored by DOE. The references cited in this section are available through OSTI, the open literature, or through proceedings volumes for symposia and technical conferences.

Copies of YMP reports and other documents published by DOE and the participating organizations, which are available through OSTI, can be ordered from:

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

Annotated outlines of YMP-sponsored reports can be found in the YMP Bibliography. Updates are published every six months. The bibliography segments released to date are as follows:

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ACRONYMS/ABBREVIATIONS LIST

ACD	Advanced Conceptual Design
ACNW	Advisory Committee on Nuclear Waste
AECL	Atomic Energy of Canada Limited
AFM	atomic-force-microscopy
AGU	American Geophysical Union
ALARA	As Low As Reasonably Achievable
Am	americium
ANDRA	Agence Nationale pour la Gestion des Dechets Radioactifs
ANL	Argonne National Laboratory
ANS	American Nuclear Society
APDs	areal power densities
Ar	argon
ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials
ATDD	Atmospheric Turbulence and Diffusion Division
AVS	applications-visualization system
B	boron
BGRA	Branch of Geologic Risk Assessment
BLM	U.S. Bureau of Land Management
BRWM	Board on Radioactive Waste Management
C	carbon
Ca	calcium
CH	Calico Hills
CAR	Corrective Action Report
CHBRA	Calico Hills Risk/Benefit Analysis
CCB	Change Control Board
CCDF	complementary cumulative distribution function
CFCs	chlorofluorocarbons
CM	Construction Management
CO_2	carbon dioxide
CRWMS	Civilian Radioactive Waste Management System
Cs	cesium
CSM	Colorado School of Mines
DNA	Defense Nuclear Agency
DOE	U.S. Department of Energy
DP	detailed technical procedure
DRI	Desert Research Institute
DSI	Disposal Safety, Inc.
DVNM	Death Valley National Monument
EBS	engineered barrier system

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EEI	Edison Electric Institute
EPA	Environmental Protection Agency
EPRI	Edison Power Research Institute
ESAAB	Energy Systems Acquisition Advisory Board
ESCA	electron spectroscopy for chemical analysis
ESFAS	Exploratory Studies Facility Alternatives Study
ESFDR	Exploratory Studies Facility Design Requirements
ESSE	Early Site Suitability Evaluation
ESF	Exploratory Studies Facility
ESTSC	Energy Science and Technology Software Center
ET	Evapotranspiration Studies
Fe	iron
FEPs	features, events, and processes
FY	fiscal year
GCM	general circulation model
Gd	gadolinium
GIS	Geographic Information Systems
GIT	Geochemistry Integration Team
GMS	Geoscience Modeling System
GOES	Geostationary Operation Environmental Satellite
GPS	Global Positioning Satellite
GSIS	Geoscience Information System
GWTT	groundwater travel time
He	helium
HIT	Hydrology Integration Team
HLRW	high-level radioactive waste
HRF	Hydrologic Research Facility
HRUs	hydrologic response units
HVAC	heating, ventilating, and air conditioning
I	iodine
ICE	Independent Cost Estimation
ICP	inductively coupled plasma
IDAS	Integrated Data Acquisition System
IEA	Institutional and External Affairs
IGSG	Isotope and Geochemistry Support Group
IHLRWM	International High Level Radioactive Waste Management
IIS	insulated instrument shelter

PROGRESS REPORT #7

ACRONYMS/ABBREVIATIONS LIST

IITS	items important to safety
IITWI	items important to waste isolation
INEL	Idaho National Energy Laboratory
ISP	Individual Software Plan
ISR	Institute for Standards Research
ITE	Integrated Test Evaluation
K	potassium
ksi	kilopounds per square inch
LAD	License Application Design
LANL	Los Alamos National Laboratory
LBL	Lawrence Berkeley Laboratory
Li	Lithium
LLNL	Lawrence Livermore National Laboratory
LRW	low-level radioactive waste
LT	low temperature
LVDT	linear variable differential transformer
M&O	Management and Operating
Mg	magnesium
MGDS	Mined Geologic Disposal System
MnO	manganese oxide
MPa	megapascal
MRS	Monitored Retrievable Storage
MS	mass spectrometry
MTU	metric tons of uranium
NaC1	sodium chloride
NAS/NRC	National Academy of Sciences/National Research Council
NCAR	National Center for Atmospheric Research
NCDC	National Climate Data Center
Nd	Neodymium
NER	New England Research, Inc.
NERSC	National Energy Research and Supercomputing
Ni	nickel
NIST	National Institute for Standards and Testing
NMR	nuclear magnetic resonance
NOAA	National Oceanic and Atmospheric Administration
Np	neptunium
NPS	U.S. National Park Service

ACRONYMS/ABBREVIATIONS LIST

NRC	U.S. Nuclear Regulatory Commission
NTS	Nevada Test Site
NWPA	Nuclear Waste Policy Act
NWTRB	Nuclear Waste Technical Review Board
O_2	oxygen
OCF	Open Computing Facility
OCRWM	Office of Civilian Radioactive Waste Management
OER	Office of External Relations
OQA	Office of Quality Assurance
OSTI	Office of Scientific and Technical Information
PA	performance assessment
PACS	Planning and Control System
PAS	photoacoustic spectroscopy
Pb	lead
ppb	parts per billion
ppm	parts per million
psi	pounds per square inch
PNL	Pacific Northwest Laboratory
PR	Progress Report
PRMS	precipitation-runoff modeling system
PTn	nonwelded Paintbrush Tuff
Pu	plutonium
PuO_2	plutonium dioxide
QA	quality assurance
QARD	Quality Assurance Requirements Documents
Rb	rubidium
RCM	regional climate model
REECo	Reynolds Electrical and Engineering Co.
RFP	request for proposal
RIB	Reference Information Base
RSN	Raytheon Services Nevada
SAB	Science Advisory Board
SAIC	Science Applications International Corporation
SCA	Site Characterization Analysis
sccm	standard cubic centimeter
SCP	Site Characterization Plan
SCPB	Site Characterization Program Baseline

ACRONYMS/ABBREVIATIONS LIST

SCRF	Stanford Center for Reservoir Forecasting
Se	selenium
SEB	Source Evaluation Board
SEM	scanning electron microscopy
SEPDB	Site and Engineering Properties Data Base
SF_6	sulphur hexafluoride
SGBSN	Southern Great Basin Seismic Network
SIAM	Society for Industrial and Applied Mathematics
SIIP	Scientific Investigation Implementation Package
SKB	Svensk Karnbranslehantering AB
SLAR	Side-Looking Airborne Radar
slpm	standard liters per minute
SNL	Sandia National Laboratories
SOC	Sample Overview Committee
SQAP	Software Quality Assurance Plan
Sr	strontium
STA	saturation test apparatus
SZ	saturated zone
T&MSS	Technical and Management Support Services
TBM	tunnel-boring machine
Tc	technetium
TCA	thermal conductivity analyzer
TCw	welded Tiva Canyon
TDB	Technical Data Base
TDR	time-domain reflectrometry
TEM	Transmission Electron microscope
TGA	Thermogravimetric Apparatus
Th	thorium
TM	Thematic Mapper
TPP	test planning package
TPT	Test Prioritization Task
TSPA	Total System Performance Assessment
TSw	welded Topopah Spring
U	uranium
UDEC	Universal Distinct Element Code
UNE	underground nuclear explosion
UNLV	University of Nevada-Las Vegas

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ACRONYMS/ABBREVIATIONS LIST

UNR	University of Nevada at Reno
UNRSL	University of Nevada-Reno Seismological Laboratory
USBR	U.S. Bureau of Reclamation
USGS	U.S. Geological Survey
UZ	unsaturated zone
VIDB	Visual Integrated Data Base
VSP	vertical seismic profiling
WIPP	Waste Isolation Pilot Plant
WSNSO	Weather Service office
XRD	x-ray diffraction
XPS	x-ray photoelectron spectroscopy
YMIM	Yucca Mountain Integrating model
YMIO	Yucca Mountain Information Office
YMP	Yucca Mountain Site Characterization Project
YMPO	Yucca Mountain Site Characterization Project Office
YMQAD	Yucca Mountain Quality Assurance Division
YMTF	Yucca Mountain Test Facility

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