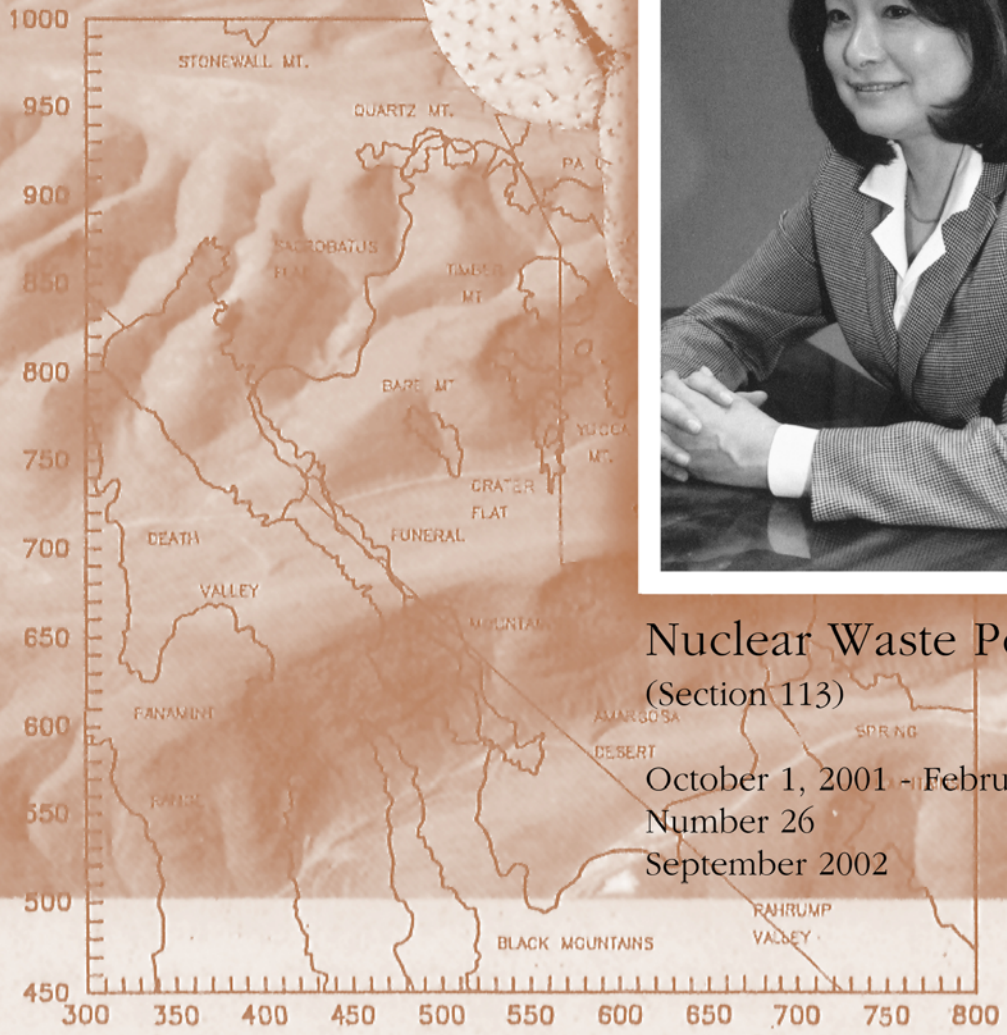
DOE/RW-0554

Site Characterization Progress Report

Yucca Mountain, Nevada



Nuclear Waste Policy Act

(Section 113)

October 1, 2001 - February 14, 2002

Number 26

September 2002

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

NOTE INSIDE FRONT COVER

The Nuclear Waste Policy Act of 1982 (NWPA) established the U.S. Department of Energy Office of Civilian Radioactive Waste Management. The Nuclear Waste Policy Act, as amended[1], directs the Office of Civilian Radioactive Waste Management to dispose of the nation's high-level radioactive waste and spent nuclear fuel in a geologic repository and prescribes other related activities. The Nuclear Waste Policy Act, as amended, requires the Secretary of the Department of Energy to semiannually report to the U. S. Nuclear Regulatory Commission and to the Governor and Legislature of the State of Nevada on site characterization activities. Title 10 of the Code of Federal Regulations, Part 63 (10 CFR 63.16(b)), Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada, requires the report to:

- Describe the results of site characterization activities and information developed to date
- Describe waste form and waste package research and development
- Identify new issues and plans to resolve these issues
- Discuss any planned studies eliminated because they are no longer necessary to site characterization
- Identify decision points reached and schedule modifications.

This is the 26th progress report issued by the U.S. Department of Energy. This report provides a summary-level discussion of the Yucca Mountain Site Characterization Project activities. Accomplishments this period are presented in a format that identifies important progress achieved and conveys how that progress supports the near-term objectives in the U.S. Department of Energy. Greater detail is documented in the cited references and in the deliverables listed in Appendices A and B to this report. Readers may request any of these approved documents by contacting the Office of Civilian Radioactive Waste Management Information Line at 1-800-225-6972.

This document provides a discussion of recently completed and ongoing activities conducted by the Yucca Mountain Site Characterization Project during this reporting period from October 1, 2001, through February 14, 2002. This reporting period ends on February 14, 2002, instead of March 31, 2002, because the Secretary of Energy recommended the Yucca Mountain site to the President on February 14, 2002, thus ending the site characterization phase on that date. Progress Report 26 is therefore the last of the series of semiannual site characterization progress reports.

Documentation of Program Change, Revision 04 ICN 01, was issued in April 2002. It compares site characterization activities through September 30, 2001, to those activities described in the 1988 *Site Characterization Plan Yucca Mountain Site, Nevada Research and Development Area, Nevada*. Prior to April 1997, the *Documentation of Program Change* was included as an appendix to the semiannual progress reports, but has since been published as a separate document and revised annually. No future revisions of the *Documentation of Program Change* are planned because the site characterization phase ended on February 14, 2002, when the Secretary recommended the Yucca Mountain site to the President and because 10 CFR 63 does not require a license application to contain a comparison with the 1988 Site Characterization Plan, as was required by 10 CFR 60.

1 The Nuclear Waste Policy Act of 1982, as amended, consists of Public Law 97-425 (96 Stat. 2201) enacted on January 7, 1983, and subsequent amendments: Public Law 100-203 (December 22, 1987) and Public Law 102-486 (The Energy Policy Act of 1992, October 24, 1992). The Act is codified at 42 U.S.C. 10101 and following.

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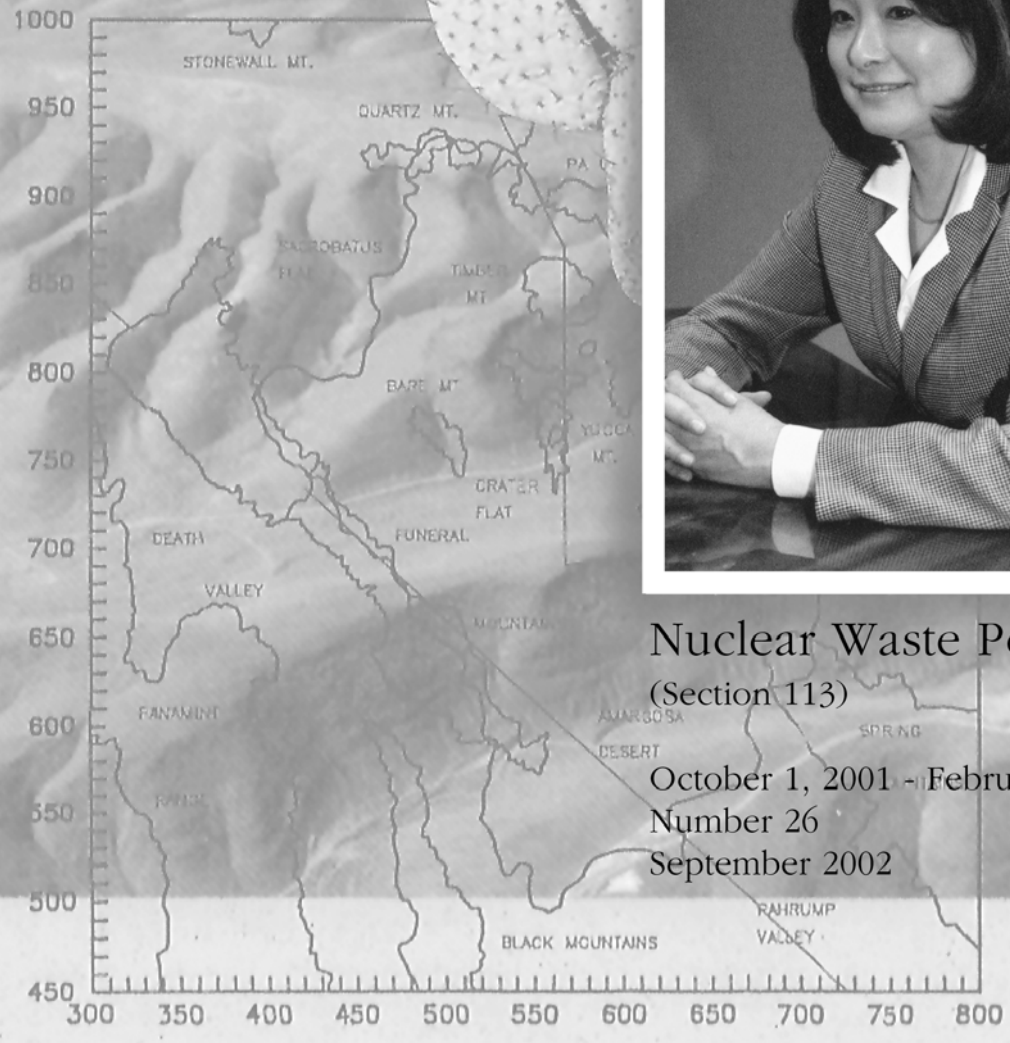
Site Characterization Progress Report

Yucca Mountain, Nevada



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ACRONYMS, ABBREVIATIONS, AND SYMBOLS

ACRONYMS AND ABBREVIATIONS

AMR	Analysis and Model Report
BWR	Boiling Water Reactor
°C	degrees Celsius
CHn	Calico Hills nonwelded
cm	centimeter
DIRS	Document Input Reference System
DOE	U.S. Department of Energy
ECRB	Enhanced Characterization of the Repository Block
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
ESF	Exploratory Studies Facility
FBA	Fluorobenzoic Acid
FEPs	Features, Events, And Processes
HLW	High-Level Radioactive Waste
KTI	Key Technical Issue
LA	License Application
m	meter
mg/L	milligrams per liter
ml/hr	milliliters per hour
mm	millimeter
mm/yr	millimeter per year
NC-EWDP	Nye County-Early Warning Drilling Program
NRC	U.S. Nuclear Regulatory Commission
NWPA	Nuclear Waste Policy Act
NWTRB	Nuclear Waste Technical Review Board
ppb	parts per billion
ppm	parts per million
PTn	Paintbrush Tuff nonwelded
PWR	Pressurized Water Reactor
SITP	Scientific Investigation Test Plan
SNF	Spent Nuclear Fuel
SR	Site Recommendation
SSCs	Structures, Systems, And Components
SZ	Saturated Zone

ACRONYMS, ABBREVIATIONS, AND SYMBOLS (Continued)

Tac	Calico Hills Formation
TCw	Tiva Canyon Tuff, welded
Tptpll	Topopah Spring Tuff, crystal poor lower lithophysal unit
TSPA	Total System Performance Assessment
TSPA-SR	Total System Performance Assessment for the Site Recommendation
TSw	Topopah Spring Unit, welded
USGS	U.S. Geological Survey
UZ	Unsaturated Zone
W/m K	Watts per meter Kelvin
WP	Waste Package

SYMBOLS

As	arsenic
Br	bromine
C	carbon
Ca	calcium
Ce	cerium
Cl	chlorine
Co	cobalt
CO_2	carbon dioxide
Cs	cesium
Eh	hydrogen potential
F	fluorine
I	iodine
K	potassium
K_d	batch sorption coefficient
Li	lithium
Mg	magnesium
Mn	manganese
N	nitrogen
Na	sodium
Ni	nickel
nm	nanometer
NO_3	nitrate ion
Np	neptunium

ACRONYMS, ABBREVIATIONS, AND SYMBOLS (Continued)

O	oxygen
P	phosphorus
Pb	lead
pH	scale of acidity and alkalinity (hydrogen-ion concentration notation)
Ra	radium
S	sulfur
Si	silicon
Sm	samarium
SO_4	sulfate ion
Sr	strontium
Tc	technetium
Th	thorium
U	uranium

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SECTION 1 – EXECUTIVE SUMMARY

This 26th semiannual progress report of the Yucca Mountain Site Characterization Project summarizes site characterization activities from October 1, 2001, through February 14, 2002. This progress report documents the Project site characterization and other activities that contributed to completing the U.S. Department of Energy's (DOE's) near-term programmatic and statutory objectives. Major accomplishments during this reporting period are summarized briefly in this Executive Summary, and the detailed accomplishments are summarized in Sections 2 through 5. Section 2 summarizes the detailed progress on activities related to the near-term objectives, and Sections 3 through 5 present Project work on site characterization, design and construction, and repository performance, respectively. Section 6 (Epilogue) documents significant events that have occurred after the close of the reporting period. Section 7 provides the complete list of the cited references.

1.1 PROGRESS TOWARD NEAR-TERM OBJECTIVES

1.1.1 Site Recommendation

During this reporting period, the Secretary of Energy determined, in accordance with the Nuclear Waste Policy Act of 1982 (NWPA[2]), as amended, that the Yucca Mountain site was suitable to serve as a nuclear waste repository. Further details are discussed in Section 2.1.

On January 10, 2002, the Secretary notified the Governor of the State of Nevada (Governor Kenny Guinn) and the Nevada Legislature of his intention to recommend the site to the President. On February 14, 2002, the Secretary forwarded a recommendation to the President regarding the siting of a proposed repository. The reporting period for this 26th semiannual progress report ended on February 14, 2002, instead of March 31, 2002, because the site characterization phase and this series of semiannual progress reports ended on the date that the Secretary of Energy recommended the Yucca Mountain site to the President. Section 6 (Epilogue) of this report explains that, on February 15, 2002, the President forwarded his recommendation of the site to Congress. On April 8, 2002, Governor Kenny Guinn of the State of Nevada submitted a notice of disapproval of the Yucca Mountain site to Congress. On May 8, 2002, the U.S. House of Representatives passed a resolution of approval of the Yucca Mountain site for development of a nuclear waste repository. On July 9, 2002, the U.S. Senate passed a resolution of approval of the Yucca Mountain site for development of a nuclear waste repository. On July 23, 2002, the President signed the joint resolution for development of a nuclear waste repository into law, completing the formal designation of the Yucca Mountain site, per section 115(c) of the NWPA, as amended.

1.1.2 Environmental Impact Statement

Work was completed on those activities related to preparation of the *Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada* (Final EIS), including the provision of opportunities for public involvement. The Final EIS demonstrated that during the 10,000 years after repository closure, the repository is not expected to result in radiation exposure to the public beyond the prescribed radiation standard exposure and activity concentration limits in 40 CFR 197 and 10 CFR 63. The Final EIS concluded that a repository at Yucca Mountain would cause small, short-term public health impacts due primarily to the transportation of spent nuclear fuel (SNF) and high-level radioactive waste (HLW) from

[2] The Nuclear Waste Policy Act of 1982, as amended, consists of Public Law 97-425 (96 Stat. 2201) enacted on January 7, 1983. Subsequent amendments are Public Law 100-203 (December 22, 1987) and The Energy Policy Act of 1992, October 24, 1992 (Public Law 102-486). The Act is codified at 42 U.S.C. 10101 and following.

the existing commercial and DOE sites to the repository. The Final EIS activities are summarized in Section 2.2.

1.1.3 Regulatory Framework, Interactions, and Strategy

The Energy Policy Act of 1992 signaled a broad shift from a generic to a site-specific regulatory framework for evaluation of and decision-making about a proposed repository at Yucca Mountain. The remaining site-specific regulatory framework essential to determining the suitability of the Yucca Mountain site for development as a repository was finalized during this reporting period. The following regulations form the regulatory framework that protects both public health and safety and the environment:

- The U.S. Environmental Protection Agency (EPA) final rule 40 CFR 197, Public Health and Environmental Radiation Protection Standards for Yucca Mountain, Nevada, became effective on July 13, 2001.

- The U.S. Nuclear Regulatory Commission (NRC) final rule 10 CFR 63, Disposal of High-Level Radioactive Waste in a Geologic Repository at Yucca Mountain, Nevada, became effective on December 3, 2001.

- The DOE final rule 10 CFR 963, Yucca Mountain Site Suitability Guidelines, became effective on December 14, 2001.

The DOE interactions with the NRC continue to focus on addressing and resolving Key Technical Issues (KTIs), topics that the NRC considers important to evaluating performance of a proposed repository at Yucca Mountain. During this reporting period, the Project provided the NRC with eight responses to KTI agreement items, and the NRC has closed four KTI agreement items.

The Project continues to apply substantial resources to addressing crosscutting quality assurance (QA) issues. Necessary changes will be made at all levels of the program to ensure that important QA issues are expeditiously resolved and that actions are taken to prevent recurrence of significant QA problems.

The Project has committed to the creation and maintenance of a nuclear safety culture and rigorous compliance with QA procedures, two key elements necessary for successful licensing and safe operation of the repository. Improved implementation of quality affecting processes used on the Project is expected to result in a culture of adherence to procedures and in a continuous improvement of the procedures. Activities are currently being carried out in a quality manner; however, these positive quality changes should result in the improved collection and management of data; improved software qualification; and more transparent (defensible) analysis methods, models, and calculations. The importance of sound quality processes and effective implementation of those processes is being emphasized throughout the Project by all management levels within DOE and its contractors.

The status and progress of the QA program and related activities are reported to the NRC on a periodic basis in other forums. The DOE keeps the NRC informed via quarterly QA Management Meetings, semi-annual quality trend reports, submittal of its audit reports, submittal of reports of conditions adverse to quality, and via the NRC On-Site Representative's monthly report of Project activities.

Additional interactions with the NRC included QA and management meetings held in December 2001. Interactions with the NRC Advisory Committee on Nuclear Waste continued to provide the status of Project activities and address issues raised by the Committee.

1.1.4 Nuclear Waste Technical Review Board Interactions

During this reporting period, interactions with the Nuclear Waste Technical Review Board (NWTRB) provided an opportunity to update the NWTRB on technical aspects of the Project and for the NWTRB to provide recommendations to the DOE on the results of the DOE's scientific and engineering investigations. These interactions are summarized in Section 2.4. The NWTRB sent the DOE a letter with recommendations for the DOE's consideration.

1.1.5 Planned Studies No Longer Necessary

No planned studies were eliminated during the reporting period.

1.1.6 Decision Points Reached

The Secretary of Energy notified the Governor of the State of Nevada of his intention to recommend the Yucca Mountain site to the President as a suitable site for a geologic repository, and on February 14, 2002, the Secretary forwarded his recommendation regarding the Yucca Mountain site to the President (see Section 6).

1.1.7 Modifications to Schedules

During this reporting period plans were made to change the program's schedule date for the submittal of an LA for a construction authorization of the repository, if the site is approved. The new recommended date for this milestone is December 2004.

1.2 SITE CHARACTERIZATION

1.2.1 Geologic Investigations

During this reporting period two new models were added to the Integrated Site Model: the Thermal Conductivity of the Potential Repository Horizon and the Thermal Conductivity of Non-Repository Lithostratigraphic Layers (reports are in progress, see Appendix B). In addition, the Thermal Conductivity Analysis of Field Thermal Tests was completed.

1.2.2 Natural Analogues

The *Natural Analogue Synthesis Report* was completed in February 2002. The report includes quantitative and qualitative studies that contribute to the understanding of conceptual process models and aid in building confidence in models that provide input to performance assessment. This report provides updates to studies presented in the *Yucca Mountain Site Description* and new examples gleaned from the literature.

1.2.3 Geologic Field Investigations

Geologic field investigations focused on geologic mapping of the area immediately south of the central block of Yucca Mountain, characterization of excavation-induced fractures, and hydrogeological features of faults that could affect groundwater flow (see Section 3.1.3). Geologic mapping of the area immediately south of the central block of Yucca Mountain indicates additional lithophysal zones not present in the central block. Field geologic mapping has revealed several previously unrecognized faults in the Abandoned Wash and Dune Wash areas.

1.2.4 Altered-Zone and Near-Field Environment

The thrust of modeling work during this period was on validating the models for the thermally-driven coupled processes (thermal-hydrological, thermal-hydrological-chemical, and thermal-hydrological-mechanical) using the measurements from the in situ field tests.

Large-scale, field thermal tests, like the Drift Scale Test, are used to validate conceptual models of coupled thermal, mechanical, hydrological, and/or chemical processes. The Drift Scale Test completed a four-year heating phase on January 14, 2002, when the power supply to heaters was switched off. Scientists predict that it will take about one year for drift wall temperatures to fall from 205°C to below boiling. Data acquisition will continue during cooling to gain an understanding of cooling effects on the coupled process. Some of the samples acquired from superheated zones show relatively high fluoride concentrations and low pH values. Analyses of water samples taken both before and after the introduction of fluoroelastomer materials demonstrate clearly that the source of the fluoride contamination is from the fluoroelastomer packer seal material, and not the host rock.

1.2.5 Site Unsaturated Zone Flow and Transport

Testing continued both in the Enhanced Characterization of the Repository Block (ECRB) Cross Drift and the Exploratory Studies Facility (ESF) Main Drift. The ECRB Cross Drift tests included passive monitoring of in-drift moisture dynamics and systematic hydrologic characterization involving active liquid release experiments. Niche 5 in the ECRB Cross Drift is located in the Topopah Spring Tuff crystal poor lower lithophysal unit (Tptpll), and contains a large number of lithophysal cavities ranging from a few centimeters to over a meter in diameter. Air permeability and seepage tests conducted in Niche 5 indicated that lithophysal cavities act as local capillary barriers and that liquid flow predominantly occurs in fractures.

In the Alcove #8 to Niche 3 flow and transport test, water and tracers were released in Alcove #8 of the ECRB Cross Drift, and seepage recovered in Niche 3 of the ESF Main Drift. The release of water, under ponded conditions, along the fault in Alcove #8 began in early March 2001, and continued largely uninterrupted through February 14, 2002. At that time, the flux of water introduced along the fault was reduced to half the flux under ponded conditions. The results from the tracer test show that under lower flow rates there is more retardation of the nonreactive pentafluorobenzoic acids tracer, suggesting movement of the tracer into the rock matrix.

Cross Drift Bulkhead Moisture Studies are long-duration, confirmatory observations designed to detect seepage in sealed drift sections and to evaluate the drying effects of ventilation and construction activity on the underground moisture conditions. Moisture monitoring behind the bulkheads in the ECRB Cross Drift continued during the reporting period. Through February 14, 2002, none of the nine video cameras behind the bulkheads had detected any seepage.

Early data from sensors behind the bulkhead for Alcove #7 indicate that the pneumatic pressure fluctuates daily in response to barometric pressure changes, indicating that the bulkheads do not dampen the barometric signal. While air temperature in front of the bulkheads fluctuates by several degrees Celsius in response to ESF ventilation, the temperatures behind both bulkheads show very small diurnal fluctuations that are totally independent of ESF ventilation.

In the Busted Butte Unsaturated Zone Transport Test, Phase 1B testing consisted of a sub-meter scale tracer test in the unsaturated Topopah Springs welded tuff unit that was designed to encompass a naturally occurring fracture. This would determine the role of fracture flow in transport through unsaturated tuff.

The test concluded that models using simple combinations of advective flow and diffusion are sufficient to provide a good representation of the measured field data.

The transport of colloids has also been tested at the Busted Butte field study, where microspheres were injected into the Calico Hills Tuff unit. Crushed rock samples from the overcores were qualitatively analyzed for 280 nm microspheres, indicating that the microspheres traveled at least 45 cm during the experiment.

The laboratory tandem radionuclide migration experiment through the one cubic meter block of nonwelded tuff obtained from the Busted Butte Transport Field Test Facility was continued under saturated and unsaturated conditions during the reporting period. After 338 days of radionuclide injection under saturated conditions, the block material is retaining most of the injected ^{99}Tc under the chemically reducing conditions being maintained.

The ^{36}Cl Validation Study used a carefully developed leaching procedure to prepare 29 leachate samples from crushed core taken from the ^{36}Cl validation boreholes. None of the analyses completed to date show any indication of bomb-pulse ^{36}Cl within the Sundance fault zone. At an inter-participant ^{36}Cl Validation Study technical exchange meeting held in Denver on January 16, 2002, Project scientists agreed upon a path forward to resolve outstanding issues.

A systematic survey was conducted of secondary-mineral occurrences on the right rib of the ECRB Cross Drift to determine the origin of secondary calcite and silica deposits and fluid inclusions. U-Pb ages of sub-samples from silica layers in lithophysal cavities in the Topopah Spring welded unit (TSw) indicate that many coatings formed at slow growth rates. In contrast, U-Pb ages for sub-samples of silica from fractures in the TCw indicate much faster depositional rates. The difference in growth rates probably indicates that the nonwelded tuffs (PTn), located between the welded TCw and TSw, play an important role in moderating unsaturated zone (UZ) flow.

In December 2001, the monitoring at surface-based UZ boreholes was terminated after over six years of continuous operation. Closeout activities, which include preparation of the final data package, are continuing.

Uranium-series isotopic analyses of samples of fractured and unfractured tuffs indicate that fractured rock appears not to be a dominant pathway for groundwater flow through the Topopah Spring Tuff; therefore, rapid flow from the surface to the level of the ESF within the last 50 years appears to be improbable.

Surficial carbonate-source validation continued during the reporting period with isotopic analysis of O, C, and Sr. The State of Nevada has interpreted their C and O isotope data to mean that deposits have a groundwater source. Project data collected to evaluate the State of Nevada's interpretations are consistent with a meteoric water source of O, C, and Sr, and thereby contradict the groundwater source hypothesis.

1.2.6 Site Saturated Zone Flow and Transport

Geologic support to the Nye County Early Warning Drilling Program (NC-EWDP) continued during the reporting period. The data from the NC-EWDP will prove of value for interpretation of subsurface geology and in development of hydrostratigraphic cross sections in that vicinity of Nye County, Nevada.

Chemical and isotopic analysis of water samples collected from NC-EWDP Phase III boreholes and the Alluvial Testing Complex will be used in investigation of hydrochronology of the Yucca Mountain flow system. In closely-related work, ^{14}C dating was completed, and the ^{14}C ages ranged from about 15,000

years to about 19,000 years, which is consistent with results from other samples from that borehole as well as from other boreholes in the area.`

The Alluvial Testing Complex work includes preparation of the single-hole tracer testing report and planning efforts for cross-hole hydraulic and tracer testing. Single-well injection-withdrawal tracer testing supports the conclusion that a single-porosity conceptual transport model applies.

Anticipated permission for further testing was denied by the State of Nevada. In addition, the Alluvial Testing Complex water-discharge waiver was revoked by the state, because the state's interpretation of completion of "site characterization" is the Presidential acceptance of the DOE recommendation of the Yucca Mountain site. Consequently, testing activities at the Alluvial Testing Complex are temporarily terminated, pending resolution of the water permit issue.

In the Death Valley regional flow-system modeling project, an update of the Hydrogeologic Framework Model for the Yucca Mountain region was finalized and will result in much more consistency between the site-scale and regional groundwater flow models.

1.2.7 Engineered Barrier System Testing

Engineered barrier system testing during the reporting period focused on natural convection testing to support resolution of NRC KTI agreement items related to in-drift thermal transport phenomena, laboratory thermal conductivity testing of samples from the Tptpll, and field thermal conductivity tests in the Tptpll. These tests improve the predictions of heat and temperature distributions in the repository, in both the open spaces of the drift and in the host rock.

Two pilot-scale test cells were built at the Atlas facility to conduct a series of natural convection tests, one is 25 percent and the other is 44 percent of repository scale. Data from these tests will be used to validate a computational fluid dynamics computer code that predicts natural convection and other heat transfer phenomena for use in performance assessment and facility design. Four tests were conducted during the reporting period: two in each test cell. Observations made to date confirm the validity of the computer models.

During the reporting period, the second thermal conductivity field test in the Tptpll was conducted in the ECRB Cross Drift at low heater power. The maximum rock temperatures were maintained below approximately 50°C at saturation conditions consistent with the undisturbed rock mass. These field thermal conductivity measurements include the effects of lithophysae too large to be included in laboratory samples. Initial results from the thermal conductivity field-test program (approximately 1.6 to 1.7 W/m K) are consistent with the thermal conductivity (1.75 W/m K) used in Volume 1 of the *FY01 Supplemental Science and Performance Analyses*. Laboratory thermal conductivity tests were also conducted on rock matrix specimens from the Tptpll. The measured values range between approximately 0.9 W/m K and 2.2 W/m K.

1.2.8 Disruptive Events

A literature study of buried basaltic volcanic centers concluded that basalts that erupted near Yucca Mountain are typical of basalts of similar age from the western Great Basin and generally originated as magma generated by partial melting of the upper mantle. Accordingly, volcanism could be expected to decrease over time as local magma reservoirs become depleted and the zone of melting is pushed to greater mantle depths with a cooling lithosphere. This conclusion is consistent with apparently waning volcanism deduced from field studies.

Geotechnical data obtained from drilling and testing of the geologic structure under the current gravel pad at the site, is summarized in analysis model report (AMR) *Geotechnical Data for a Potential Waste Handling Building and for Ground Motion Analyses for the Yucca Mountain Site Characterization Project.*

1.3 DESIGN AND CONSTRUCTION

During this reporting period, the Project continued to develop repository design requirements, test the waste form and waste package (WP) materials, evolve the WP design, evolve the surface and subsurface repository designs, and construct sites for testing activities in the ESF. Details of the advances in these areas are described in Sections 4.1 through 4.8.

1.3.1 Design Requirements

The Project continued to develop and revise the *Monitored Geologic Repository Project Description Document* and *Yucca Mountain Site Characterization Project Requirements Document*.

1.3.2 Waste Form Testing

Eight waste form calculations and AMRs were issued during this reporting period (see Section 4.2).

Tests involving humid air exposure of two samples of perforated commercial spent fuel rods showed that the cladding on both samples unzipped at a rate faster than the rates used in the *Yucca Mountain Science and Engineering Report*. The observed rate of unzipping was consistent with the upper bound value used in Volume 1 of *FY01 Supplemental Science and Performance Analyses*. A more conservative unzipping model is being developed for incorporation into the next revision of the cladding degradation AMR, *Clad Degradation – Summary and Abstraction*.

1.3.3 Waste Package Materials Testing

The materials testing effort is continuing to generate data and analyses relevant to the performance of the WP and drip shield materials under expected Yucca Mountain repository conditions. These include determination of credible environments expected in the repository and measurement of critical potentials for localized corrosion initiation and propagation. In addition, work continues on monitoring stress corrosion crack propagation in highly stressed and pre-cracked compact tension test specimens. Results substantiate earlier findings that it is extremely difficult to crack Alloy 22 (UNS N06022) in any of the relevant repository environments.

1.3.4 Waste Package Design

Thirteen engineering drawings were prepared for the SR baseline. Three WP design reports and two calculations were completed during this reporting period (see Section 4.4).

1.3.5 Repository Design

A set of baseline drawings was completed during this reporting period to reflect the major surface and subsurface system concepts developed for the Site Recommendation (SR). A Project Design Criteria document that will contain codes and standards, laws, regulations, and general design criteria to be used for the design of the surface and subsurface structures, systems, and components (SSCs) is in preparation. The repository systems architecture was redefined and consolidated along discipline lines and task subgroups in order to be compatible with a system designation methodology better suited to LA design.

This architecture allows related systems to be consolidated into one system that accomplishes a major Project function.

A series of design evolution studies were initiated to reevaluate surface and subsurface repository design concepts and to recommend options for further study. The purpose of these studies was to identify areas for process improvements using the value engineering methodology.

1.3.6 Repository Surface Facilities Design

During this reporting period, work on the surface facility design focused on supporting the evolution studies for waste emplacement, a waste handling facility, and aging options. The proposed options developed from these studies were to modularize the construction and operation of the waste handling facilities by utilizing multiple task-oriented buildings, rather than a single multi-purpose waste handling building, and to further evaluate an omni-directional transporter for moving WPs from the surface facility to the subsurface emplacement drift.

1.3.7 Repository Subsurface Facilities Design

During this reporting period, work on the subsurface facilities design focused on the reevaluation of the subsurface repository design concepts. The *Design Evolution Study–In-Drift Configuration* recommended continuing with the SR design, which utilized a circular drift cross-section with a steel drift invert, and further evaluation of a ground support system that utilizes rockbolts and heavy-duty wire mesh. The *Design Evolution Study–Underground Layout* defined a layout area suitable for a repository that would meet performance requirements for long-term waste isolation and would be compatible with design configuration requirements. The study also identified an optional repository layout for further evaluation to allow a modular construction approach. This approach would reduce the size of the emplacement panels thereby reducing the excavation time necessary to establish emplacement areas and would provide greater flexibility in meeting changeable waste receipt and thermal loading goals.

1.3.8 Exploratory Studies Facilities and Construction

Operations and maintenance of the ESF were provided throughout the repository period in support of the continuing testing activities. The Busted Butte Transport Field Test Facility has completed its planned scientific experiments and has been placed in temporary shut down. Design and construction for the ECRB Hydrologic Bulkhead Study was completed. Modifications to the ESF Switchgear Building were suspended in February 2002. Installation of a one-million-gallon non-potable water tank and a fifty-thousand-gallon potable water tank was completed in February 2002. Designs for the Mine Power Center Niches and ECRB Refuge Chambers were completed during this period. Preparation for excavation of Alcove #10 will take place during the remainder of FY 2002.

1.4 REPOSITORY PERFORMANCE

During this reporting period, the Project accomplished several advances in preclosure radiological safety assessment, postclosure performance assessment, and performance confirmation. These advances are described fully in the Sections 5.1, 5.2, and 5.3, respectively.

1.4.1 Preclosure Safety Analysis

The *Design Basis Frequency and Dose Calculation for Site Recommendation* was revised to update an assumption concerning ingestion doses and to support the *Preliminary Preclosure Safety Assessment for Monitored Geologic Repository Site Recommendation*. This safety assessment work includes the

identification of facility hazards and their potential for initiating events, identification of design basis events, evaluation of design basis event occurrence frequencies and consequences, and the identification of those SSCs important to safety. This report also provides the repository strategies for criticality safety, radiation protection, and fire protection, along with the provisions for the control and management of low-level radioactive waste.

During this reporting period, the initial version of *Preclosure Safety Analysis Guide* was completed. This guide combines elements of probabilistic risk assessment and deterministic analyses that comprise a risk-informed performance-based safety analysis. The guide was written to provide guidance for developing and documenting the Preclosure Safety Analysis that will support the LA. The Preclosure Safety Analysis will address the safety of the repository operations area during the preclosure period and compliance with the performance objectives of 10 CFR 63. In addition, AP-2.22Q, *Classification Criteria and Maintenance of the Monitored Geologic Repository Q-List*, was issued to provide risk-informed criteria for identifying SSCs important to safety.

1.4.2 Postclosure Performance Assessment

During this reporting period, *Uncertainty Analyses and Strategy* was developed and issued. This report summarizes uncertainties contained in technical documents supporting the *Total System Performance Assessment for the Site Recommendation* and *FY01 Supplemental Science and Performance Analyses*, and provides a strategy for future treatment and communication of uncertainties.

The *TSPA-SR Errata Analyses* was also issued. This letter report presented an evaluation and impact analysis of documented errata for the performance results of the Total System Performance Assessment for the Site Recommendation (TSPA-SR) model, as identified through internal review and NRC review.

A KTI letter report, *Effect of Forced Ventilation on Thermal-Hydrologic Conditions in the Engineered Barrier System and Near Field Environment*, was prepared and issued. It addressed KTI agreements RDTME 3.01, RDTME 3.14, and TEF 2.07.

The AMRs and calculations that were completed or updated during this reporting period are identified in Section 5.2.3.

The major UZ flow and transport developments presented in the *Unsaturated Zone Patterns and Analysis* include site-scale flow processes above the repository, drift-scale seepage, radionuclide release into the drift shadow zone, and radionuclide transport below the repository (see Section 5.2.4 for details).

Various saturated zone (SZ) flow and transport technical issues have been addressed or are in the process of being addressed with field and laboratory investigations. These investigations and the resulting data have been analyzed and are reported in Project documents, journal articles, reports, and presentations (see Section 5.2.5).

The technical work continued on the flow model validations for the SZ site-scale model based on new hydrostratigraphy, new water-level data, and new fluxes from the regional flow model.

An impact review was conducted of biosphere-related information developed after publication of the *Yucca Mountain Science and Engineering Report* and the *Yucca Mountain Site Suitability Evaluation*. The findings focused on revised dietary and lifestyle characteristics of the dose receptor and on an alternative dosimetric model of the dose receptor. The results of this impact review were included in the *Technical Update Impact Letter Report*.

1.4.3 Performance Confirmation

During this reporting period, the *Monitored Geologic Repository Test & Evaluation Plan* and *Performance Confirmation Plan* were updated to reflect Project requirements, the evolution of the design concept, and the finalization of 10 CFR 63 and 40 CFR 197.

SECTION 2 – PROGRESS TOWARD NEAR-TERM OBJECTIVES

During this reporting period, Project activities continued to support major near-term objectives that enabled the Secretary of Energy to determine that Yucca Mountain would be recommended as the site of a geologic repository. Before deciding to recommend the site to the President, the Secretary considered the information presented in the SR decision materials prepared by the Office of Civilian Radioactive Waste Management, including the comments received during public hearings and as part of the public involvement process. The activities related to the Secretary's site recommendation are discussed in Section 2.1.

Work also continued on those activities related to preparation of the Final EIS ([155970][3] DOE 2002), including the provision of opportunities for public involvement. In accordance with the NWPA, as amended [101681], the Final EIS was included as part of the comprehensive statement of the basis for the Secretary's site recommendation. These activities are discussed in Section 2.2.

Project personnel continued meeting with regulators, and progress was made in finalizing the regulatory framework and evolving the Yucca Mountain Licensing Strategy. These activities are discussed in Section 2.3. Information regarding issue resolution, elimination of planned studies, decision points reached, and modifications to schedules are contained in Sections 2.4 through 2.7, respectively.

2.1 SITE RECOMMENDATION

The Secretary of Energy determined that the Yucca Mountain site is suitable to serve as a nuclear waste repository and forwarded a recommendation regarding the siting of a proposed repository to the President. To support the site recommendation process, a suite of documents providing information required by law was prepared and submitted. These documents included:

Revision 1 of the *Yucca Mountain Science and Engineering Report* ([155943] DOE 2002). This report contains a description of a repository at Yucca Mountain, including preliminary engineering specifications, a description of the waste form and packaging, a discussion of the data obtained from site characterization activities relating to the safety of the site, and a description of the analyses performed to evaluate the safety of the proposed repository. This report provides the information required by the NWPA, as amended, Section 114(a)(1)(A-C) [101681].

Yucca Mountain Site Suitability Evaluation ([156958] DOE 2002). This report includes an evaluation of the Yucca Mountain site's performance against the DOE's site suitability guidelines ([157934] 10 CFR 963).

Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada ([155970] DOE 2002), per the NWPA, as amended, Section 114(a)(1)(D).

Site Recommendation Comment Summary Document ([157080] DOE 2002) and *Supplemental Site Recommendation Comment Summary Document* ([157724] DOE 2002). These documents include a delineation of the views and comments of the governor and legislature of any state or the governing body of any affected Native American tribe, together with the Secretary of Energy's response to such views and comments, as required by the NWPA, as amended, Section 114(a)(1)(F). In addition, these

[3] References are cited in text by DIRS (Document Input Reference System) number and numerically sorted by DIRS number in each subsection of the reference list. The unique DIRS number is placed in the text before the author-date callout (e.g., ([155950] CRWMS M&O 2000).

documents present the comments received from members of the U.S. Senate and House of Representatives; elected officials of the State of Nevada and Inyo County, California, and local elected officials; representatives of Native American tribes; and members of the general public. Individual responses were provided to the comments received from government entities and summary responses were provided for comments received from members of the general public:

- A letter from the NRC entitled "Preliminary Comments Regarding a Possible Geologic Repository at Yucca Mountain, Nevada" ([156977] Meserve 2001). This letter (commonly referred to as the NRC Sufficiency Letter) addresses the extent to which the DOE's at-depth characterization analysis and waste form proposal for Yucca Mountain appear to be sufficient for inclusion in any application to be submitted by the Secretary of Energy for licensing of the Yucca Mountain site as a nuclear waste repository. The document provides the information required by the NWPA, as amended, per Section 114(a)(1)(E) [101681].

- Other documents as deemed appropriate by the Secretary, such as updates to the *Analysis of the Total System Life Cycle Cost of the Civilian Radioactive Waste Management Program* ([153255] DOE 2001) and *Nuclear Waste Fund Fee Adequacy: An Assessment* ([153257] DOE 2001).

During this reporting period, several significant events occurred related to the SR process. These included:

- DOE continued the previously announced public hearings that were held in the vicinity of the Yucca Mountain site and throughout the State of Nevada (and Inyo County, California) to receive comments regarding the possible recommendation of the site by the Secretary of Energy. These hearings were held and elicited a substantial number of comments from interested members of the public. Although the SR comment period closed on October 19, 2001, the DOE continued to accept and address comments received through October 31, 2001. Approximately 15,000 comments were received during the comment period and responses to these comments were developed for inclusion in *Site Recommendation Comment Summary Document* ([157080] DOE 2002).

- DOE issued the following three reports in early November 2001:

  – *Total System Performance Assessment–Analyses for Disposal of Commercial and DOE Waste Inventories at Yucca Mountain–Input to Final Environmental Impact Statement and Site Suitability Evaluation* ([157307] Williams 2001)

  – *Total System Performance Assessment Sensitivity Analysis for Final Nuclear Regulatory Commission Regulations* ([156743] Williams 2001)

  – *Technical Update Impact Letter Report* ([157151] BSC 2001).

  Following the issuance of these reports, the Secretary announced a supplemental comment period from November 14, 2001, through December 14, 2001. This enabled members of the public to provide comments on these reports, which addressed the impact of recently issued NRC and DOE regulations regarding the Yucca Mountain site. The result of this supplemental comment period was the receipt of approximately 2,500 additional comments, the responses to which were provided in *Supplemental Site Recommendation Comment Summary Document* ([157724] DOE 2002).

- By late December, draft copies of each of the SR documents cited above had been forwarded to the Secretary for his review. On January 10, 2002, the Secretary notified the Governor of the State of Nevada of his intention to recommend the Yucca Mountain site to the President. This action initiated a 30-day period mandated by the NWPA, as amended, before a formal recommendation to the President could be submitted.

- On February 14, 2002, the Secretary forwarded his recommendation of the Yucca Mountain site to the President. Section 6 (Epilogue) of this report explains that on February 15, 2002, the President forwarded his recommendation of the site to Congress. On April 8, 2002, Governor Kenny Guinn of Nevada issued a notice of disapproval of the Yucca Mountain site to Congress. On May 8, 2002, the U.S. House of Representatives passed a resolution of approval of the Yucca Mountain site, approving it for development of a nuclear waste repository. On July 9, 2002, the U.S. Senate passed a resolution of approval of the Yucca Mountain site for development of a nuclear waste repository. On July 23, 2002, the President signed the joint resolution for development of a nuclear waste repository into law, completing the formal designation of the Yucca Mountain site, per section 115(c) of the NWPA, as amended.

- On February 6, 2002, the State of Nevada submitted an impact assessment report ([158452] Nevada Agency for Nuclear Projects 2002) delineating those aspects of the DOE's proposed action that the state feels would be inimical to the interests of the state. This report was reviewed and evaluated by the DOE. No new overarching issues were found that DOE has not already considered and addressed in the *Site Recommendation Comment Summary Document* ([157080] DOE 2002). The state's analyses did not contain any new information or insights that would materially change the technical basis for the Secretary's site recommendation.

2.2 ENVIRONMENTAL IMPACT STATEMENT

DOE issued the Final EIS ([155970] DOE 2002), which demonstrated that during the 10,000 years after closure the repository is not expected to cause radiation exposure to the public beyond those prescribed radiation standard exposure and activity concentration limits in 40 CFR 197 [155238] and 10 CFR 63 [156605]. The Final EIS concluded that a repository at Yucca Mountain would cause small, short-term public health impacts due primarily to the transportation of SNF and HLW from the existing commercial and DOE sites to the repository. As a result of the conclusions in the Final EIS, the DOE has identified the following proposed actions as the preferred alternative: construct, operate, monitor, and eventually close a geologic repository for the disposal of SNF and HLW at Yucca Mountain. In addition, the DOE has identified rail as its preferred mode of transportation, both nationally and in the State of Nevada.

The Final EIS is based on the *Draft Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada* (Draft EIS) ([105155] DOE 1999) and the *Supplement to the Draft Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada* ([152985] DOE 2001). The Final EIS incorporates analyses that evaluated the higher- and lower-temperature operating modes of the flexible repository design and the resultant environmental impacts. A number of those that commented on these two

documents requested that the DOE make changes, and the DOE did so where appropriate. However, some suggested changes were inappropriate because they would have introduced errors or because they were not germane to the proposed action. The following list highlights the major areas of change incorporated into the Final EIS versus the Draft EIS:

- More information regarding potential impacts, particularly impacts associated with transportation of SNF and HLW within Nevada
- Use of a "representative" fuel assembly in the accident analysis
- Use of updated population data and other data in the impact analyses
- Use of updated versions of computer models for assessing human health and transportation impacts
- A more detailed discussion of the issue of potential impacts associated with negative perceptions about the repository project
- Corrections or editorial changes for accuracy and clarity
- Addition of an appendix that contains general information about transportation of radioactive materials not specifically used in the analysis, but provided for public information
- Addition of the U.S. Fish and Wildlife Service Biological Opinion as an appendix
- Addition of a Readers Guide to help readers understand the Final EIS.

2.3 REGULATORY FRAMEWORK, INTERACTIONS, AND STRATEGY

2.3.1 Status of the Regulatory Framework

The Energy Policy Act of 1992 [100017] signaled a broad shift from a generic to a site-specific regulatory framework for evaluation of and decision-making about a proposed repository at Yucca Mountain. The remaining site-specific regulatory framework essential to determining the suitability of the Yucca Mountain site for development as a repository was finalized during this reporting period. The following regulations form the regulatory framework that protects both public health and safety and the environment:

- EPA final rule 40 CFR 197, Public Health and Environmental Radiation Protection Standards for Yucca Mountain, Nevada [155238], became effective on July 13, 2001.
- The NRC final rule 10 CFR 63, Disposal of High-Level Radioactive Waste in a Geologic Repository at Yucca Mountain, Nevada [156605], became effective on December 3, 2001.
- The DOE final rule 10 CFR 963, Yucca Mountain Site Suitability Guidelines [157934], became effective on December 14, 2001.

The NRC issued a "For Comment" draft of Revision 2 of the *Yucca Mountain Review Plan* ([158449] CNWRA 2002). Revision 2 is consistent with the NRC and the EPA final regulations applicable to Yucca Mountain and provides the guidance needed to evaluate an LA for a geologic repository.

The DOE continues to play an active role in implementing the Licensing Support Network Rule found in 10 CFR 2, Subpart J [103537]. The Licensing Support Network is a web-based system that makes documentary material available electronically to the public and to participants in any proceedings associated with an application for a construction authorization for a geologic repository. Work continues to focus on the Project's implementation strategy and plans for development of the electronic system and procedures to ensure compliance with Subpart J.

2.3.2 Regulatory Interactions

The purpose of the DOE-NRC pre-licensing interactions is to allow the complex technical issues present at a proposed geologic repository site to be addressed early so that potential health and safety issues are identified and can receive the attention they deserve. The NRC considers KTIs important to evaluating performance of a proposed repository at Yucca Mountain.

The NRC staff maintains a list of 10 KTIs and their sub-issues, importance to repository performance, acceptance criteria, and resolution status. The DOE holds meetings and technical exchanges with the NRC to advance the issue resolution process. A series of meetings related to the KTIs, the NRC sufficiency review, and the DOE SR decision have been conducted since August 2000. These meetings have resulted in 293 agreements between DOE and NRC that describe the additional work that the DOE will complete during the pre-licensing period to advance resolution of the KTIs. Meetings between DOE and the NRC to discuss and review the progress in resolving the KTIs will continue throughout the pre-licensing period.

The DOE interactions with the NRC continue to focus on the KTIs and on the associated issue resolution status reports that provide a framework for addressing and resolving the KTIs. Issues are closed if the DOE approach and available information acceptably address NRC questions such that no information beyond what is currently available will likely be required for regulatory decision-making at the time of the initial LA. Issues are considered to be "closed-pending" if the NRC has confidence that the DOE proposed approach, together with the DOE agreement to provide the NRC with additional information (through specified testing, analysis, etc.), acceptably addresses the NRC's questions such that no information beyond that provided or agreed to will likely be required at the time of the initial LA. Issues are "open" if the NRC has identified questions regarding the DOE approach or information, and the DOE has not yet acceptably addressed the questions or agreed to provide the necessary additional information in the LA. The DOE and the NRC have continued to interact on KTIs, including topics such as features, events, and processes (FEPs) screening; igneous activity; preclosure safety; total system performance assessment (TSPA); repository thermal management; and a range of repository operating temperatures. The resolution status of the KTIs is discussed in Section 2.3.3. Interactions will continue to be held to update the NRC on new information that relates to the KTIs and to discuss the information being developed in response to the individual KTI agreements.

The Project continues to apply substantial resources to addressing crosscutting quality assurance (QA) issues. Necessary changes will be made at all levels of the program to ensure that important QA issues are expeditiously resolved and that actions are taken to prevent recurrence of significant QA problems.

The Project has committed to the creation and maintenance of a nuclear safety culture and rigorous compliance with QA procedures, two key elements necessary for successful licensing and safe operation of the repository. Improved implementation of quality affecting processes used on the Project is expected to result in a culture of adherence to procedures and in a continuous improvement of the procedures. Activities are currently being performed in a quality manner; however, these positive quality changes should result in the improved collection and management of data; improved software qualification; and more transparent (defensible) analysis methods, models, and calculations. The importance of sound

quality processes and effective implementation of those processes is being emphasized throughout the Project by all management levels within DOE and its contractors.

The status and progress of the QA program and related activities are reported to the NRC on a periodic basis in other forums. The DOE keeps the NRC informed via quarterly QA Management Meetings, semi-annual quality trend reports, submittal of its audit reports, submittal of reports of conditions adverse to quality, and via the NRC On-Site Representative's monthly report of Project activities.

Additional interactions with the NRC included QA and management meetings with the NRC, which were held in December 2001. Interactions with the Advisory Committee on Nuclear Waste continued to provide the status of Project activities and address issues raised by the Committee. The meetings provided multiple opportunities for the DOE to explain the bases for Project positions and decisions and to gain greater understanding of the Committee’s concerns.

2.3.3 Issue Resolution

The DOE and the NRC held additional interactions during this reporting period on topics pertaining to the NRC KTIs. These interactions have resulted in identifying or clarifying agreements that must be met to close the “closed-pending” issues. Fifty-nine KTI agreements have a “closed” status, and 234 have a “closed-pending” status. By the end of the reporting period, the DOE had submitted additional information to the NRC to meet 40 of 293 individual KTI agreements.

As part of the work prioritization and planning to identify the scope of work needed to support an LA submittal in December 2004, a re-evaluation of the scope of work necessary to provide a basis for disposition of each of the KTI agreements was performed. The re-evaluation focused on the complete inventory of KTI agreements to ensure that the work plans include all the work necessary to disposition each item prior to the submittal of the LA. A firm schedule for delivery of KTI agreements was established for FY 2002 and will serve as the basis for developing a detailed schedule for delivery of the agreements in FY 2003-2004.

The prioritization process involved a comprehensive evaluation of each of the 293 KTI agreements. Each item was evaluated and binned (i.e., grouped) according to regulatory basis, planned disposition method (consistent with the regulatory requirements of 10 CFR 63 [156605]), completion milestone, and work scope necessary to develop the basis for disposition with the NRC. Once the regulatory basis was determined, a method for dispositioning the KTI agreements was proposed based on the requirements of the final 10 CFR 63. As allowed for in the NRC regulations, a number of KTI agreements are planned to be dispositioned consistent with the risk-informed performance-based requirements of the final regulation.

During this reporting period, the Project provided the NRC with eight responses to KTI agreement items, and the NRC closed four KTI agreement items.

2.3.4 Yucca Mountain Licensing Strategy

A key consideration for an SR and for NRC licensing decisions for a geologic repository at Yucca Mountain is the ability of the site to protect the public from any undue risk during repository operations and after its permanent closure. The DOE is preparing preclosure and postclosure safety analyses for the repository system, as well as a Yucca Mountain Licensing Strategy. The purposes of the licensing strategy are:

- Identifies the strategy, processes, mechanics, guidelines, and documentation approach for developing an LA
- Describes the concepts, philosophy, overall approach, and methods (i.e., the safety strategy) that will be used to develop and present the Yucca Mountain repository safety analyses for demonstrating compliance with preclosure and postclosure performance objectives and requirements
- Serves as a common source for the Project position on strategic licensing issues
- Provides guidance regarding the framework within which requirements are identified and implementing details are developed
- Focuses the work that is necessary to develop and submit an LA, resolve licensing issues, and receive a license
- Defines the licensing roles and responsibilities between DOE, the Management and Operating Contractor, and other affected Project entities, and outlines the approach for interactions with the NRC
- Discusses the need for and approach to communications with oversight organizations and the public, including the potential use of the Licensing Strategy as a communications tool
- Provides a glossary of regulatory terms for consistent use in the licensing context.

2.4 NUCLEAR WASTE TECHNICAL REVIEW BOARD INTERACTIONS

During this reporting period, interactions with the NWTRB provided an opportunity to update the NWTRB on technical aspects of the Project and for the NWTRB to provide recommendations to the DOE on the results of the DOE's scientific and engineering investigations. These interactions continued to focus on the NWTRB's four priority areas:

- Meaningful quantification of conservatisms and uncertainties in the DOE's performance assessments.
- Progress in understanding the underlying fundamental processes involved in predicting the rate of WP corrosion.
- An evaluation and comparison of the base-case repository design with a low-temperature design.
- Development of multiple lines of evidence to support the safety analysis of the proposed repository. These lines of evidence should be derived independently of performance assessment and, thus, are not subject to the limitations of performance assessment.

In October 2001, the NWTRB provided comments on the September 2001 Board meeting for DOE consideration ([158444] Cohon 2001). The following specific gaps were noted in the DOE's evaluation of the Board's priority areas:

- Incomplete comparison of high- and low-temperature repository designs
- Questions about the contributions of natural and engineered barriers
- A lack of rationale for going forward with SR in the face of unresolved technical issues, such as igneous consequence models and the source of water in the bulk-headed section of the ECRB Cross Drift.

A full Board meeting was held in January 2002 to discuss ongoing scientific investigations and regulatory evaluations of the Yucca Mountain site. Discussion topics included the regulatory framework for SR, scientific updates on fluid inclusion studies, ^{36}Cl studies, and UZ and SZ modeling. The DOE also provided updates on scientific and materials testing. Representatives of Nye County discussed the status of the Early Warning Drilling Program at the Yucca Mountain site. Representatives of the U.S. Geological Survey (USGS), the Advisory Committee on Nuclear Waste, and Clark County discussed their reviews of the DOE's technical basis for SR.

In January 2002 the Board issued a letter report to Congress and the Secretary of Energy, commenting on the DOE's technical and scientific work related to a decision on an SR ([158453] NWTRB 2002). The Board stated that DOE's technical basis for repository performance estimates is weak to moderate, noting that gaps in data and basic understanding create important uncertainties in the concepts and assumptions on which the estimates of system performance are based. They recommended that the DOE continue vigorous and well-integrated scientific investigations to increase its fundamental understanding of the potential behavior of the repository system following designation of the Yucca Mountain site. In closing, the NWTRB reiterated their four priority areas of concern (shown on page 2-7). They also recommended that the DOE could strengthen their arguments on how multiple barriers in the repository system provide defense-in-depth.

The NWTRB sent the DOE a letter commenting on the January 2002 full Board meeting ([158477] Cohon 2002). They provided three principal recommendations for the DOE's consideration if the Yucca Mountain site is designated:

- Because of existing uncertainties, a sustained commitment to continued scientific and engineering investigations is required to improve the technical basis for evaluating system performance.
- Data and analyses from this research should be assimilated into a realistic TSPA.
- The DOE needs to communicate its results more clearly and effectively to decision-makers and the public.

The DOE will take these recommendations into consideration in plans for future work, if the site is designated.

2.5 PLANNED STUDIES NO LONGER NECESSARY

During this reporting period, the studies and activities were conducted in accordance with the Project baseline scope and schedule for FY 2002. No planned studies were eliminated during the reporting period. More detail regarding how Project activities have evolved over time can be found in the latest version of the *Documentation of Program Change* ([158447] BSC 2002).

2.6 DECISION POINTS REACHED

During this reporting period, the Secretary of Energy considered the information presented in the SR materials prepared by the Office of Civilian Radioactive Waste Management, including the comments received as part of the public involvement process. On January 10, 2002, the Secretary notified the Governor of the State of Nevada of his intention to recommend the Yucca Mountain site to the President as a suitable site for a geologic repository. On February 14, 2002, the Secretary forwarded his recommendation regarding the Yucca Mountain site to the President (see Section 6).

2.7 MODIFICATIONS TO SCHEDULES

During this reporting period, plans were made to change the Program's schedule date for the submittal of an LA for a construction authorization of the repository, if the site is approved. The new recommended date for this milestone is December 2004. This date was selected following an evaluation to identify the scope of work to balance Project management risks considering the latest requirements of the NRC's 10 CFR 63 [156605], interactions with the NRC, and the budgetary constraints from Congressional appropriations.

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SECTION 3 - SITE CHARACTERIZATION

This section of the report summarizes preliminary results from ongoing geologic and scientific investigations. The final results of these investigations will be incorporated into future revisions of the appropriate AMRs.

3.1 GEOLOGIC INVESTIGATIONS

This section summarizes the progress, during this reporting period, of selected site characterization activities and other scientific investigations that support performance confirmation activities.

Geologic investigation work focused on:

- Updating model reports that support the Integrated Site Model
- Natural analogue studies to improve confidence in conceptual models
- Rockfall analysis
- Lithophysal studies
- Field investigations to map the southern expansion area south of the current proposed repository block.

Prior to this reporting period, test planning was captured in scientific notebooks, but, upon approval of AP-SIII.7Q, *Scientific Investigation Laboratory and Field Testing*, all active field testing and all new testing required a Scientific Investigation Test Plan (SITP). For geologic investigations, the following SITPs were produced:

- SITP-02-NA-001, *Scientific Investigation Test Plan for Peña Blanca and Drift Shadow Zone Natural Analog Studies* ([157538] LBNL 2002)
- SITP-02-ISM-001, *Test Plan for: TSW Fracture and Lithophysal Studies* ([158182] Bureau of Reclamation 2002)
- SITP-02-ISM-002, *Test Plan for: Geologic Mapping of Repository Footprint Southern Expansion Area and Jet Ridge* ([158184] USGS 2001).

3.1.1 Integrated Site Model

The Integrated Site Model provides a three-dimensional portrayal of site geologic features and includes the Geologic Framework Model, the Mineralogic Model, and the Rock Properties Model. During the reporting period two new models and an analysis were initiated: Thermal Conductivity of the Potential Repository Horizon, Thermal Conductivity of Non-Repository Lithostratigraphic Layers, and Thermal Conductivity Analysis of Field Thermal Tests (reports are in progress, see Appendix B).

The two new thermal conductivity model reports will apply a theoretical model of thermal conductivity that will be used to calculate bulk thermal conductivity and utilize the more abundant and more easily measured rock properties data (e.g., matrix porosity, matrix thermal conductivity, bulk density, lithophysal porosity).

3.1.2 Natural Analogues

The *Natural Analogue Synthesis Report* ([158164] BSC 2002) was completed in February 2002. The report includes quantitative and qualitative studies that contribute to the understanding of conceptual process models and aid in building confidence in models that provide input to performance assessment. This report provides updates to studies presented in Section 13 of the *Yucca Mountain Site Description* ([151945] CRWMS M&O 2000) and new examples gleaned from the literature, along with results of quantitative studies conducted specifically for the Project. The intent of the natural analogue studies was to collect as much corroborative evidence as possible from analogues to demonstrate additional understanding of processes expected to occur during the postclosure period at a proposed Yucca Mountain repository. The report focuses on key processes by providing observations and analyses of natural and anthropogenic (human-induced) systems to improve understanding and confidence in the operation of these processes under conditions similar to those that could occur in a nuclear waste repository. The process models include those that represent both engineered and natural barrier processes. Key topics for this report are:

- Analogues to emplacement drift degradation
- Waste form degradation
- WP degradation
- Degradation of other materials proposed for the engineered barrier
- Seepage into drifts
- Radionuclide flow and transport in the UZ
- SZ coupled thermal-hydrological-mechanical-chemical processes
- Potentially disruptive events
- Impacts of radionuclide release on the biosphere.

This report also documents the various applications of natural analogues to geologic repository programs, focusing primarily on the way analogues have been used by the Yucca Mountain Project. The specific analogue information needs for Project performance assessment are listed, and each of the analogues covered in the report is mapped to its use in either conceptual model development, provision of data, or model validation. In a few cases, topics are identified where the use of analogues could increase confidence in the performance assessment.

3.1.3 Geologic Field Investigations (also see Section 3.6, Disruptive Events)

Geologic Mapping–Detailed geologic mapping of the area immediately south of the central block of Yucca Mountain indicates lateral changes in the Tiva Canyon Tuff as evidenced by additional lithophysal zones not present in the central block. This suggests that the Topopah Spring Tuff also might exhibit more complex lithophysal zonation south of the central block. The area also exhibits unexpected complexity in several fault zones in that both block-bounding and intrablock faults exhibit great variability along strike, which may affect hydrologic properties.

Field geologic mapping has revealed several previously unrecognized faults in the Abandoned Wash and Dune Wash areas.

Rockfall Analysis and Lithophysal Studies–As input to rockfall analysis, the underground mapping team has begun analyzing full-periphery geologic maps of the Topopah Spring Tuff middle nonlithophysal unit in the ECRB Cross Drift (Figure 3-1). In other geologic work, collection of lithophysal panel data continued during the reporting period in support of lithophysal studies in the ECRB Cross Drift. Five-meter surveys were conducted in the ECRB Cross Drift from Station 17+60 to Station 23+50 through the Tptpll. Technical efforts concentrated on digital mapping of lithostratigraphic features

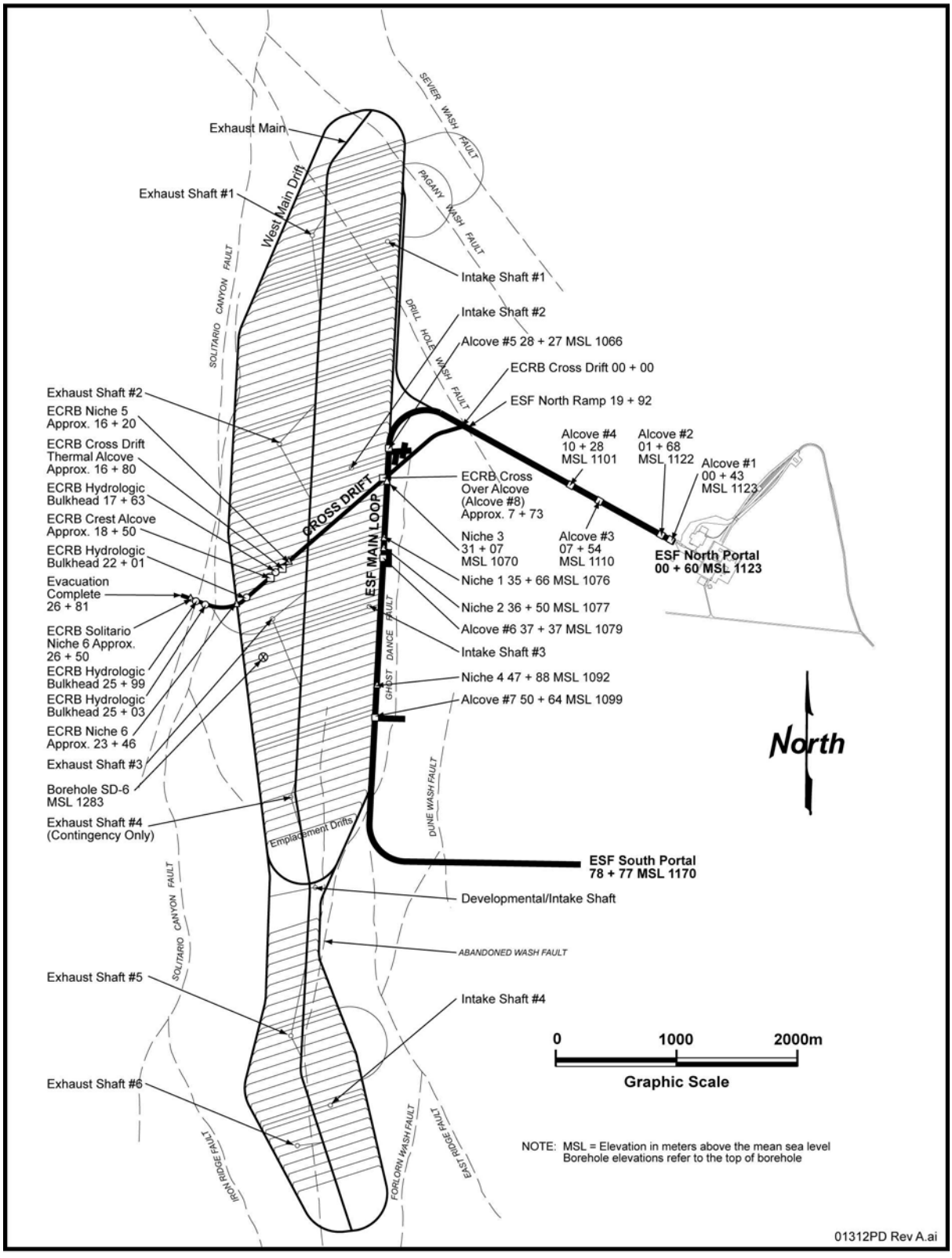

Figure 3-1. Layout of Proposed Repository Showing the ESF Main Loop, the ECRB Cross Drift, and Test Alcoves and Niches

of the Tptpll unit on panel photographs and maps. Limiting values were determined for the "abundance of features" data collected and calculated from the angular traverse data (i.e., different tunnel radii were used in calculation of length along the perimeter).

3.2 ALTERED-ZONE AND NEAR-FIELD ENVIRONMENT

3.2.1 Thermally Driven Coupled Processes

The thrust of modeling work during this period is on validating the models for the thermally driven coupled processes (thermal-hydrological, thermal-hydrological-chemical, and thermal-hydrological-mechanical) using the measurements from the in situ field test presented in Section 3.2.2. The thermal-hydrological model compares simulated temperature and time evolution of liquid saturation in matrix and fractures with the measured temperatures and geophysical and air permeability measurements that track drying and wetting in the test block. The thermal-hydrological-chemical model predicts time evolution of gas phase CO_2 concentration, liquid phase pH and chlorides, as well as mineral dissolution and precipitation. The model predictions are corroborated by the gas phase, liquid phase, and mineral petrology data. The thermal-hydrological-mechanical model predicts fracture permeability changes from the opening and closing of fractures from thermally induced stress. The model prediction is compared to the periodic air injection tests that track changes in fracture permeability.

3.2.2 Thermal Tests

Large-scale, field thermal tests are integral parts of the program to characterize Yucca Mountain. Data from thermal tests are used to validate conceptual models of coupled thermal, mechanical, hydrological, and/or chemical processes. Details of the only active large-scale thermal test can be found in the recently issued *Test Plan for: Drift Scale Test* ([158190] BSC 2002).

The Drift Scale Test completed a four-year heating phase at 10:00 AM on January 14, 2002, when the power supply to nine canister/floor heaters and fifty wing heaters was switched off. Scientists predict that it will take about one year for drift wall temperatures to fall below boiling. The drift wall temperature averaged about 205°C for the final 1.75 years of heating. Meanwhile, data acquisition continues enabling scientists to gain an understanding of cooling effects on the coupled process. Geophysical surveys conducted in boreholes were performed several times over the first three months of 2002 to capture large-scale changes in the rock saturation levels brought on by cooling. Sample collection activities and video camera observations also increased.

During October 2001, a new borehole was drilled in Alcove #5 to support the investigation of thermal-hydrological-chemical processes. The 10.1-cm diameter hole was drilled from the access/observation drift, toward and above the heated drift, for a distance of about 40 m. This borehole penetrates the boiling zone that surrounds the heated drift. Drilling a new borehole while the test was in progress offered the potential to examine all fractures encountered in a 40-m traverse of the test block. This new borehole allows a better assessment of the spatial distribution of fluid flow and mineral deposition away from the influence of pre-existing boreholes. Almost half of the core recovered was sealed in Lexan tubes and ProteCore envelopes to prevent moisture loss. The sealed core will be shipped to Denver where the USGS plans to extract pore water using an ultracentrifuge. Unsealed portions of core were examined in detail under the stereoscopic microscope. Available core was also surveyed under ultraviolet illumination to detect fluorescence of amorphous silica. Some fractures did exhibit signs of mineral deposition particularly in a zone located 20 to 22 m from the collar.

During this reporting period, water was sampled from hydrology boreholes on 12 different occasions. Some of these samples acquired from superheated (>140°C) zones within hydrological test boreholes of the Drift Scale Test show relatively high fluoride concentrations (5 to 66 ppm) and low pH (3.1 to 3.5) values. In these high-temperature regions of the rock, water is present as superheated vapor only; liquid water for sampling purposes is obtained by cooling during the sampling process. A field test was conducted in Alcove #5 to determine if the fluoride contamination in water samples was from the Teflon™ tubing, from the fluoroelastomer packer seal materials that were installed in 1997, or from the host rock. Analyses of water samples taken both before and after the introduction of fluoroelastomer materials to a previously clean zone in the Drift Scale Test demonstrate clearly that the source of the fluoride is the introduced materials. The results from the field testing were presented in a white paper sent to the DOE in December 2001 ([158134] Williams 2001). Laboratory tests were conducted to confirm the field results. Results confirm that the fluoride contamination is from the fluoroelastomer packer seal material, and not the host rock.

Rapid cooling after heater shutoff was expected to cause further scaling or loosening of rock along the surface of the heated drift. Additional observations were made with the remote camera system and from the window located on the lower left side of the bulkhead. The remote camera was employed weekly to characterize the progression of loose rock held within the welded wire mesh and to observe evidence of water dripping from the drift crown. Observations through the window were made daily with binoculars. The only significant observation was noted two days after the heaters were shut off when the remote camera failed to travel beyond the 32-m mark because a 0.5 x 0.5-m section of sagging wire mesh, filled with loose rock, contacted the rail of the remote camera.

The last major activity involved the final submittal of the heating phase data to the Technical Data Management System. This recent submittal along with previous data sets will be the topic of an analysis report titled *Thermal Testing Measurements Report* (in progress, see Appendix B).

3.3 SITE UNSATURATED ZONE FLOW AND TRANSPORT

Prior to this reporting period, test planning was captured in scientific notebooks. Since approval of AP-SIII.7Q, *Scientific Investigation Laboratory and Field Testing*, all ongoing field testing and all new testing has required an SITP. For UZ investigations the following SITPs were produced:

- SITP-02-UZ-001, *Test Plan for: Moisture Monitoring in the ECRB Bulkheaded Cross Drift* ([158187] BSC 2001)
- SITP-02-UZ-002, *Test Plan for: Niche 5 Seepage Testing* ([158200] BSC 2001)
- SITP-02-UZ-003, *Test Plan for: Alcove 8 Flow & Seepage Testing* ([157606] BSC 2002)
- SITP-02-UZ-004, *Test Plan for: Systematic Hydrological Testing in the ECRB Cross Drift* ([158202] BSC 2001)
- SITP-02-UZ-005, *Test Plan for: Chlorine-36 Validation* ([158196] USGS 2002)
- SITP-02-UZ-006, *Test Plan for the Unsaturated Zone Transport Test at Busted Butte, Nevada* ([158459] BSC 2002)
- SITP-02-UZ-007, *Test Plan for: UZ Hydrochemistry Investigations* ([158194] USGS 2002)

- SITP-02-UZ-009, *Test Plan for: Fluid Inclusions and Thermal History of Yucca Mountain* ([158203] BSC 2002)

- SITP-02-UZ-010, *Test Plan for: Moisture Monitoring Investigations and Alcove 7 Studies* ([158189] BSC 2002)

- SITP-02-UZ-011, *Test Plan for: Laboratory Sorption Investigations–UZ and SZ* ([158197] BSC 2002)

- SITP-02-UZ-015, *Test Plan for: Niche 4 Seepage Testing* ([158201] BSC 2002).

3.3.1 Enhanced Characterization of the Repository Block

Testing continued in both the ECRB Cross Drift and the ESF Main Drift. The ECRB tests included passive monitoring of in-drift moisture dynamics and systematic hydrologic characterization involving active liquid release experiments. In addition, Niche 5, located in the Tptpll, was prepared for a series of seepage tests and to assess lateral diversion of water around drift openings. A cubic meter block of rock was prepared in the ECRB Cross Drift for excavation. This block, when removed, will be used for flow and transport studies under controlled conditions. In the ESF Main Drift, relative humidity and temperature continued to be monitored, along with the seepage response to liquid releases along the fault in Alcove #8. Updates of ECRB and ESF testing activities are documented in the revision of *In Situ Field Testing of Processes* ([158463] BSC 2001).

Alcove #8/Niche 3 Test–In the drift to drift flow and transport test, water and tracers can be released in Alcove #8 of the ECRB Cross Drift, and recovered in Niche 3 accessible from the ESF Main Drift. The release of water, under ponded conditions, along the fault in Alcove #8 (Figure 3-1) (which began in early March 2001), continued largely uninterrupted through February 14, 2002. At that time, the flux of water introduced along the fault was reduced to half the flux observed under ponded conditions. During the first week of October 2001, a mix of the Li bromide and pentafluorobenzoic acids tracers was added to water being released into the fault. Changes in saturation and water potential continued to be measured in ten monitoring boreholes located along the potential flow paths in the fractured rock formation. Water that seeped into an excavated cavity below the injection zone was collected, quantified for volumes and rates, and analyzed for tracers that were released along the injection zone. The results from the tracer test show that under lower flow rates, there is more retardation of the non-conservative tracer, suggesting movement of the tracer into the rock matrix. The seepage response showed a gradual decrease in the amount of injected water that was recovered in the Niche 3 area, suggesting a system with dynamic flow paths. In this reporting period, the data collected was prepared for the Technical Data Management System and submitted as DTN: LB0204A8N3LIQR.001 [158465] and DTN: LB0204NICH3TRC.001 [158478]. Details of this test can be found in the recently issued *Test Plan for: Alcove 8 Flow & Seepage Testing* ([157606] BSC 2002).

In anticipation of conversion to the unsaturated phase of the test, four tensiometers and seven heat-dissipation probes were added to the trenches. The tensiometers were installed at depths ranging from 50 to 70 cm. In one trench, drilling for tensiometer installation disturbed flow patterns in the vicinity of the fault and caused the flow rate to increase from 25 liters per day to a rate of about 60 liters per hour. The rate subsequently dropped back into the 25 liter per day range. These observations indicate that the drillhole penetrated some barrier (such as a clay lens) or cleaned out a fracture that allowed flow to increase abruptly and then to decrease as debris again accumulated. In the three other trenches, no disruption of flow was observed during drilling to install tensiometers. Data from the tensiometers revealed that unsaturated flow conditions existed in the rock matrix even though saturated conditions were maintained in the fracture network associated with the fault. After a year of water application under

saturated conditions, the matrix remains dry in relation to the fault/fracture flow path(s) carrying the water. The conversion to unsaturated flow conditions is expected to occur in early April.

Niche Seepage Studies at Niche 5–This study is part of a series of tests performed in the ECRB Cross Drift and ESF Main Drift intended to measure hydrologic conditions, parameters, and processes leading to the moisture movement into and around an underground opening or drift. Niche 5, which is 1,650 m into the ECRB Cross Drift, is located in the Tptpll and contains a large number of lithophysae cavities ranging from a few centimeters to over a meter in diameter. During this reporting period, automated test equipment was developed to allow for remote control, operation, and monitoring for seepage experiments in Niche 5. Details of this test can be found in the recently issued *Test Plan for: Niche 5 Seepage Testing* ([158200] BSC 2001).

Systematic Hydrologic Characterization–Air-permeability and seepage tests were conducted along multiple zones in 20-m long boreholes drilled into the crown of the ECRB Cross Drift at regularly spaced intervals. The systematic approach of conducting hydrological tests at regular intervals irrespective of local features (such as abundance or scarcity of fractures) is intended as a way to gain insight into the governing flow processes in a spatially heterogeneous fractured rock. The injection and seepage collection equipment is mounted on mobile rail flatbeds. In this period, data acquired from boreholes ECRB SYSTB LA#1, #2, and #3 were submitted to the Technical Data Management System as DTN: LB0110ECRBLIQR.001 [156878], DTN: LB0110ECRBLIQR.002 [156879], DTN: LB0110ECRBLIQR.003 [156877], and DTN: LB0203ECRBLIQR.001 [158462]. Current data indicate that lithophysal cavities act as local capillary barriers and that liquid flow predominantly occurs in the fractures. Furthermore, the small amount of water that is introduced is diverted around the drift opening because of flow channeling and capillary-barrier effects. Details of this test can be found in the recently issued *Test Plan for: Systematic Hydrological Testing in the ECRB Cross Drift* ([158202] BSC 2001).

Active Fracture Model Block Excavation–An approximately 1-m scale block is to be used for validation of the Active Fracture Model and validation/confirmation of transport models, in addition to quantification of physical phenomena. The DOE has contracted with Atomic Energy of Canada, Limited, to perform the wire sawing needed for block removal. The drilling needed for the block extraction is half completed. All personnel that will be involved with block removal have been trained for ESF and ECRB access, and DOE has designed, constructed, and tested a rock support/dolly to support the block during cutting, transportation, and support during testing.

Cross Drift Bulkhead Moisture Study–The ECRB Bulkhead Studies, as described in the *Test Plan for: Moisture Monitoring in the ECRB Bulkheaded Cross Drift* ([158187] BSC 2001), are long-duration, confirmatory observations designed to detect seepage in sealed drift sections and to evaluate the drying effects of ventilation and construction activity on the underground moisture conditions. Moisture monitoring behind the bulkheads in the ECRB continued during the reporting period.

On October 1, 2001, the ECRB bulkhead doors were opened. In addition to the existing bulkhead doors, an additional bulkhead door was installed at approximately 2,200 m into the ECRB Cross Drift. Once completed, this door and the two terminal bulkhead doors (located at approximately 2,500 and 2,600 m into the ECRB Cross Drift) were closed in mid-November 2001. The final bulkhead door (located at approximately 1,763 m into the ECRB Cross Drift) was closed in December 2001. The power to the tunnel boring machine has been off since April 6, 2001, and current observations suggest that the temperature gradients between the sections defined by the bulkhead doors have been significantly reduced. Humidity is highest in the section of tunnel between the second and fourth bulkhead doors, whereas temperature measurements indicate that the terminal end of the ECRB Cross Drift and the section of tunnel between the first and second bulkhead doors are warmer than the two sections in between.

During the reporting period, temperature, relative humidity, wind-speed, and heat-dissipation data from moisture-monitoring stations in the ECRB Cross Drift were processed and reduced on a continuous basis. Temperature probes at 45-degree intervals around the circumference of the drift are being used to investigate whether the upper parts of tunnels become cooler as that area becomes wet through saturation. Through February 14, 2002, none of the nine video cameras behind the bulkheads has detected any seepage.

When the bulkheads in the ECRB Cross Drift (Figure 3-1) were opened in November and December 2001, a string of 46 sensors, consisting of thermistors, pressure transducers, and thermocouple psychrometers were installed to monitor temperature, pneumatic pressure, and humidity of the air of the ECRB Cross Drift. Seven instrument stations consisting of redundant sensors were installed as follows: behind the fourth bulkhead (26+05), in front of the fourth bulkhead (25+86), behind the third bulkhead (25+38), in front of the third bulkhead (23+50), behind the second bulkhead (22+26), in front of the second bulkhead (21+65), and behind the first bulkhead (17+98). Additional sensors were added to fill in intermediate points, especially behind the first bulkhead. In addition, a pressure transducer and thermistor were installed at the data collection rack at 17+50. Since closure of the bulkhead at Station 17+65 on December 20, 2001, temperature, relative humidity, and pneumatic-pressure data have approached steady-state values, except for the region from Stations 17+65 to 22+00, where values fluctuate, possibly from changes in barometric pressure.

Concentrations of CO_2 gas in the drift were much higher than expected, perhaps due to barometric pumping of soil gas from Solitario Canyon. Water-sampling absorbers installed behind the bulkheads prior to closure in December 2001 continued to collect minute quantities of liquid water from the walls and ceiling of the ECRB Cross Drift. Geochemical and isotopic analysis of gas and water vapor from behind the bulkheads is being conducted to help determine the source (condensation or seepage) of moisture in the ECRB Cross Drift.

Alcoves #3 and #4–Analysis of data from moisture monitoring using heat dissipation probes (for April 2000 to August 2001) in vertical boreholes in ESF Alcoves #3 and #4 (Figure 3-1), indicates that water-potential gradients in the PTn and TSw hydrogeologic units are significantly different. The Alcove #3 data indicate that water potentials in the PTn during this time period ranged from -50.8 bars to -0.3 bars, required 3 to 11 months to equilibrate, and increased with depth through most of the PTn. The Alcove #4 data indicate that water potentials in the upper TSw unit ranged from -4.3 bars to -0.7 bars, required only 1 to 3 months to equilibrate, and decreased with depth. Analysis of water-potential data through December 2001 indicates that stations located at depths greater than 2 m have stabilized. In Alcove #4 (TSw), water potential at a depth of 2.4 m has stabilized at -0.9 bar despite an annual-wave temperature fluctuation of 2.4°C. Analysis of temperature data indicates that these measured water potentials have been significantly affected by drying due to ESF ventilation because the annual temperature wave has penetrated to >14.6 m in Alcove #3 (PTn) and >10.0 m in Alcove #4 (TSw) with a three- to four-month lag.

In March 2002, water-potential monitoring in Alcoves #3 and #4 was discontinued because all of the sensors have stabilized and no additional useful information is likely to be gained. The two-year moisture monitoring program (April 2000 to February 2002) has shown that the steady-state water-potential values in the PTn range from -0.5 to -1.5 bars, which is consistent with data obtained from monitoring of surface-based boreholes.

Alcove #7–When the bulkheads in Alcove #7 (Figure 3-1) were opened in September 2001, a string of 22 sensors, consisting of thermistors, pressure transducers, and thermocouple psychrometers were installed to monitor temperature, pneumatic pressure, and humidity of the air in the alcove. Four instrument stations, consisting of redundant sensors, were installed as follows: behind the second bulkhead

(Station 01+44), in front of the second bulkhead (Station 01+26), behind the first bulkhead (Station 00+72), and in front of the first bulkhead (Station 00+57). In addition, a pressure transducer and a thermistor were installed at the entrance of the alcove in the ESF Main Drift.

Early data from the Alcove #7 monitoring string indicate that pneumatic pressure fluctuates 400 to 500 Pascals daily at all stations in response to barometric changes in the atmosphere, indicating that the bulkheads do not dampen the barometric signal. While air temperature in front of the bulkheads fluctuates by several degrees Celsius in response to ESF ventilation, temperatures behind both bulkheads show very small (0.01°C to 0.05°C) diurnal fluctuations that are totally independent of ESF ventilation. In the first month after instrumentation, relative humidity was less than 95 percent, suggesting that the thermocouple psychrometers and the air in the alcove had not yet equilibrated since opening of the bulkheads and exposure to dry, ventilated ESF air. Further analysis of pneumatic-pressure data from behind the bulkheads indicates that both daily barometric and winter-storm related pressure changes are being detected.

After four months of monitoring, temperatures stabilized at about 21.5°C, which coincides with long-term temperature data from instrumented surface-based borehole USW UZ-7a, located several tens of meters from Alcove #7. Nevertheless, abrupt temperature drops of up to 1.0°C occur when storm fronts move through southern Nevada. These temperature drops appear to be associated with the rise in atmospheric pressure after the passage of a low-pressure system, indicating a more complex gas-phase flow system at Yucca Mountain than was previously hypothesized. Consequently, temperature and pressure measured behind the bulkheads were compared to temperature and pressure data from borehole USW UZ-7a at about the same elevation. Although the data from USW UZ-7a showed similar winter-storm related pressure responses, no abrupt temperature drops were observed. This indicates that the abrupt temperature drops in Alcove #7 somehow are associated with air transport in the ESF and/or Alcove #7.

3.3.2 Field-Scale Unsaturated Zone Transport Test at Busted Butte

The Busted Butte UZ transport test is an integrated field, laboratory, and modeling effort to address uncertainties associated with the TSPA site-process models. The test is designed to address solute and colloid movement through tuff layers that underlie the proposed repository horizon. The test involved field-scale tracer injection tests, laboratory analysis of tracer samples extracted from absorbent pads collected in the field, and computational modeling to test the conceptual models being used for the Project. The UZ transport test has focused on addressing the original six test objectives:

- Quantify the effect of heterogeneities on flow and transport in unsaturated and partially saturated conditions in the Calico Hills Formation (Tac)
- Address issues relevant to fracture-matrix interactions and permeability contrast boundaries
- Understand migration behavior of colloids in fractured and unfractured areas of the Tac
- Validate transport modeling and predictions through field testing of laboratory sorption experiments in the unsaturated Tac
- Evaluate the three-dimensional site-scale flow and transport process model used in the performance assessment abstractions for an LA
- Validate scaling assumptions made when moving from lab scale to field scale and site scale.

Busted Butte Applicability–Appendix VIII of *In Situ Field Testing of Processes* ([158463] BSC 2001) presents the results of the applicability study comparing Busted Butte with the geology, mineralogy, and stratigraphy at the Yucca Mountain proposed repository block. An informal internal lithostratigraphy of the Tac devised by Moyer and Geslin ([101269] 1995, pp. 5-9) provides a useful basis for comparing the Busted Butte and Yucca Mountain rock sections. The Tac is divided into five ash-flow/air-fall tuff units plus a bedded tuff and volcaniclastic sandstone (sand grains are mostly from volcanic rocks) at the base of the formation. Moyer and Geslin ([101269] 1995, p. 5) speculated that each of the pyroclastic units may correspond to one of the five Calico Hills lava flows recognized east of Yucca Mountain. The majority of units (other than bedded tuff/sandstones) are laterally discontinuous, but pyroclastic unit 3 is present in most, and perhaps all, of the drill cores examined by Moyer and Geslin ([101269] 1995, pp. 6, 8-9).

The applicability study confirmed that the Calico Hills section exposed in the Busted Butte Transport Field Test Facility does not contain all the informal units of the formations that are present at Yucca Mountain. Given this limitation, correspondence of the Busted Butte test-facility section with unit 3 provides the best possible applicability because this is the unit of widest occurrence within the Yucca Mountain region. Unit 3 comprises at least one-third of the thickness of the Tac wherever the formation is predominantly vitric, based on the interpretations of Moyer and Geslin ([101269] 1995, p. 8). Therefore, in a lithostratigraphic sense, the Busted Butte section represents a substantial portion of the vitric Tac at Yucca Mountain. Correspondence of other rock properties, such as mineralogy or permeability, is a separate issue and not considered here.

UZ Transport Test Phase 1B–Phase 1B was a sub-meter scale tracer test in the unsaturated Topopah Springs welded tuff unit that was designed to encompass a naturally occurring fracture. The principal objective of the study was to determine the role of fractured flow in site transport through UZ tuff.

An extensive analysis of the role of fracture flow and transport in the TSw unit at Busted Butte was undertaken. Finite Element Heat and Mass Transfer software was used to model the multiphase flow and transport of tracers. The model is intended to represent the physical system as accurately as possible. It is conceptualized as a homogeneous cylinder with the fracture running vertically along the axis of the cylinder. The injection and collection boreholes are modeled as spheres along the central axis of the cylinder, each intersecting the fracture.

Modeling of Phase 1B was performed using:

- Laboratory measured average properties
- An estimate of the bromide diffusion coefficient in partially saturated media ([102010] Jury et al. 1991)
- Average injection rate and concentrations from the field test measurements.

Conclusions based on the phase 1B test are:

- The phase 1B test did not show effects of fracture flow for the given injection rate.
- Solute transport for this test can be modeled most effectively using parameters determined through laboratory experiments and a soil liquid diffusion coefficient calculated from a modified version of the Millington quirk tortuosity relationship.

- The amount of capillary suction, available porosity, and saturated permeability in the tuffs strongly influenced mass transport.

- The modeling results demonstrate that the simple combination of advective flow and diffusion are sufficient to provide a good representation of the measured field data.

Laboratory Tracer Analyses–Laboratory extractions of rock samples from the mineback and overcores were completed during January 2002. Final counts for rock sample analyses are: approximately 2,500 rock samples were collected; 1,500 were analyzed for Br, fluorobenzoic acids (FBAs), and I (iodine); and 1,200 were analyzed for metals.

Analyses of tracers extracted from absorbent pads have also been completed. Of the 18,925 absorbent pads collected from the Phase 2 test, 4,130 absorbent pads were analyzed for Br and FBAs; 3,020 were analyzed for Li; 2,340 were analyzed for I; and 940 were analyzed for Mn, Ni, Co, Ce, and Sm.

Metals Analyses–Mineback and overcore successfully demonstrate the extent of metal transport. The overcore program collected samples from borehole #20 (a high flow injector array (50 ml/min)) using a 25 x 125 cm core barrel. Overcore analyses show that FBAs and Li are relatively nonreactive on a meter scale, and the metals (Ni and Co) are reactive on a scale of centimeters. Face 7 of the Phase 2 mineback exposed borehole #20. Analysis of mineback data is consistent with the overcore data, as would be expected.

Overcore analyses demonstrated that Ni and Co moved less than 20 cm from the highest injection rate (50 ml/hr) borehole. Mineback and overcore results agree with laboratory batch sorption study prediction of metal mobility, Li>>Ni>Co, and FBA behavior assessed from both mineback and overcores is consistent with nonreactive transport.

Colloids–In the Busted Butte field study, latex microspheres were injected into the Calico Hills Tuff unit, at a steady state flow rate under partially saturated conditions. The colloid study included field and laboratory experiments on the host rock.

In the field, 280-nm and 1,000-nm latex microspheres were injected at a rate of 50 ml/hr. Colloid movement in the field was assessed from the overcores. There was no indication of colloid breakthrough on the collection absorbent pads, but colloid identification from field samples was very difficult. Crushed rock samples were collected from the overcores, below injector #3, borehole #20. Samples were qualitatively analyzed to determine if 280-nm colloids were present. Using the Automated Video Microscopic Imaging and Data Acquisition System, microspheres were distinguished from other colloidal material (e.g., clay) based on Brownian motion and size.

Qualitative analysis indicates that the microspheres traveled at least 45 cm during the field experiment. Colloid transport data were compared to the clay content determined from x-ray diffraction analysis. Results indicate that higher microsphere concentrations are located in layers with high clay content.

Laboratory colloid studies included saturated column experiments to determine if the colloids could move through the material under optimal conditions, and unsaturated three-dimensional block experiments to examine the effects of imbibition on colloid transport. The results showed that:

- Ionic strength of the tracer mix affected the percent of colloids recovered.

- Higher colloid breakthrough concentration was related to the method and duration of injection.

- There is an optimum colloid size for transport through the system that is dependent on the material properties.

- Under partially saturated conditions, the lateral transport of colloids due to imbibition affects the results in a way that cannot be captured by one-dimensional column tests.

The field experiments did not detect colloids on the absorbent pads, so a portion of the samples collected from overcores was used to determine if colloids were present in the samples. The data qualitatively indicate that the latex microspheres were able to migrate away from the injection location.

A colloid transport model based on the geometric properties of matrix material was developed as part of a particle-tracking algorithm. The match between the experimental data and the model is good.

The experiments were fit using a coordination number (z) and a factor (d). The coordination number is unique for each material type. Physically it represents the number of pathways the particle can take at each location in the porous medium, so the higher the number the faster the colloid travels through the column. A coordination number of 7.5 and 9.5 was used to fit the data. The "d" variable accounts for the colloid charge and roughness of the pore space. A value of 33 was the best fit for this data. The model is working well for matrix material on the scale of laboratory experiments, but there is a scaling issue of using the parameters fit to laboratory data in the larger scale site model. This scaling issue is currently being worked.

A simulation was also done on the field scale, which matches the qualitative data from the overcore samples. The model is an improvement over the previous colloid model used for Yucca Mountain, but could be enhanced by incorporating chemical effects, improving the theoretical basis of the model, and addressing unsaturated fracture transport.

Block Laboratory Experiments–The program to study radionuclide migration under unsaturated and saturated conditions is designed to provide experimental information on the transport behavior of radionuclides in nonwelded tuff from blocks obtained from the Busted Butte Transport Field Test Facility near Yucca Mountain. The results will be compared with the behavior observed for non-radioactive tracers during in situ experiments at the facility, and those predicted on the basis of laboratory sorption data. The experiments support the *Integrated Site Model Process Model Report* ([146988] CRWMS M&O 2000) and the environmental assessment of Yucca Mountain as a proposed repository for the disposal of HLW.

The tandem radionuclide migration experiment, through the approximately 1-m^3 block of nonwelded tuff under unsaturated conditions, continued during the reporting period. Addition of the tracer solution was started on April 12, 2001, at the two locations on the upper surface of the block. In late December, a small amount of activity was observed in some of the water eluted from the UZ block. The addition of the tracers was continued through December, January, and February 2002. At the end of February, approximately 77 liters of tracer solution had been added to each of the two locations for a total of approximately 154 liters.

The injection of radionuclide tracers at a flow rate of 10 ml/hr into the block of tuff under saturated conditions continued during the reporting period. By the end of February, 338 days had elapsed since the injection of the radionuclides was started and a total of 81 liters of solution had been injected. Minor changes made to the SZ experiment appear to have solved the problems that led to an unexpected flow path through and over the block, although small amounts of gas are being eluted with the water from the SZ block. Under saturated conditions, the geological material is retaining most of the injected ^{99}Tc and chemically reducing conditions are being maintained.

A total of 13, 1-1/2-inch (38 mm) diameter boreholes have now been drilled vertically into the trial block at various locations and the geological material from these boreholes sampled in 3-cm increments. Post-experiment radiometric analysis of the trial block continued during the reporting period. Results obtained from samples removed from the top of the block confirm that the transport of ^{60}Co was highly retarded by sorption, transport of ^{137}Cs was retarded slightly less, and transport of ^{22}Na was retarded even less. Results obtained from samples removed by coring show the front of the ^{22}Na plume and the tail of the ^{237}Np plume. This is consistent with our understanding of the sorptive and transport behavior of these radionuclides.

3.3.3 Exploratory Studies Facility Alcove and Niche Studies

^{36}Cl Validation Study–Following an agreed-upon leaching procedure developed over several months of experimentation, 29 leachate samples were prepared using crushed core from the ^{36}Cl validation boreholes and distributed to the two participating laboratories for Cl extraction and ^{36}Cl analysis. All of the samples are from the ESF Main Drift just north of the intersection with the Sundance fault, where previous analyses showed a well-defined ^{36}Cl anomaly with ^{36}Cl/Cl ratios as large as 4100 x 10^{-15}. Results from the two laboratories are in agreement, with both data sets yielding a mean ^{36}Cl/Cl ratio of 313 x 10^{-15}, which was a positive outcome of the experiment (the modern background value is about 500 x 10^{-15}). The mean value, however, is lower than assumed Holocene or Pleistocene meteoric-component values (^{36}Cl/Cl ratios in the range 500 x 10^{-15} to 900 x 10^{-15}). The lower value from the leachates could reflect a significant component of rock Cl with a ratio less than 50 x 10^{-15}, but the low Cl contents of the leachates argue against that possibility. None of the analyses completed to date show any indication of bomb-pulse ^{36}Cl within the Sundance fault zone. Among various hypotheses discussed was the observation that most of the samples yielding bomb-pulse values in the original data set were taken primarily from tunnel walls, whereas the validation samples were obtained by drilling and coring up to 12 ft into the rock mass. An exception to this is a data set reported for core from boreholes drilled from ESF Niche 1 (at Station 35+66) and analyzed in 1997. Seven of ten sub-samples of core from three boreholes yielded ^{36}Cl/Cl ratios that could be unambiguously interpreted as bomb pulse ^{36}Cl.

At an inter-participant ^{36}Cl Validation Study technical exchange meeting held January 16, 2002, in Denver, Project scientists agreed to the following path forward to attempt to resolve outstanding issues:

- Obtain Cl concentration data, if such exist, for ^{36}Cl/Cl analyses reported for the Niche 1 core to evaluate results in the “mixing space.”

- Conduct additional step leaching experiments to understand better how bomb-pulse values were obtained from samples prepared by 48-hour to 1-week leaching, when current studies argue for very short leach periods to minimize release of rock chloride.

- Check the timing of the early analyses with respect to other non-Project analyses for evaluation of possible computer-memory problems.

- Conduct in situ leaching experiments at selected ^{36}Cl validation boreholes.

- Analyze dust from the ESF and from outside the North Portal for ^{36}Cl.

- Obtain and analyze sub-samples of previously analyzed core from Niche 1 where bomb-pulse ^{36}Cl was detected.

Subsequent to the January technical exchange, the Niche 1 borehole core was located in the Area 25 Hydrologic Research Facility, returned to the Sample Management Facility for inventory, and prepared for shipment for leaching and ^{36}Cl analysis.

Origin of Secondary Calcite and Silica Deposits and Fluid Inclusions–A systematic survey was conducted of secondary-mineral occurrences on the right rib of the ECRB Cross Drift (Figure 3-1). Areas of focus were the TSw crystal poor lower lithophysal unit between bulkheads 1 and 2 (Stations 17+50 to 22+00) and the TSw upper lithophysal unit between Stations 7+50 and 10+00. Preliminary results indicate larger calcite/silica abundances in the upper of the two lithophysal units, which is consistent with predictions made for the ECRB Cross Drift in 1998 and with calcite abundances determined from USW SD-6 borehole cuttings. Lower calcite abundances in the deeper lithophysal unit may imply decreases in flux with depth in the repository block.

The U-Pb ages of sub-samples from silica layers in lithophysal cavities in the TSw indicate that many coatings formed at slow, long-term average growth rates of 1 to 5 mm/million years ([158673] Neymark et al. 2001). These data imply that the deeper parts of the UZ at Yucca Mountain maintained long-term hydrologic stability throughout periods of significant climate variations over the past 10 million years. U-Pb ages for sub-samples of silica from fractures in the TCw indicate faster depositional rates up to 23 mm/million years and the absence of deposited materials for the last 3 to 5 million years. These differences between the characteristics of the coatings for samples from the shallower and deeper parts of the UZ probably indicate that the nonwelded tuffs (PTn), located between the welded TCw and TSw, play an important role in moderating UZ flow.

More recent work involving micro-digestions of secondary opal deposits from the TSw in the ESF has revealed differences between faster pluvial (1.2 mm million/years) and slower interpluvial (0.35 mm/ million years) growth rates. The absence of recently deposited materials in the TSw indicates that mineral growth may have stopped about 5,000 years ago because fracture flow had ceased. These data are the first evidence that mineral growth rates may correlate with climate-controlled percolation flux.

3.3.4 Other Unsaturated-Zone Field Investigations

Monitoring at Surface-Based UZ Boreholes–In December 2001, the remaining deep UZ monitoring boreholes (USW NRG-7a, UE-25 UZ#4, and UE-25 UZ#5) were shut down after over six years of continuous operation. Closeout activities are continuing and include documentation of closing calibrations, reduction of data, and preparation of the final data package. All equipment that requires closing calibration was packaged and shipped to the appropriate vendor or calibration facility.

The final report on the infiltration event that occurred in Pagany Wash during the winter of 1997-1998 was published ([158511] LeCain et al. 2002). The report documents data interpretations and numerical modeling that were used to estimate infiltration during a runoff event in February 1998.

UZ Geochemistry–As part of the effort to provide updated technical findings to support the SR, new pore water geochemistry data were analyzed and interpreted. Analyses of 13 pore water samples from the welded crystal-poor member of the Topopah Spring Tuff were compared to analyses of water from well UE-25 J-13 and the mean pore water composition in the PTn. Where multiple samples of water were obtained from a single core of welded Topopah Spring Tuff, the analyses indicated significant compositional variation at the meter scale or finer. Apparently, variations in pore water composition are not erased or homogenized by molecular or mechanical dispersion. This observation, if validated by additional work, has important implications for the potential efficacy of matrix diffusion as a retardation mechanism for radionuclide transport in the UZ.

Samples of tuff from boreholes drilled into fault zones in the ESF and relatively unfractured rock of the ECRB Cross Drift have been analyzed by uranium-series isotopic methods. Both fractured and unfractured tuffs show approximately the same deficiency of ^{234}U, indicating that pore fluids are moving equally through fractured and unfractured rock ([154800] Gascoyne et al. 2002). More importantly, fractured rock appears not to be a dominant pathway for groundwater flow because both $^{234}U/^{238}U$ and $^{226}Ra/^{230}Th$ ratios are close to secular equilibrium. Overall, the U-series data suggest that fractured rock, specifically the Sundance and Drill Hole Wash faults, are not preferred flow paths for percolation through the Topopah Spring Tuff and, by implication, rapid-flow from the surface to the level of the ESF within the last 50 years is improbable.

Extraction and analyses of pore water from the core of densely welded units of the TSw from the ECRB Cross Drift and from boreholes USW SD-9 and USW NRG-7a continued during the reporting period. To date, 21 samples of crystal poor unit from the ECRB Cross Drift and four from the surface-based boreholes have been analyzed for anions and major and trace cations. In addition, 10 of the ECRB Cross Drift samples have been analyzed for $^{87}Sr/^{86}Sr$ and $^{234}U/^{238}U$ isotopes. The $^{234}U/^{238}U$ ratios increase along the ECRB Cross Drift with the largest values obtained in samples from Station 20+00, which may indicate a decrease in percolation in a southwesterly direction along the ECRB Cross Drift.

Because of previous identification of organic compounds in pore water centrifuged from ECRB Cross Drift core samples, two samples were sent to an outside laboratory for quantification of metabolic acids. Results indicate that organic acids (formic and acetic) are present in TSw pore water from the ECRB Cross Drift at low values (10 mg/L). However, propionic acid was present at about 150 mg/L, indicating that microbial activity may have produced the organic compounds.

In the ongoing geochemical delineation of UZ flow zones, 18 hand samples of Tiva Canyon and Topopah Spring Tuff were collected from representative hydrologically active (high flux) and inactive (low flux) areas for U-series disequilibrium analyses. The hydrologically active areas are represented by the Bow Ridge fault (Figure 3-1), where both elevated levels of tritium and bomb-pulse ^{36}Cl have been detected. The inactive areas are represented by unfractured rock adjacent to the Bow Ridge fault and unfractured upper and lower lithophysal zones of the TSw in the ECRB Cross Drift. Those samples will be used for initial characterization of high- and low-flux UZ areas. Initial U and Th isotope results have been obtained for several samples of the Tiva Canyon welded unit near the Bow Ridge fault and from a series of sub-samples of the Topopah Spring welded unit from deep in the ECRB Cross Drift. Although the data are preliminary and incomplete, $^{234}U/^{238}U$ activity ratios appear to vary from near secular-equilibrium values (1.0) to mildly depleted ratios (about 0.93). These results indicate that the shallow material tends to exhibit greater disequilibrium than rock from the ECRB Cross Drift. Although initial U and Th isotope results were completed, the number of analyses is insufficient (statistically) to capture potential variations in the shallow and deep UZ environments. Additional samples will be analyzed in the next several months and will be incorporated into the investigation.

Surficial carbonate–Source validation of surficial carbonate continued during the reporting period with analysis of O, C, and Sr isotope data. Data of particular interest include isotopic variations for deposits of soil calcite present at the surface in Solitario Canyon Wash at Crater Flat, and address the hydrologic source of water (groundwater or meteoric source) that deposited the calcites. Although a meteoric water source has been demonstrated for similar surface deposits, representatives of the State of Nevada have interpreted their C and O isotope data to mean that deposits in Solitario Canyon Wash have a groundwater source. Project data collected to either validate or refute the State of Nevada's interpretations are consistent with a meteoric water source of O, C, and Sr in the samples studied, and thereby contradict the groundwater source hypothesis. It is believed, however, that the profiles (trends) identified by the State of Nevada may be artifacts of a limited number of analyzed samples.

Additional insight on surficial carbonate source was provided through U-series analyses conducted on eight sub-samples of silica-rich calcrete from the USW WT-7 drill pad. The main purpose of this work was to investigate ages of those soils and to obtain estimates of the initial $^{234}U/^{238}U$ composition for comparison with other pedogenic and groundwater sources. Results indicate that soils of the USW WT-7 drill pad have had a long depositional history with gradual addition of calcite and silica throughout the Quaternary. Both young and old soil components are likely present in the same horizon or hand specimen. Therefore, comparison of materials of similar age may be very difficult without extensive dating efforts. Calculated $^{234}U/^{238}U$ initial activity ratios of the calcretes are consistent with origin from surface waters and inconsistent with a groundwater discharge source.

3.4 SITE SATURATED ZONE FLOW AND TRANSPORT

Prior to this reporting period, test planning was captured in scientific notebooks. Upon approval of AP-SIII.7Q, *Scientific Investigation Laboratory and Field Testing*, all active field testing and all new testing required SITPs. The following SITPs were produced for SZ investigations:

- SITP-02-SZ-001, *Test Plan for: Nye County EWDP Borehole Lithostratigraphy* ([158199] USGS 2001)
- SITP-02-SZ-002, *Test Plan for: Hydrologic/Hydrochemistry Studies in Cooperation with Nye County EWDP* ([158195] USGS 2002)
- SITP-02-SZ-003, *Test Plan for Alluvial Testing Complex – Single-Well, Multi-Well, and Laboratory Studies* ([158198] BSC 2002).

3.4.1 Nye County Drilling Program

Geologic support to the NC-EWDP continued during the reporting period. Ongoing revisions to subsurface lithostratigraphic interpretations of borehole NC-EWDP-18P (Figure 3-2) continued, with revisions based on both thin-section analysis and interpretation of x-ray fluorescence data derived from selected sub-samples of bit cuttings. Sub-samples of bit cuttings from borehole Borax NA-6 also were submitted for x-ray fluorescence analysis to aid interpretation of three tentatively identified tuffs. Lithostratigraphic analysis of this drillhole may prove of value for interpretation of subsurface geology in the vicinity of the NC-EWDP-12 (Figure 3-2) series of boreholes and in development of hydrostratigraphic cross sections for the NC-EWDP.

In isotopic and hydrochemical support to the NC-EWDP, “first-water” samples were collected from Nye Country Phase III boreholes NC-EWDP-10, NC-EWDP-10S, and NC-EWDP-2DB. Water samples also were collected during preliminary cross-hole tracer testing conducted at the Alluvial Testing Complex. Results of chemical and isotopic analysis will be used in investigation of hydrochronology of the Yucca Mountain flow system. Preparations for re-sampling of Phase I and Phase II boreholes continued. In closely related work on characterization of the hydrochronology of the Yucca Mountain SZ flow system, ^{14}C dating was completed for samples from five zones in borehole NC-EWDP-19IM1. Calculated ^{14}C ages for those samples range from about 19,000 years to about 15,000 years. Those ages are consistent with results from other samples from that borehole as well as from other boreholes in the area.

Possible geochemical processes were examined that might explain the absence of elevated $^{234}U/^{238}U$ activity ratios that characterize downgradient groundwater beneath Yucca Mountain. Groundwater mixing and chemical reaction models were created to examine the combined chemical and isotopic data from the CIND-R-LITE and NC-EWDP-15P boreholes as a function of mixing and chemical reactions of groundwater from upgradient areas.

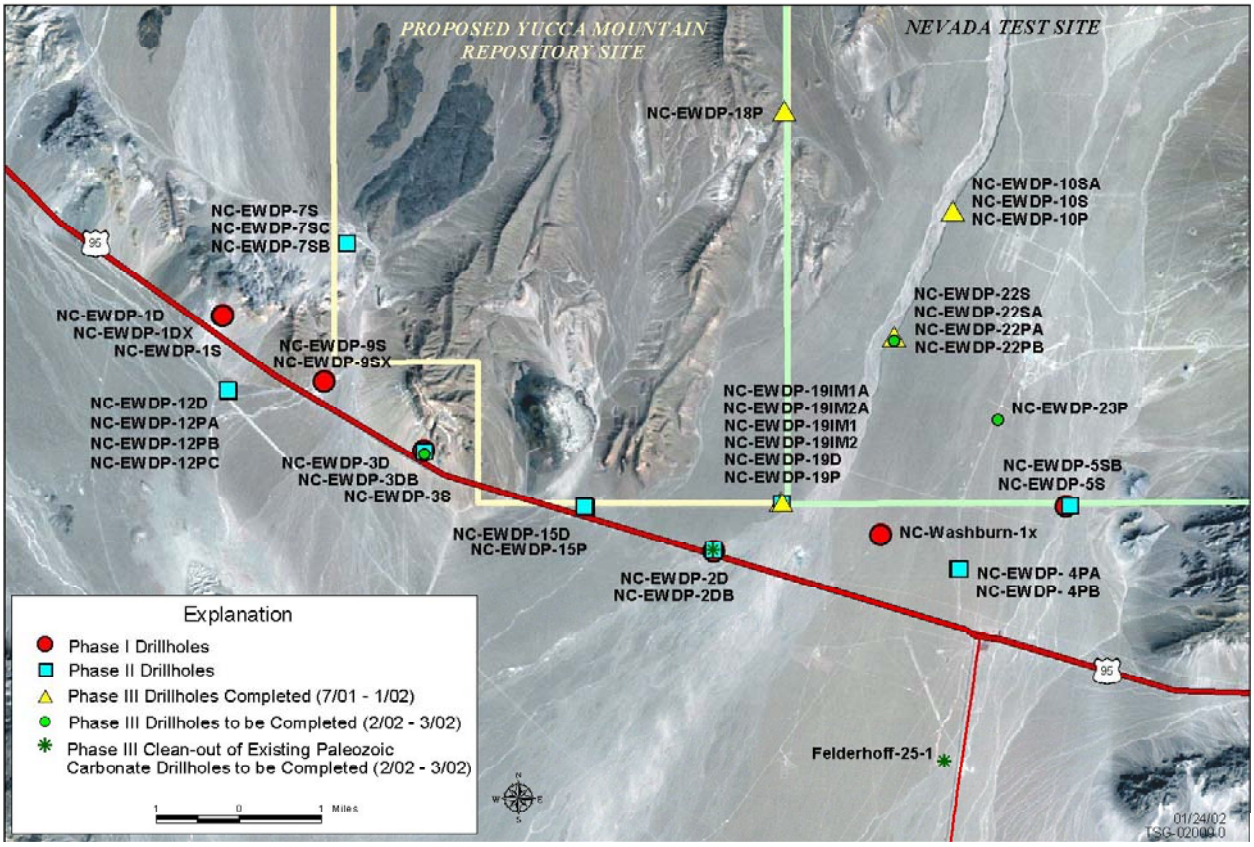

Figure 3-2. Map Showing Locations of Nye County Early Warning Drilling Program Wells

Experiments continued on colloid concentrations and size distributions, attachment and detachment rates, and sorption studies.

Eh-pH measurements were taken in all five zones containing the NC-EWDP wells. Work continued on the bases for probability distribution functions.

3.4.2 Alluvial Testing Complex

Technical activities associated with the Alluvial Testing Complex included work on the single-hole tracer testing report and planning efforts for cross-hole hydraulic and tracer testing. In December 2001, the instrument system was installed in borehole NC-EWDP-19D1 and a short-term, 48-hour hydraulic test was conducted by pumping screens located in the tuff and Tertiary sediments below the alluvium. This was the first of three "confirmatory tests" to evaluate the pumping behavior and contribution to total discharge of screened intervals prior to cross-hole tracer testing. Although instrumentation was installed in monitoring borehole NC-EWDP-19IM1, instrumentation of monitoring borehole NC-EWDP-19IM2 was postponed until after completion of the additional confirmatory tests. In January 2002, two additional 48-hour confirmatory tests were conducted and involved pumping of intervals #4 and #5 and monitoring intervals in borehole NC-EWDP-19IM1. Analysis of the three tests indicated that leakage from intervals #5, #6, and #7 into interval #4 of NC-EWDP-19D1 would amount to no more than 1 or 2 percent of the pumping rate. Consequently, plans were finalized to proceed with the original approach for cross-hole tracer testing with pumping from interval #4 and monitoring of boreholes NC-EWDP-19IM1 and NC-EWDP-19IM2.

In late January and early February, two additional hydraulic tests were conducted with well NC-EWDP-19D1 pumped in open-alluvium conditions. In the first test (48 hours), borehole NC-EWDP-IM2 was packed off to isolate specific intervals. In the second test (6 days), borehole NC-EWDP-IM2 was unpacked to allow open-alluvium response. In March, the pump-back phase of the single-hole, injection-pumpback tracer test in screen #4 of borehole NC-EWDP-19D1 was conducted for a period of two weeks. The resulting breakthrough curve, representing tracer concentration as a function of time, closely followed predicted behavior. Peak concentration reached 7.7 ppm then declined at the expected rate. Monitoring the recovery phase continued for eight days when recovery was interrupted by water injection in borehole NC-EWDP-19IM2 in shakedown trials for upcoming tracer injection and partial re-circulation in borehole NC-EWDP-IM2.

Single-well injection-withdrawal tracer testing in the alluvium at the NC-EWDP-19D1 location, supports the conclusion reported in the *Yucca Mountain Site Suitability Evaluation* ([156958] DOE 2002) that a single-porosity conceptual transport model applies to the alluvium at the NC-EWDP-19D1 location, at least in the uppermost screened interval in the well.

Both laboratory batch sorption and column transport tests have been conducted using water and alluvium material from wells NC-EWDP-19D1 and NC-EWDP-19P. K_d values for Li as a function of smectite and clinoptilolite weight percentage in the alluvium have been reported. Also, K_d values of various radionuclides of interest have been measured.

Anticipated permission for further testing was denied by the State of Nevada. In addition, the Alluvial Testing Complex water-discharge waiver was revoked under the state's interpretation of completion of site characterization with Presidential acceptance of the DOE recommendation of the Yucca Mountain site. Consequently, testing activities at the Alluvial Testing Complex are temporarily terminated, pending resolution of the water permit issue.

3.4.3 Regional Groundwater-Flow Model

In the Death Valley regional flow system modeling project, an update of the Hydrogeologic Framework Model for the Yucca Mountain region was finalized and is in preparation for publication on the Internet. The hydrogeologic framework model update uses new data and interpretations, which will result in much more consistency between the site-scale and regional groundwater flow models in terms of hydrogeologic units and geometry. Two internal, informal reports were completed, one on the status of the regional modeling database and one on the status of groundwater flow modeling. In addition, work also continued on revisions to the site-scale hydrogeologic framework model. The AMR text was revised to incorporate new geologic information primarily derived from the NC-EWDP and related geologic cross sections.

Groundwater flow modeling progressed, and updates on modeling progress were presented to management officials in both the Yucca Mountain and Nevada Test Site environmental restoration program at the Nevada Operations Office. Topics included steady-state model report status, calibrated steady-state model results, and knowledge exchange protocols for modeling activities. Data-management, process re-engineering, and model maintenance issues also were presented. Additional discussions covered incorporation of geologic data into the flow model, review of the hydrogeologic framework, flow-model tools and evaluation criteria, and flow modeling plans. Responses were compiled to the latest reviewer comments on the pre-development flow model report, and discussions were held regarding resolution of the remaining review comments. Preparations with documentation of transient flow model issues were made for upcoming stakeholder meetings. Coordination continued with the water use group in regard to development of transient-pumpage input data sets. Work on documentation of internal project review described current methodology for computation of head observations and weights for model calibration targets during pre-pumping and pumping model simulations. Details of input-

observation definitions and associated weights for transient simulations of pumping conditions were developed.

Probability distributions in the hydrogeologic units of the transient-flow model were documented in a report published on the Internet ([158458] Belcher and Elliot 2001). The report is comprised of estimates of transmissivity, hydraulic conductivity, storage coefficient, and anisotropy ratios for hydrogeologic units within the Death Valley region study area. Hydrogeologic units previously proposed for the Death Valley regional transient groundwater flow model were recognized for the purpose of studying the distribution of hydraulic properties. Analyses of regression and covariance between hydraulic conductivity and depth showed a weak, quantitatively indeterminate relation for most hydrogeologic units.

3.4.4 Other Saturated Zone Investigations

Water Level Monitoring–Revision 1 of *Water-Level Data Analysis for the Saturated Zone Site-Scale Flow and Transport Model* ([157611] USGS 2001) was completed and released for distribution. The revision includes a potentiometric surface map depicting an alternate conceptual model for the large-hydraulic gradient area north of Yucca Mountain. The alternate conceptual model assumes that water levels in wells USW G-2 and UE-25 WT#6 represent perched conditions, resulting in a hydraulic gradient that is reduced from about 0.11 to about 0.07. Potentiometric contours in southern Crater Flat and along Highway 95 also were revised based on data from the NC-EWDP Phase II. The revision includes tabulation of vertical head differences at various locations within the site-scale SZ flow and transport model area. Vertical head differences between the shallowest and deepest monitored intervals at 17 sites range from about 55 m (indicating an upward gradient) to minus 38 m (indicating a downward gradient).

3.5 ENGINEERED BARRIER SYSTEM TESTING

Engineered barrier system testing during the reporting period focused on:

- Natural convection testing to support resolution of NRC KTIs related to in-drift thermal transport phenomena
- Laboratory thermal conductivity testing of samples from the Tptpll
- Field thermal conductivity tests in the Tptpll.

All of these tests contribute to supporting predictions of heat and temperature distributions in the repository, either in the open spaces of the drift or in the host rock mass. These predictions are needed for performance assessment.

Prior to this reporting period, test planning was captured in scientific notebooks. Upon approval of AP-SIII.7Q, *Scientific Investigation Laboratory and Field Testing*, all active field testing and all new testing required an SITP. The following SITPs were prepared to cover the engineered barrier system testing:

- SITP-02-EBS-001, *Scientific Investigation Test Plan for: Ventilation Test-Phase 3* ([158191] BSC 2002)
- SITP-02-EBS-002, *Atlas Natural Convection Test Plan* ([158192] BSC 2002)
- SITP-02-EBS-003, *Test Plan for: Field Thermal Conductivity Testing*. ([158183] BSC 2002)

- SITP-02-EBS-004, *Test Plan For: Reactive Transport Column Experiments* ([158460] BSC 2002)

- SITP-02-EBS-005, *Test Plan for: Atlas Breached Waste Package Test and Drip Shield Experiments* ([158193] BSC 2002)

- SITP-02-EBS-006, *Laboratory Thermal Conductivity Testing* ([158186] BSC 2002).

3.5.1 Natural Convection Testing

The assembly of two pilot-scale test cells to facilitate the conduct of a series of natural convection tests were completed–one is built to 25 percent of repository scale and is 11-m long, and the other is built at 44 percent of repository scale and is 18-m long. Data from these tests will be used to validate a computational fluid dynamics computer code that predicts natural convection and related heat transfer phenomena for use in performance assessment and facility design. The cells are geometrically similar so that measured thermal characteristic differences as a function of scale can be discerned. Each cell can be configured with either six or seven simulated WPs and with or without drip shields. Four tests were conducted during the reporting period, two in each test cell. The first test was conducted with seven simulated WPs in each cell with a uniformly distributed thermal load along the axis of the cell. The second test conducted in each cell was configured with only six WPs spaced to give a lower thermal output along the cell length, and the power output along the WP line was non-uniform. None of these tests included drip shields. Flow visualization of thermal convection air currents were observed and recorded using small helium bubbles released into the convection streams. Observations made to date confirm the validity of the computer models that predict the effect of natural convection and related thermal transport phenomena.

3.5.2 Thermal Conductivity Field Tests in the Lower Lithophysal Unit

Thermal analyses for the repository horizon described in Volume 1 of the *FY01 Supplemental Science and Performance Analyses* ([155950] BSC 2001) were developed using thermal conductivity estimates based on temperature data collected from several thermal field tests and laboratory measurements of thermal conductivity.

During the reporting period, the second field thermal conductivity test (the first was discussed in Progress Report 25) in the Tptpll was conducted in the ECRB Cross Drift. The test employs three parallel 5-m long heaters and three parallel temperature sensor holes containing more than 90 sensors total. The test was conducted at low heater power, and maximum rock temperatures were maintained below approximately 50°C at saturation conditions consistent with the undisturbed rock mass. A second part of the test is planned where the heater power will be increased to create a dry-out zone in which thermal property measurements can be repeated.

A third thermal conductivity test in the Tptpll was also started during the reporting period. It includes a single 5-m long heater in one hole and 60 temperature sensors located in two sensor holes oriented perpendicular to the heater hole. These field thermal conductivity measurements include the effects of lithophysae too large to be included in laboratory samples. Initial results from the thermal conductivity field test program (approximately 1.6 to 1.7 W/m K) are consistent with the range of thermal conductivities used in Volume 1 of the *FY01 Supplemental Science and Performance Analyses* ([155950] BSC 2001). These analyses used a mean, lower lithophysal porosity of 12.5 percent and a saturation of 80 percent, which resulted in a model conductivity of 1.75 W/m K, close to the value measured in these field tests.

3.5.3 Thermal Conductivity Laboratory Tests from Lower Lithophysal Unit Samples

Thermal conductivity laboratory tests were conducted on rock matrix specimens from the Tptpll. The data are used to confirm thermal transport models that are applied to facility design and performance assessment calculations. Forty-nine specimens were tested dry at temperatures ranging between 30 and 250°C. Thirteen samples were tested using a transient laser flash technique and 30 were tested using the guarded heat flow meter. Six specimens were tested using a transient radial heat transfer method. The values measured range between approximately 0.9 W/m K and 2.2 W/m K. These values are consistent with previous specimens tested from this Tptpll.

Six of the specimens were tested at fully saturated conditions. The thermal conductivity for these specimens ranged between 1.6 and 2.3 W/m K. This range of values is consistent with previously measured values.

3.5.4 Column Testing

Thermal-Hydrological-Chemical tests were conducted using crushed tuff columns to provide data for geochemical model validation. This test evaluated the processes by which minerals and salts in tuff can be dissolved and redeposited in a wet environment at elevated temperature. A report that documents the findings of the test, *Engineered Barrier Systems Thermal-Hydraulic-Chemical Column Test Report* ([157900] Lowry 2001), was finished during the reporting period.

3.6 DISRUPTIVE EVENTS

Buried Basaltic Volcanic Centers–A literature study of buried basaltic volcanic centers concluded that basalts erupted near Yucca Mountain are typical of basalts of similar age from the western Great Basin and generally originated as magma generated by partial melting of the upper mantle, uncontaminated by crustal components ([158861] O'Leary 2001). Given the low rate of post-Miocene extension near Yucca Mountain (<2 mm/yr), melt generation is not likely to be influenced by decompression (decreased pressures due to tectonic motions), and given the small extrusive volumes, magma accumulation and ascent are not likely to be influenced by buoyancy. The small-volume eruptions (aligned north–northeast), apparent relatively high volatile content of extrusions, and lack of crustal contamination, or evidence of fractionation, imply that basaltic magmas ascended directly from the upper mantle source along fractures influenced by right-lateral extensional and strike-slip structural motions. A tectonic model that treats Crater Flat basin and the Amargosa trough as a graben/rift feature modified by right-lateral shear, and which accounts for dilational effects and fracturing in the upper mantle melting zone, provides a through-the-crust mechanism for basaltic intrusion, as well as structural association with observed tectonic features. Accordingly, volcanism could be expected to decrease over time as local magma reservoirs become depleted and the zone of melting is pushed to greater mantle depths with a cooling lithosphere. That conclusion is consistent with apparently waning volcanism deduced from field studies.

In another study, a high-resolution aeromagnetic survey has defined a number of small dipolar anomalies indicating the presence of magnetic bodies buried beneath the surface of Crater Flat and the Amargosa Desert ([158468] O'Leary et al. 2002). Results of potential-field modeling indicate that isolated, small-volume, highly magnetic bodies embedded within the alluvial deposits of both areas produce the anomalies. Their physical characteristics and the fact that they tend to be aligned along major structural trends provide strong support for the hypothesis that the anomalies reflect buried basaltic volcanic centers. Other, similar anomalies are identified as possible targets for further investigation. High-resolution gravity and ground-magnetic surveys, perhaps along with drilling sources of selected anomalies and radiometric age determinations, can provide valuable constraints in estimating potential volcanic hazard to the proposed nuclear waste repository at Yucca Mountain.

Seismic Monitoring–Seismic-related work consisted of four major activities:

- Validation of computer software to support calculations of seismic design input ground motions for preclosure design and postclosure performance assessment
- Processing, analyses, and documentation of the geotechnical data collected in 2000-2001 at the potential Waste Handling Building location and above the emplacement area on Yucca Mountain
- Development of preliminary ground motions for input into sensitivity analyses for rockfall
- Development of base case velocity and correlation models for the Waste Handling Building location and repository block for the seismic design input calculations.

Geotechnical data obtained from drilling and testing of the geologic structure under the current gravel pad at the site is summarized in *Geotechnical Data for a Potential Waste Handling Building and for Ground Motion Analyses for the Yucca Mountain Site Characterization Project* (in progress, see Appendix B). The Seismic Design Input team met with the Seismic Design Input Review Panel on February 28 to review the input into the ground motion calculations. Preliminary base case velocity models for the Waste Handling Building location and repository, correlation model for the Waste Handling Building location, and strain-dependent dynamic material properties were presented and discussed. The DOE is planning installation of strong motion seismic instruments at the Waste Handling Building location.

Major projected work activities for the remainder of FY 2002 include:

- Finalizing input for seismic design input calculations.
- Developing seismic design input ground motions for preclosure design and postclosure analyses. The first set of ground motions will be for an annual exceedance probability of 10^{-6} for the postclosure performance assessment of the repository.
- Having an Appendix 7 meeting with the NRC to present overviews of the 2000-2001 geotechnical site investigations, the approach to be used in development of ground motion input calculations and the postclosure seismic analyses.
- Completing *Geotechnical Data for a Potential Waste Handling Building and for Ground Motion Analyses for the Yucca Mountain Site Characterization Project* (in progress, see appendix B).

Igneous Consequences–Prior to this reporting period, test planning was captured in scientific notebooks. Upon approval of AP-SIII.7Q, *Scientific Investigation Laboratory and Field Testing*, all active field testing and all new testing required an SITP. For disruptive events field investigations *Test Plan for Ash Redistribution, Lava Morphology, and Igneous Processes Studies* ([158185] BSC 2002) was produced. In the area of igneous activity analyses, software programs will be used to implement models of magma and gas flow in drifts (CFDLIB V2.0) and the interaction of an intruding dike (NPHF2D V1.0) with the stress field established by topography, thermal effects, and the presence of drifts. These codes are currently being qualified in accordance with AP-SI.1Q, *Software Management*.

Major projected work activities for the remainder of FY 2002 include:

- Qualifying the software programs mentioned above and initiating the analyses
- Performing an evaluation of aeromagnetic data collected after completion of the Probabilistic Volcanic Hazard Assessment to determine the impact of the data on probability of intersection of a dike with the repository
- Completing field investigations of physical volcanology and ash and soil redistribution
- Validating the ASHPLUME model of ash dispersal in the atmosphere
- Developing an annotated outline for a planned document, *Roadmap to Igneous Activity Models, Analyses, and Calculations*.

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SECTION 4 – DESIGN AND CONSTRUCTION

During this reporting period, the Project continued to develop repository design requirements, evolve the surface and subsurface repository design, evolve the WP design, and construct sites for testing activities in the ESF. Advances in these areas are described in the following sections.

4.1 REQUIREMENTS

The Project continued to revise the *Yucca Mountain Site Characterization Project Requirements Document* ([154138] YMP 2001), which established the repository design requirements and supported the SR and the LA.

The Project initiated the development of the following documents that further establish requirements traceability and configuration control:

- *Project Requirements Document* (in progress, see Appendix B)
- *Project Design Criteria* (in progress, see appendix B)
- *Requirements Management Plan* (in progress, see appendix B)
- *Configuration Management Plan* (in progress, see appendix B).

4.2 WASTE FORM

The following calculation and AMRs were issued.

4.2.1 Calculations

Relative Contribution of Individual Radionuclides to Inhalation and Ingestion Dose ([153595] CRWMS M&O 2000) determined the relative importance of individual radionuclides when calculating inhalation and ingestion doses. The calculation addresses the effects of inventory abundance, radionuclide longevity, element solubility, and element transport affinity on a radionuclide's contribution to dose. The scope encompasses wastes that are between 100 and 10,000 years old. Radionuclides with half-lives less than twenty years are not considered. Average and bounding commercial SNF, defense SNF, and HLW are considered.

4.2.2 Analysis Model Reports

Miscellaneous Waste-Form FEPs ([153938] CRWMS M&O 2001) demonstrated that regulatory-specified performance objectives of proposed 10 CFR 63 [156605] could be achieved for a 10,000-year postclosure period. The Yucca Mountain Project is implementing a stochastic scenario-development methodology based on the work of Cranwell et al. ([101234] Cranwell et al. 1990). The methodology provides a systematic approach for considering, as completely as practicable, the possible future states of the proposed repository system. It seeks to span the set of all possible future states using a finite set of scenarios. Here, each scenario represents the ensemble of possible future states corresponding to parameter and model uncertainties present in the group of FEPs comprising the scenario.

Colloid-Associated Radionuclide Concentration Limits ([154071] CRWMS M&O 2001):

- As part of the FEP-identification step, summarizes the screening decisions for 86 waste form FEPs and relates them to the AMRs in which they are documented
- Shows correspondence between waste form FEPs and the sub-issues and acceptance criteria of three KTIs
- Documents the screening discussions and/or TSPA dispositions for the 54 miscellaneous waste form FEPs of this AMR.

Identification and Analysis–To demonstrate that regulatory-specified performance objectives of a proposed repository system can be achieved for a 10,000-year postclosure period, the Yucca Mountain Project is implementing a stochastic scenario-development methodology based on the work of Cranwell et al. ([101234] 1990). The methodology provides a systematic approach for considering, as completely as practicable, the possible future states of the proposed repository system. It seeks to span the set of all possible future states using a finite set of scenarios. Here, each scenario represents the ensemble of possible futures corresponding to parameter and model uncertainties present in the group of FEPs comprising the scenario. The methodology begins with a comprehensive FEP identification step followed by a rigorous FEP screening step. With its focus on waste form FEPs, this AMR considers these first two steps of scenario development.

Performance Assessment and FEP Relationship–Generally, the process of assessing whether a radioactive-waste disposal system meets a set of performance criteria is a performance assessment.

The NRC specifically defines, in 10 CFR 63.2 [156605], that the process of performance assessment means a probabilistic analysis that includes:

- Identification of FEPs that might affect the performance of the geologic repository
- Examines the effects of such FEPs on the performance of the geologic repository
- Estimates of the expected annual dose to the average member of the critical group as a result of releases from the geologic repository.

EPA standard 40 CFR 197 [155238] has similar wording but the performance measure was cumulative releases of radioisotopes and associated uncertainties expressed as a complementary cumulative probability function. Thus, FEPs are a fundamental aspect of a performance assessment, where a feature is some aspect of the disposal system, an event is a phenomenon that occurs in a short time frame relative to the life of the disposal system, and a process is a phenomenon relevant to the functioning of the disposal system that occurs on a long time frame.

The identification of FEPs that are potentially relevant to the functioning of the disposal system conceptually produces the initial domain or parameter space of the model of the disposal system. The screening process omits those portions of the domain that are not pertinent. The formal and defensible selection of the pertinent domain of FEPs when developing the conceptual model of the disposal system is one aspect that sets performance assessment apart from typical scientific or engineering analysis. The criteria employed to omit FEPs are based on either regulatory guidance for the modeling style (e.g., regulatory period, omission of purposeful intrusion, or omission of inadvertent intrusion other than exploratory drilling) or the prediction of negligible influence on the performance measure (the probabilistic estimate of the annual dose). Because of the nature of FEP screening and model

development, several iterations of the performance assessment process are potentially necessary to eliminate those FEPs of negligible influence and improve the modeling of those FEPs retained.

The NRC period for conducting the performance assessment, per 10 CFR 63, is 10,000 years.

Use of a WP that lasts beyond this 10,000-year regulatory period does not necessarily justify the elimination of most FEPs except those that potentially influence the WP life for several reasons. First, the NRC regulation also calls for an environmental impact statement to comply with the NWPA, as amended [101681]. This modeling would require the inclusion of FEPs beyond those influencing the life of the WP because the modeling may need to evaluate behavior for up to one million years. Furthermore, the NRC regulations require multiple barriers and a simulation of the disposal system after failure of the WP provides some evaluation of the resiliency of other barriers in the disposal system.

In-Package Chemistry Abstraction ([154620] BSC 2001) developed the in-package (WP) chemistry abstraction model using updated technical information. The processes included in this model are seepage interaction with the waste form and WP materials and the resulting fluid chemistry. The output of this abstraction will be a response surface of pH (as a function of time, water flux through the WP, metal corrosion rate, and fuel exposure) for the commercial SNF packages. For the DOE co-disposal packages, the pH will be set to fixed ranges as determined from the process models output. For both commercial SNF and co-disposal packages, the hydrogen potential and total carbonate are calculated based on thermodynamic relations relating them to pH. The parameters of ionic strength, chloride, and fluoride will be set to fixed ranges based on the output of the process model.

The *Clad Degradation-Summary and Abstraction* ([151662] CRWMS M&O 2001) developed the summary cladding degradation abstraction that is consistent with and used in *Total System Performance Assessment for the Site Recommendation* ([153246] CRWMS M&O 2000). This analysis describes the postulated condition of commercial Zircaloy clad fuel as a function of time after it is placed in the proposed Yucca Mountain repository, and it describes cladding degradation from the expected failure modes. These include:

- Cladding failure before receipt at the proposed repository due to reactor operation impacts (including incipient failures)
- Failures during spent fuel storage in pool and dry storage
- Failures due to transportation and cladding degradation failures that occur in the repository due to cladding creep, seismic failures, localized corrosion, and cladding unzipping.

This contains a revision of the creep calculations and includes cladding failure from rockfalls. This AMR does not address potential damage to assemblies that might occur at the repository surface facility.

There are constraints, caveats, and limitations to this analysis. This cladding degradation analysis is based on commercial pressurized water reactor (PWR) fuel with Zircaloy cladding but is applicable to boiling water reactor (BWR) fuel. Fuel reliability from reactor operation is determined for both PWR and BWR data.

DSNF and Other Waste Form Degradation Abstraction ([155609] BSC 2001) was developed to select and/or abstract conservative degradation models for DOE-owned SNF and the immobilized ceramic plutonium disposition waste forms for use in the TSPA model.

Summary of Dissolved Concentration Limits ([155455] BSC 2001) was developed to document solubility limits in the form of functions, distributions, or constants for all transported radioactive elements identified by the radioisotope screening for performance assessment.

Results from an expert elicitation for solubility limits of most radioactive elements were used in the previous TSPAs. However, the elicitation conducted in 1993 did not meet the NRC criteria due to lack of documentation and tractability. Therefore, at the Waste Form Abstraction Workshop held on February 2-4, 1999, in Albuquerque, New Mexico, the Project decided to develop geochemical models to study solubility for the proposed repository, and to develop process-level solubility models, including review and compilation of relevant thermodynamic data. Abstractions of the process models combined with projections of the chemical conditions yield solubility distributions or response surfaces applicable to the proposed repository.

The results of this analysis and conceptual model will feed the performance assessment for *Total System Performance Assessment for the Site Recommendation* ([153246] CRWMS M&O 2000), and the *Waste Form Degradation Process Model Report* ([150707] CRWMS M&O 2000) section on concentration limits.

Clad Degradation–FEPs Screening Arguments ([153947] CRWMS M&O 2000) summarized the cladding degradation FEPs screening that is consistent with the FEPs screening used in *Total System Performance Assessment for the Site Recommendation* ([153246] CRWMS M&O 2000). This screening describes the FEPs that are to be included in the TSPA-SR model and documents the reason for excluding others.

The DOE must provide a reasonable assurance that the regulatory-specified performance objectives for the Yucca Mountain Project can be achieved for a 10,000-year postclosure period. This must be demonstrated in the form of a performance assessment that:

- Identifies the FEPs that potentially affect the performance of the geologic repository
- Examines the effects of such FEPs on the performance of the geologic repository
- Estimates the expected annual dose to a specified nearby population group. The performance assessment must also provide the technical basis for inclusion or exclusion of specific FEPs.

The *Total System Performance Assessment for the Site Recommendation* ([153246] CRWMS M&O 2000) has chosen to satisfy the above-stated performance assessment requirements by adopting a scenario development process. This decision was made based on the TSPA-SR model adopting a definition of "scenario" that is not limited to a single, deterministic future state of the system, but can have a set of similar future states that share common FEPs. Even though the NRC has not defined nor used the term "scenario" in the pertinent regulations, the DOE has chosen to adopt a scenario development process based on the methodology developed for the NRC by Cranwell et al. ([101234] 1990). The first step of this scenario development process is the identification of FEPs potentially relevant to the performance of the Yucca Mountain repository; the second step includes the screening of each FEP.

This AMR identified and documented the analysis, screening decision, and TSPA-SR disposition or screening argument for FEPs related to clad degradation. Both primary and secondary FEPs are considered. The screening decisions and the associated TSPA-SR disposition or screening argument for the subject FEPs will be cataloged separately in a project-specific FEPs database. This AMR and the database are being used to document information related to the FEPs screening decisions and associated screening argument, and to assist reviewers during the license review process.

Tests involving humid air exposure of two samples of perforated commercial spent fuel rods showed that the cladding on both samples unzipped at a rate faster than the range used in the *Yucca Mountain Science and Engineering Report* ([155943] DOE 2002). The observed rate of unzipping was consistent with the upper bound value used in Volume 1 of *FY01 Supplemental Science and Performance Analyses* ([155950] BSC 2001). Metalographic analysis of the unzipped area showed the formation of an as-yet unidentified alteration product, which may have provided the cladding stress that caused the unzipping. It is planned to resolve this issue by developing a more conservative unzipping model and incorporating it in the next revision of the current cladding degradation AMR *Clad Degradation – Summary and Abstraction* ([151662] CRWMS M&O 2001).

A re-analysis of some archived leachate samples from the commercial SNF flow-through tests showed uranium concentrations that averaged 20 percent higher than in the original measurements. It is currently hypothesized that fine particulate and/or colloidal release may be responsible for the higher uranium concentration values. The low-pH commercial SNF degradation behavior model is being further developed in response to current testing results. These issues will be further analyzed and, if appropriate, the commercial SNF release model revised in a revision of *CSNF Waste Form Degradation: Summary Abstraction* ([136060] CRWMS M&O 2000).

A draft revision of the current ASTM Standard Practice C1174-97, *Standard Practice for Prediction of the Long-Term Behavior of Materials, Including Waste Forms, Used in Engineered Barrier Systems (EBS) for Geologic Disposal of High-Level Radioactive Waste* ([105725] ASTM 1998), was produced for the purpose of incorporating the model validation and confirmatory testing requirements of 10 CFR 63 [156605]. This revision is scheduled to be submitted to ASTM subcommittee C26.13 in June 2002.

4.3 WASTE PACKAGE MATERIALS TESTING

The container materials testing effort is continuing to generate data and analyses relevant to the performance of the WP and drip shield materials under expected Yucca Mountain repository conditions. These include determination of credible and relevant environments expected in the repository, measurement of critical potentials for localized corrosion initiation, and propagation. Several different electrochemical measurement techniques are being utilized for comparison purposes, and to determine which technique should be used in supporting performance models. In addition, work continues on monitoring stress corrosion crack propagation in highly stressed and pre-cracked compact tension test specimens. Results substantiate earlier findings that it is extremely difficult to crack Alloy 22 (UNS N06022) in any of the relevant repository conditions.

Meetings were held with subject matter experts and subgroups of the Waste Package Materials Corrosion Peer Review Panel on a variety of technical areas to provide additional information and clarification to the panel members. The Peer Review Panel presented their findings and recommendations in their final report.

During the reporting period, work also focused on detailed prioritization of the WP testing and modeling activities needed to achieve overall project requirements.

The *Technical Update Impact Letter Report* ([157151] BSC 2001) (on WP and drip shield degradation) was prepared during this reporting period. This report includes updates of data and analyses carried out subsequent to the preparation of SR documents, and evaluates their impact on the SR.

4.4 WASTE PACKAGE

4.4.1 Drawings

The following engineering drawings were prepared for the SR baseline:

DWH-UDC-ME-000001	21-PWR Waste Package With Absorber Plate
DWG-UDC-ME-000002	44-BWR Waste Package
DWG-UDC-ME-000003	24-BWR Waste Package
DWG-UDC-ME-000004	12-BWR Waste Package
DWG-UDC-ME-000007	21-BWR Waste Package
DWG-EDS-ME-000001	Interlocking Drip Shield
DWG-EDS-ME-000002	Emplacement Pallet
DWG-EDS-ME-000003	Short Emplacement Pallet
DWG-VDC-ME-000002	Naval Long Waste Package
DWG-VDC-ME-000003	Naval Short Waste Package
DWG-DDC-ME-000001	5-DHLW/DOE SNF-Short Waste Package
DWG-DDC-ME-000002	5-DHLW/DOE SNF-Long Waste Package
DWG-EDC-ME-000001	2-MCO/2-DHLW Waste Package

4.4.2 Reports

The following reports were completed during this reporting period:

- *Waste Package Design Methodology Report* ([158010] McKenzie 2002) described the analytical methods and processes used to establish the integrity of the various WP designs, the emplacement pallet, and the drip shield. The scope of this report covers the methodology used in criticality, risk-informed, shielding, source term, structural, and thermal analyses. The basic features and the appropriateness of the methods are illustrated, and the processes are defined whereby input values and assumptions flow through the application of those methods to obtain designs that ensure defense-in-depth as well as to satisfy requirements on system performance. Such requirements include those imposed by federal regulation, from both the DOE and the NRC, and those imposed by the Yucca Mountain Project to meet regulatory performance goals. The report is to be used, in part, to describe the WP design methods and techniques to be used for producing input to the LA.

- *Design Evolution Study: Thermal Operating Methodology* ([157944] Mitchell 2002) provided decision-makers with a thermal operation methodology that will illustrate potential for flexible thermal operation of the repository. A flexible thermal methodology is defined as a process that will allow management of the thermal energy density within the repository horizon for any waste stream that conforms to the *Waste Acceptance System Requirements Document* ([110306] DOE 1999). The focus of this study is to enable repository thermal management at low temperature operations and provide operational parameters for varying the repository's operating temperature. The present study examines operational variations necessary to limit the peak postclosure WP surface temperature to 85°C.

- *Design Evolution Study–Waste Package Design Support* ([157954] Schmitt 2002) described the SR baseline designs for the drip shield and possible alternatives to the designs to support the process of assessing whether the drip shield design should be carried forward to LA. This report will also support assessment of the drift geometry. Both of these issues have a direct impact on the WP design. The scope of this report includes the SR baseline designs, previously explored

design considerations, and alternatives currently being explored. This report does not discuss the other WP or emplacement pallet designs or possible alternatives, and does not propose any new alternatives. The purpose of this report is to evaluate drift geometry being considered in *Design Evolution Study–In-Drift Configuration* ([157717] Linden 2002).

4.4.3 Calculations

Two major calculation documents were completed during this reporting period.

- *Waste Package Barrier Stresses Due to Thermal Expansion* ([154004] BSC 2001) determined the radial and tangential stresses produced from thermal expansion of the inner and outer shells of the WP designs. The scope of this activity is limited to determining the maximum radial and tangential stresses that the WP inner and outer shells are subject to due to the interference fit produced by having two different shell coefficients of thermal expansions. The inner shell has a greater coefficient of thermal expansion than the outer shell, creating a pressure between the two shells. Radial and tangential stresses due to WP internal and external pressures are outside the scope of this calculation. The calculations are performed for the following WP designs: 21-PWR, 44-BWR, 24-BWR, 12-PWR Long, 5-DHLW/DOE SNF-Short, 2-MCO/2-DHLW, and Naval SNF Long.

- *Waste Package Outer Barrier Stress Due to Thermal Expansion with Various Barrier Gap Sizes* ([152655] BSC 2001) determined the tangential stresses of the outer shell, due to uneven thermal expansion of the inner and outer shells of the WP designs. Based on the results of the calculations in *Waste Package Barrier Stresses Due to Thermal Expansion* ([154004] BSC 2001), only tangential stresses are considered for this calculation. The tangential stresses are significantly larger than the radial stresses associated with thermal expansion, and at the WP outer surface, the radial stresses are equal to zero. The scope of this activity was limited to determining the tangential stresses the WP outer shell is subject to due to the interference fit produced by having two different shell coefficients of thermal expansions. The inner shell has a greater coefficient of thermal expansion than the outer shell, producing a pressure between the two shells. The calculations are performed for the following WP designs: 21-PWR, 44-BWR, 24-BWR, 12-PWR Long, 5-DHLW/DOE SNF-Short, 2-MCO/2-DHLW, and Naval SNF Long.

4.5 REPOSITORY DESIGN

4.5.1 Flexible Repository Design

Much of the work done for repository design during the reporting period was common to both surface and subsurface design areas. Baseline drawings completed during this period reflect the major surface and subsurface system concepts developed for the SR and are based on the reports, analyses, and calculations used to support the SR. In progress is a Project Design Criteria document that will present codes and standards, laws, regulations, and general discipline design criteria that are to be used as a basis for LA surface and subsurface structure, system, and component designs. For the system description documents, the architecture of the monitored geologic repository developed to support SR was reevaluated. To be compatible with a system designation methodology better suited to LA design, the monitored geologic repository architecture systems were redefined and consolidated along discipline lines and task subgroups. This process allows related systems to be consolidated into one system that accomplishes a major Project function. A set of information exchange documents was initiated for the surface and subsurface work. These controlled documents will support design integration by identifying specific data needs and design interfaces.

A planning effort was also initiated to reevaluate surface and subsurface repository concepts prior to beginning LA design. A series of design evolution studies that recommend potential options for further study was carried out in support of this evaluation process. The purpose of the design evolution studies was to evaluate the SR baseline design and identify areas for process improvements through the value engineering methodology.

4.5.2 Surface Design

During the reporting period, work in the surface design area focused on support of the reevaluation planning effort. The surface evolution studies are:

- *Design Evolution Study–Waste Emplacement* ([157947] Silva 2002)
- *Design Evolution Study–Waste Handling Facility* ([157758] Brown 2002)
- *Design Evolution Study–Aging Options* ([157949] McDaniel 2002).

For these surface studies, proposed recommended options were developed to modularize the construction and operation of the waste handling facilities by utilizing multiple task-oriented buildings rather than a single waste handling building, and to further evaluate an omni-directional transporter option for transporting WPs from the surface waste handling facility to the subsurface emplacement drift. Work has been started to further develop process flow from waste receipt to final emplacement. The process flow will be documented in material flow diagrams and simulated using the WITNESS software (Witness V2001, STN: 10495-2001-00, SMN: 10495-PC-2001-00 [158872]), an equipment time-motion studies code. The verification and validation of the WITNESS software has been completed, and the code is qualified for Q-level work.

4.5.3 Subsurface Design

During this reporting period, work in the subsurface design area focused on support of the planning effort that was initiated to reevaluate surface and subsurface repository concepts prior to the start of LA design. Subsurface studies are the *Design Evolution Study–In-Drift Configuration* ([157717] Linden 2002) and the *Design Evolution Study–Underground Layout* ([157756] Board et al. 2002). The in-drift configuration study recommended continuing with the SR design, which included a circular drift opening with the steel drift invert, and also recommended further evaluation of the ground support system to utilize rockbolts and heavy-duty wire mesh. This study was supported by a ground control reevaluation of materials, systems, and methods. The Underground Layout study defined an area suitable for locating a repository that would meet performance requirements for long-term waste isolation and be compatible with design configuration requirements. The study also identified an optional repository layout for further evaluation to allow a modular construction approach. This approach would reduce the size of the emplacement panels thereby reducing the excavation time necessary to establish emplacement areas and would provide greater flexibility in meeting changeable waste receipt and thermal loading goals.

In the ventilation design area, work was initiated on calculations for emplacement ventilation system design and for properties of air entering the emplacement drifts. Preparations are also being made to initiate airflow volume calculations and an overall ventilation analysis.

Repository Design and Thermal Mechanical Effects KTI resolution required an extensive effort during this reporting period. Portions of this KTI address the effects on ground control systems from exposure to a range of relative humidities, as well as the occurrence of localized liquid-phase water.

4.6 EXPLORATORY STUDIES FACILITY AND CONSTRUCTION

4.6.1 Operations and Maintenance of the ESF

Operations and maintenance of the ESF were provided throughout the repository period in support of continuing testing activities. The Busted Butte Transport Field Test Facility has completed its planned scientific experiments and has been placed in temporary shutdown. Design and construction for the ECRB Hydrologic Bulkhead Study were completed. Modifications to the ESF Switchgear Building were suspended in February. Installation of a one million-gallon non-potable water tank and a fifty thousand-gallon potable water tank was completed in February. Designs for the Mine Power Center Niches and ECRB Refuge Chambers were completed during this period.

Preparation for excavation of Alcove #10 will take place during the remainder of the fiscal year. The Radon Test Bulkhead Design will be issued prior to the end of FY 2002.

4.6.2 Geochemical Analyses of ESF Dust Samples

Geochemical analyses of 27 dust samples collected from throughout the ESF were analyzed for chemical elements that could accelerate the corrosion of the WP and drip shield materials. The analyses of the elements Cl, F, N, S, Br, Ca, K, Mg, Na, Si, and P were reported in ppm relative to the mass dust. Other trace elements were reported in ppb. Two sets of analyses were performed on each dust sample: one involving total dissolution of the bulk dust sample in acid to obtain the total composition of the dust, and one involving dissolution of water-soluble components in deionized water. The mean concentrations of the water-soluble anions were found to be Cl, 181±56 ppm; F, 14.5±9.4 ppm; NO_3, 418±351 ppm; SO_4, 816±472 ppm; and Br, 29±14 ppm. No correlation was found between sample location and concentrations of any of the elements, indicating that the dust was relatively uniform. A correlation between Cl/Br ratios and Br content indicate that construction water was a significant contributor to the soluble Cl and Br content of the dust. Mean concentrations of water-soluble cations of particular interest with respect to canister corrosion were As at 96±36 ppb and Pb at 1.2±0.7 ppb. These low (ppb) concentrations contrast with the high concentrations from the bulk dust analyses of 8.1±2.2 ppm of As, and 32±4 ppm of Pb, thus indicating that these elements are immobilized in the silicate phases of the dust and the source rock.

Phase II of the ESF dust study started with the collection of 12 dust samples from various localities throughout the ESF. The dust samples (approximately 200 to 250 cubic cm) were collected from the lower half of the right rib of the tunnel using a large vacuum cleaner interfaced with a stainless-steel cyclone adapted from an EPA design. The samples will be sized and split to determine the geochemical and physical characteristics of the dust and to perform chemical analysis of the elemental composition of bulk solids and soluble ions.

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SECTION 5 – REPOSITORY PERFORMANCE

During this reporting period, the Project accomplished several advances in developing the areas of preclosure radiological safety assessment, postclosure performance assessment, and performance confirmation. Advances in these areas are described in the following sections.

5.1 PRECLOSURE SAFETY ANALYSIS

An update was made to *Design Basis Frequency and Dose Calculation for Site Recommendation* ([157277] BSC 2001) to revise an assumption concerning ingestion doses. This document supports *Preliminary Preclosure Safety Assessment for Monitored Geologic Repository Site Recommendation* ([154857] BSC 2001). This safety assessment work includes the identification of facility hazards and their potential for initiating events, identification of monitored geologic repository design basis events, evaluation of design basis event occurrence frequencies and consequences, and the identification of those SSCs important to safety. This report also provides the monitored geologic repository strategies for criticality safety, radiation protection, and fire protection, along with a description of the provisions for the control and management of low-level radioactive waste. Descriptions of the monitored geologic repository site characteristics and facility design are provided to support the identification of hazards and the evaluation of design basis events. The information in *Preliminary Preclosure Safety Assessment for Monitored Geologic Repository Site Recommendation* was used, in part, to support conclusions concerning the preclosure safety assessment included in Section 2 of the *Yucca Mountain Site Suitability Evaluation* ([156958] DOE 2002). In addition, this information was used to support conclusions concerning the preclosure safety assessment included in the Section 5 of the *Yucca Mountain Science and Engineering Report* ([155943] DOE 2002), which was revised during the reporting period.

During this reporting period, the initial version of *Preclosure Safety Analysis Guide* ([158588] BSC 2002) was completed. The guide was written to provide guidance and the preferred methods for developing and documenting the Preclosure Safety Analysis that will support the LA, which is required to be submitted to the NRC upon approval of the repository site. The Preclosure Safety Analysis will address the safety of the monitored geologic repository operations area for the preclosure period (i.e., the period before permanent closure), in accordance with the performance objectives of 10 CFR 63. The methods described in the guide combine elements of probabilistic risk assessment and deterministic analyses that comprise a risk-informed performance-based safety analysis. In addition, AP-2.22Q, *Classification Criteria and Maintenance of the Monitored Geologic Repository Q-List*, was prepared and issued to provide the risk-informed criteria for identifying SSCs important to safety.

Work in progress includes a calculation titled *Commercial SNF Accident Release Fractions*. This calculation will be used to support future preclosure safety analyses, including those performed to support potential LA activities. Results of these analyses may also be used to determine the safety classification level of repository SSCs. Other work in progress involves the development of an aircraft hazards evaluation plan and site vicinity map to support the LA for the proposed monitored geologic repository design.

5.2 POSTCLOSURE PERFORMANCE ASSESSMENT

5.2.1 Performance Assessment

During this reporting period, the *Uncertainty Analyses and Strategy Letter Report* ([157389] Williams 2001) was developed and issued. This report summarizes uncertainties continued for technical documents supporting the *Total System Performance Assessment for the Site Recommendation* ([153246] CRWMS

M&O 2000) and Volumes 1 and 2 of the *FY01 Supplemental Science and Performance Analyses* ([155950] BSC 2001, [154659] BSC 2001), and provides a strategy for future treatment and communication of uncertainties.

The *TSPA-SR Errata Analyses* ([158589] BSC 2001) was also issued. This letter report presented an evaluation and impact analysis of documented errata on the performance results of the TSPA-SR model, as identified through internal review and NRC review.

Other performance assessment activities included:

- Prepared and issued the *Guidelines for Developing and Documenting Alternative Conceptual Models, Model Abstractions, and Parameter Uncertainty in the Total System Performance Assessment for the License Application* ([158592] BSC 2002). This document provides guidelines for a consistent treatment in developing, integrating, and documenting alternative conceptual models, model abstractions, and parameter uncertainties for use in the TSPA-LA.

- Performed TSPA model analyses for *Risk Information to Support Prioritization Report* (in preparation). This document supports prioritization of work for FY 2002-2003 and KTI resolution.

- Issued the *TSPA Sensitivity Analyses for Final Nuclear Regulatory Commission Regulations* ([156743] Williams 2001). This letter report presents the results of supplemental evaluations and analyses designed to assess long-term performance of the proposed repository.

- Supported nine supplemental SR public hearings.

5.2.2 Near Field Environment

Near-field environment work focused on the coupled effects of thermal-hydrological, thermal-hydrological-chemical, and thermal-hydrological-mechanical processes on seepage flux and chemistry in emplacement drifts during thermal periods and on changes of rock properties resulting from coupled processes. Section 3 of this document contains additional details on coupled process modeling and drift scale testing.

During this reporting period, the near-field environment investigations supported the SR with inputs to the *Technical Update Impact Letter Report* ([157151] BSC 2001).

5.2.3 Engineered Barrier System

A KTI letter report, *Effect of Forced Ventilation on Thermal-Hydrologic Conditions in the Engineered Barrier System and Near Field Environment* ([158562] Williams 2002), was prepared and issued. It addressed the KTI agreements RDTME 3.01, RDTME 3.14 and TEF 2.07.

The following AMRs were updated during this period:

- *In-Drift Precipitates/Salts Analysis* ([156065] BSC 2001)

- *Multi-scale Thermohydrologic Model* ([158204] BSC 2001).

The following calculations were completed during this period:

- *EBS Incoming Water and Gas Composition Abstraction Calculations for Different Drift Temperature Environments* ([155859] BSC 2001)
- *Seepage Grout Interactions Model Calculations* ([156183] BSC 2001)
- *Precipitates/Salts Model Sensitivity Calculations* ([156066] BSC 2001)
- *Precipitates/Salts Model Calculations for Various Drift Temperature Environments* ([156067] BSC 2001)
- *Supporting Rock Fall Calculation for Drift Degradation: Quantification of Uncertainties* ([158207] BSC 2001)
- The latest versions of the software codes RADPRO version 3.22 and MSTHAC version 6.5 are being qualified.

5.2.4 Unsaturated Zone Flow and Transport

The UZ flow and transport modeling investigations support the SR with inputs to the *Technical Update Impact Letter Report* ([157151] BSC 2001) and the publication of an AMR to substantiate the findings in Volume 1 of the *FY01 Supplemental Science and Performance Analyses* ([155950] BSC 2001). The major UZ developments presented in the *Unsaturated Zone Patterns and Analysis* ([156609] BSC 2001) are listed below and include site-scale flow processes above the repository, drift-scale seepage and radionuclide release into the drift shadow zone, and transport below the repository.

- Geochemical information was synthesized to support the UZ Flow and Transport Model. Vertical trends of ion concentrations (chloride, sulfate, sodium) in the different hydrogeologic units suggest at least some lateral flow within the nonwelded units. The increase in $^{87}Sr/^{86}Sr$ ratio in the pore water of PTn tuff suggests enhanced water-rock interaction.
- PTn lateral flow effects on percolation and chlorine distribution were studied by three-dimensional simulation with increased horizontal permeability. This scoping study suggests that several approaches may be used to obtain UZ model results consistent with the chloride data.
- A scoping study investigated the significance of episodic percolation at the repository level due to transient infiltration on the western slope of Yucca Mountain above the Solitario Canyon fault (TSw outcrop). The results of this study confirmed the abstraction approach for the *Total System Performance Assessment for the Site Recommendation* ([153246] CRWMS M&O 2000) that does not include episodic percolation as a seepage-enhancing factor ([154291] CRWMS M&O 2001, Section 6.4.4; [154659] BSC 2001, Section 3.2.2.4).
- A series of numerical studies have been conducted to evaluate flow focusing through fractures from the bottom of the PTn to the proposed repository horizon. The results obtained provide a quantitative analysis of flow focusing and discrete path formation. All simulation results indicate that the flow-focusing factor is about an order of magnitude smaller than the conservative value used for calculations in the *Total System Performance Assessment for the Site Recommendation* ([153246] CRWMS M&O 2000). The results of this model are used to support sensitivity studies for Volume 2, Section 3.2.2.3 of *FY01 Supplemental Science and Performance Analyses* ([154659] BSC 2001).

- Seepage enhancement due to rockfall was evaluated for several rockfall scenarios. These scoping calculations confirm that the approach used for seepage enhancement due to drift degradation in the *Total System Performance Assessment for the Site Recommendation* ([153246] CRWMS M&O 2000) is conservative.

- The potential for seepage enhancement due to rockbolts was investigated using a two-dimensional, radial model of a spherical opening with a rockbolt at the crown. This investigation concluded that there is no significant enhancement of seepage, confirming that the approach used for seepage enhancement due to drift degradation in the *Total System Performance Assessment for the Site Recommendation* ([153246] CRWMS M&O 2000) is conservative.

- An approximation was formulated for the effects of flow diversion around waste emplacement drifts (drift shadow zone) on radionuclide transport away from waste emplacement drifts. Modeling studies indicate that radionuclides released into matrix rocks rather than fractures below repository drifts, may significantly impact the proposed repository performance.

- Sensitivity of modeled flow and transport behavior to changes in certain key hydrological parameters assigned to major faults below the proposed repository horizon has been evaluated. Results of this study indicate that increases and decreases (by two orders of magnitude) in fracture permeability within the fault zones, and increases and decreases (by one order of magnitude) in the van Genuchten parameter (α) for both fractures and matrix within the fault zones, have little impact on tracer transport from the proposed repository horizon to the water table.

- Several conceptual models of perched water have been examined and compared for their impact on the proposed repository performance. Results from the three-dimensional UZ flow model indicate that, compared to the dominant processes of percolation fluxes or sorbing effects on rocks, which strongly affect flow and transport, perched water conceptual models have smaller effects on tracer or radionuclide transport from the proposed repository to the water table.

- New data on the vitric CHn have been incorporated into the UZ Zone Flow and Transport Model. The new data, from the Busted Butte Transport Field Test Facility, suggest higher matrix permeability and lower matrix capillarity than indicated by previous data. Further, tests at Busted Butte suggest that UZ flow and transport in the vitric CHn is completely matrix dominated.

5.2.5 Saturated Zone Flow and Transport

Various SZ technical issues have been addressed or are in the process of being addressed with field and laboratory investigations. These investigations and the resulting data have been analyzed and are reported in project documents, journal articles, reports, and presentations. Areas of investigation reported on include:

- Analyses of plume spreading caused by dispersion

- Analyses of SZ transport time

- Radionuclide transport simulation and uncertainty analyses with the SZ site-scale model

- Testing and parameterizing a conceptual solute transport model in saturated fractured tuff using unreactive and reactive tracers in cross-hole tracer tests

- Transport of a reactive tracer in saturated alluvium using a three-component cation-exchange model

- Development of a numerical model and calibration results of the site-scale SZ flow and transport model for Yucca Mountain.

5.2.5.1 Completion of KTI Letter Reports

Letter reports that addressed six KTI agreements have been completed and four more letter reports are planned by the end of FY 2002.

5.2.5.2 Revision of Saturated Zone Analysis Model Reports

The following AMRs were updated with interim change notices during this reporting period:

- *Geochemical and Isotopic Constraints on Groundwater Flow Directions, Mixing, and Recharge at Yucca Mountain, Nevada* ([158606] BSC 2001)

- *Input and Results of the Base Case Saturated Zone Flow and Transport Model for TSPA* ([157132] BSC 2001)

- *Hydrogeologic Framework Model for the Saturated-Zone Site-Scale Flow and Transport Model* ([158608] BSC 2001).

Revision 01 of *Water-Level Data Analysis for the Saturated Zone Site-Scale Flow and Transport Model* ([157611] USGS 2001) was completed. In addition, work continued on the initial issue of *Saturated Zone In-Situ Testing*.

5.2.5.3 Scientific and Technical Work Activities

The scientific and technical work activities performed during this reporting period are as follows:

- Construction of the thermal/hydraulic model of the SZ site-scale model continued. This model will incorporate much of the thermal data near Yucca Mountain.

- Design began on the UZ/SZ model that will be used for determining fluid pathways in future climate simulations. The climate-change modeling study is intended to predict the probable water-table rise in the Yucca Mountain area that would accompany a return to pluvial conditions, such as those that existed at Yucca Mountain throughout most of the Pleistocene.

- Flow model validations continued on the SZ site-scale model with new hydrostratigraphy, new water-level data, and new fluxes from the regional flow model.

- Lithologic descriptions and stratigraphic correlation have been completed for the Phase I and Phase II boreholes drilled under the NC-EWDP. Geologic cross sections Nye-1, Nye-2, and Nye-3 have been completed. The cross sections and associated geologic interpretations will be used as refinements to the hydrogeologic framework for the site-scale SZ flow and transport model as they are developed.

5.2.5.4 Workshops and Presentations

Presentations were made to the NRC and the NWTRB at the various technical-exchange meetings held during this past year. The following types of issues were addressed at these meetings:

- Repository design
- Unsaturated and saturated flow under isothermal conditions
- FEPs
- New compliance boundary
- Updates on the SZ models and integration with the regional model
- Radionuclide transport.

Workshops held during this reporting period include the following:

- Workshop on the flow path
- Workshop on Nye County stratigraphy and lithology
- Devils Hole Workshop
- Meeting and workshop on the integration of the SZ regional and site-scale models
- Project colloids integration meeting
- Workshop on matrix diffusion.

The Final EIS ([155970] DOE 2002) was supported with simulations using the site-scale flow and transport model.

5.2.6 Biosphere

An impact review of biosphere-related information developed after publication of the *Yucca Mountain Science and Engineering Report* ([155943] DOE 2002) and the *Yucca Mountain Site Suitability Evaluation* ([156958] DOE 2002) was conducted during this reporting period. This additional information focused on revised dietary and lifestyle characteristics of the receptor, and an alternative dosimetric model of the receptor. The results of this impact review were included in the *Technical Update Impact Letter Report* ([157151] BSC 2001).

Additional technical efforts during this reporting period were focused on those biosphere activities needed to support development and validation of the biosphere model for TSPA-LA, and included the following:

- Preliminary screening analysis of selected FEPs, as identified in “U.S. Nuclear Regulatory Commission/U.S. Department of Energy Technical Exchange and Management Meeting on Total System Performance Assessment and Integration (August 6 through 10, 2001)” ([158380] Reamer 2001), to determine potential applicability to the Yucca Mountain biosphere model

- Reevaluation of the biosphere model in the TSPA-SR model to identify areas in need of improvement

- Compilation of alternative mathematical representations of the biosphere sub-models from the scientific literature

- Scoping evaluations of selected biosphere sub-models in preparation for biosphere model development and validation activities

- Preliminary development activities in support of environmental transport and receptor related parameters for the biosphere model.

5.2.7 Disruptive Events

Seismic-related work consisted of four major activities:

- Validation of computer software to support calculations of Seismic Design Input ground motions for preclosure design and postclosure performance assessment

- Processing, analyses, and documentation of the geotechnical data collected in 2000-2001 at the potential Waste Handling Building location and above the emplacement area on Yucca Mountain

- Development of preliminary ground motions for input into sensitivity analyses for rockfall

- Development of base case velocity and correlation models for the Waste Handling Building location and repository block for the Seismic Design Input calculations.

Geotechnical data obtained from drilling and testing of the geologic structure under the current gravel pad at the site is summarized in *Geotechnical Data for a Potential Waste Handling Building and for Ground Motion Analyses for the Yucca Mountain Site Characterization Project* (in progress, see Appendix B). The report has been checked and a second revision is being completed. The Seismic Design Input Team met with the Seismic Design Input Review Panel to review the input into the ground motion calculations. Preliminary base case velocity models for the Waste Handling Building location and repository, correlation model for the Waste Handling Building location, and strain-dependent dynamic material properties were presented and discussed. DOE is planning the installation of strong motion instruments at the Waste Handling Building location.

In the area of igneous activity analyses, work during the reporting period was dominated by planning activities. *Technical Work Plan for: Igneous Activity Analyses for Disruptive Events* ([158612] BSC 2001), for FY 2002 and out-years, was published. Shortly thereafter, major Project replanning was performed to achieve delivery of the LA by December 2004 and the Technical Work Plan was revised to reflect the new plans. An SITP needed to obtain data in the Yucca Mountain region, concerning both physical volcanology and soil and volcanic ash redistribution, was completed and established readiness to begin the field data collection effort ([158185] BSC 2002). In the area of igneous activity analyses, two software programs will be used to implement models of magma and gas flow in drifts (CFDLIB V2.0) and the interaction of an intruding dike (NPHF2D V1.0) with the stress field established by topography, thermal effects, and the presence of drifts. These codes are currently being qualified in accordance with AP-SI.1Q, *Software Management*.

5.2.8 Waste Form

During this reporting period, Section 4.2.6 of the *Yucca Mountain Science and Engineering Report* ([155943] DOE 2002); Section 3.3.5 of the *Yucca Mountain Site Suitability Evaluation* ([156958] DOE 2002); and Volume 1, Section 9 of the *FY01 Supplemental Science and Performance Analyses* ([155950] DOE 2001) were updated to address waste form issues. See Section 4.2 of this document for further details of waste form activities during this reporting period.

5.2.9 Waste Package

The container materials testing effort is continuing to generate data and analyses relevant to the performance of the WP and drip shield materials under expected Yucca Mountain repository conditions. These effects include the determination of credible environments expected in the repository and the measurement of critical potentials for localized corrosion initiation and propagation. Several different electrochemical measurement techniques are being utilized for comparison purposes and to determine which technique should be used in supporting performance models. In addition, work continues on monitoring stress corrosion crack propagation in highly stressed and pre-cracked compact tension test specimens. Results substantiate earlier findings that it is extremely difficult to crack Alloy 22 (UNS N06022) in any of the relevant repository conditions.

Meetings were held with subject matter experts and subgroups of the Waste Package Materials Corrosion Peer review panel to discuss a variety of technical areas and to provide additional information and clarification. The Peer Review Panel presented their findings and recommendations in *Final report, Waste Package Materials Performance Peer Review Panel, February 28, 2002* ([158781] Beavers et al. 2002).

During this reporting period work also focused on developing a detailed prioritization of the WP testing and modeling activities needed to satisfy overall Project requirements, and preparing resource loaded schedules for the reprioritized activities.

Appendix E of the *Technical Update Impact Letter Report* ([157151] BSC 2001) was prepared during this reporting period. The appendix is part of a larger report containing updates on other technical areas. It includes updates of data and analyses carried out after the preparation of the SR documents, and evaluates their impact on the SR.

5.3 PERFORMANCE CONFIRMATION AND TEST AND EVALUATION

During this reporting period the *Monitored Geologic Repository Test & Evaluation Plan* ([156960] Skorska 2001) and the *Performance Confirmation Plan* ([156732] Lindner 2002) were updated to reflect Project requirements, the evolution of the design concept, and the finalization of 10 CFR 63 [156606] and 40 CFR 197 [155238]. Requirements in both documents were examined to support design evolution studies initiated by the Project during this reporting period.

The *Monitored Geologic Repository Test & Evaluation Plan* is an umbrella document for all testing activities in a licensed environment. It specifies tests, demonstrations, examinations, and analyses, and describes procedures to conduct and document testing necessary to verify meeting regulatory requirements for constructing, operating, and ultimately closing a safe and effective geologic repository for radioactive waste.

The *Performance Confirmation Plan* is closely related to the Test & Evaluation Plan in that it examines a subset of specific types of tests for performance confirmation, which are only addressed in general terms in the Test & Evaluation Plan. Performance confirmation testing is limited to those activities explicitly required in 10 CFR 63, Subpart F. The performance confirmation program, which began during site characterization and continues until permanent closure, includes activities to collect and analyze repository performance data to ensure that conditions encountered, and changes in those conditions, are within the limits to be stated in the LA. The performance confirmation program will determine whether the natural systems, engineered systems, and system components function as intended and anticipated.

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SECTION 6 – EPILOGUE

Several important developments, shown here chronologically, have occurred on the Project since the close of the reporting period on February 14, 2002. As of July 23, 2002, these developments include the following:

- On February 15, 2002, the President forwarded his recommendation of the site to Congress.
- On April 8, 2002, Governor Kenny Guinn of the State of Nevada submitted a notice of disapproval to Congress.
- On May 8, 2002, the U.S. House of Representatives passed a resolution of approval of the Yucca Mountain site for development of a nuclear waste repository.
- On July 9, 2002, the U.S. Senate passed a resolution of approval of the Yucca Mountain site for development of a nuclear waste repository.
- On July 23, 2002, the President signed the joint resolution for development of a nuclear waste repository into law, completing the formal designation of the Yucca Mountain site, per Section 115(c) of the NWPA, as amended. The DOE can now proceed with the development of an LA for the construction authorization of a nuclear waste repository.

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SECTION 7 – REFERENCES

NOTE: References are cited in text by DIRS number and numerically sorted by DIRS number in this list. The unique DIRS number is placed in the text before the author-date callout (e.g., ([155950] CRWMS M&O 2000), and is shown in the first column of this list. The list is divided into four sections: Documents Cited; Codes, Standards, and Regulations; Source Data, Listed by Data Tracking Number, and Procedures.

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7.3 SOURCE DATA, LISTED BY DATA TRACKING NUMBER

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7.4 PROCEDURES

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APPENDIX A

LIST OF COMPLETED YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT DELIVERABLES

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Table A-1. List of Completed Yucca Mountain Site Characterization Project Deliverables (October 31, 2001, to March 31, 2002)

Document Control Number	Deliverable Number	Title and Revision
29481	BM600M3	Update of the MGR Vulnerability Assessment
29668	SRV100000D	Yucca Mountain Science and Engineering Report
29683	PI8075000D	Documentation of Program Change (Revision 4)
29699	SA0362100D	Natural Analogue Synthesis Report
29787	SRSEV2000D	Yucca Mountain Site Suitability Evaluation
29844	SCC1030M3	Conduct Self Assessments
29845	SCC1270M3	Monthly Management Summary Status Report
29856	BM614M3	Update of the MGR Preliminary Safeguards & Security Plans
29899	BMK03M3	Information Technology Investment Portfolio
29942	SRTUM3	Technical Update Impact Letter Report
29953	BMK14M3	Annual Information Management Self Assessment
30045	ESJ102M3	Team Comments Included (W/PFCRD)
30147	SLDR100M3	DR 39 Closeout – Science and Analysis PM
30463	SRV391000D	Site Recommendation Comment Summary Document
30751	BS0204500D	Training Cost Information Annual Update (M&O)
30874	LAS104000D	Yucca Mountain Project Licensing Strategy
30875	ESJ205000D	Final Environmental Impact Statement (Camera-ready copy)
31167	ESJ20B000D	Complete Delivery EIS Contractor Records to M&O
31313	ESS440000D	Deliver all EIS Records to Records Center

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APPENDIX B

LIST OF YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT DOCUMENTS IN PROGRESS

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Table B-1. List of Future Project Documents Shown as “In Progress” in This Report

Work in Progress Number	Document, Deliverable, or Activity ID Number	Proposed Title	Expected Completion Date
1	DOE/RW-0553	Progress Report No. 25	01/03
2	ANL-MGR-GE-000003	Geotechnical Data for a Potential Waste Handling Building and for Ground Motion Analyses for the Yucca Mountain Site Characterization Project	09/06/02 Actual
3	TDR-WIS-PA-000009	Risk Information to Support Prioritization of Performance Assessment Models	06/02 Actual
4	ANL-WHS-SE-000002	Commercial SNF Accident Release Fractions, Rev. 1	01/03
5	MDL-NBS-GS-000005	Thermal Conductivity of the Potential Repository Horizon Model Report	8/29/02 Actual
6	TER-MGR-MD-000001	Project Requirements Document, REV 00	07/31/02 Actual
7	000-3DR-MGR0-00100-000-000	Project Design Criteria Document	09/02 Actual
8	PLN-MGR-AD-000003	Configuration Management Plan	06/28/02 Actual
9	PLN-MGR-AD-000004	Requirements Management Plan	06/19/02 Actual
10	ANL-NBS-HS-000041	Thermal Testing Measurements Report	09/26/02 Actual
11	MSL-NBS-GS-000006	Thermal Conductivity of Non-Repository Lithostratigraphic Layers Model Report	02/28/03

Table B-2. Project Documents Shown as "In Progress" in Previous Progress Reports

Work in Progress Number	Document, Deliverable, Or Activity ID Number	Proposed Title	Expected Completion Date
PR-25 Listings			
1	DOE/RW-0552	Progress Report No. 24	03/02 Actual
2	TDR-MSL-CI-000001	Site Development Plan for the Monitored Geologic Repository	10/15/02 Actual
3	DOE/EIS-0250	Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada	02/14/02 Actual
4	DOE/RW-0459	Yucca Mountain Site Suitability Evaluation	12/10/01 Actual
5	DOE/RW-0548	Site Recommendation Comment Summary Document	02/14/02 Actual
PR-24 Listings			
5	DOE/RW-0351	Rev. 4 of the Waste Acceptance System Requirements Document	01/02 Actual
PR 20 Listings			
10	SA10B315	Submit Seismic Topical Report (STR) III for QAP 6.2/ YAP-30.12 Reviews	Deferred until 3/04

APPENDIX C

GLOSSARY

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APPENDIX C

GLOSSARY

NOTE: Many of the following definitions are Yucca Mountain Site Characterization Project-specific.

Glossary Item	Definition or Explanation
Alcove	A small underground excavation (room) made to the sides of drifts used for in situ scientific studies of ambient rock characteristics or thermal perturbations of those characteristics or for installing equipment.
Alluvium	Unconsolidated soil and rock fragments deposited by the action of rivers, and sometimes the term "alluvium" is used loosely to refer to all valley-fill material, which is unconsolidated rock fragments derived from the erosion of the bordering mountains.
Analysis and Model Report	A report that documents the technical underpinnings used to defend the applicability of the model for its intended purpose of evaluating the postclosure performance of the potential Yucca Mountain Repository System.
Aquifer	A water-bearing layer of permeable rock that is capable of yielding groundwater to supply wells and springs.
Borehole	A hole bored or drilled to investigate subsurface features, sometimes referred to as drillhole.
Characterization	A study done to investigate (i.e., to determine the character or quality) and describe an item or process.
Colloid	Large molecules or small particles that have at least one dimension within the size range of 10^{-9} to 10^{-6} m, which is suspended in a liquid, such as groundwater. Some radionuclides bind with colloids (either reversibly or irreversibly) and can travel great distances in groundwater. Colloids may form directly from insoluble radionuclides (intrinsic colloids), may form from degraded SNF or glass waste forms (waste form colloids), or may form from other natural or man-made materials with which radionuclides can bind (pseudocolloids).
Cross Drift	The Enhanced Characterization of the Repository Block (ECRB) Cross Drift is a west-southwest trending excavation extending from near the base of the north ramp of the ESF, above and across the block of the potential repository through the main trace of the Solitario Canyon fault.
Design Alternative	A considered alternative to a major design feature that is important to waste isolation or a fundamentally different conceptual repository design, which could stand alone as the License Application repository design concept.

Glossary Item	Definition or Explanation
Design Feature	Enhancements to design that can be easily incorporated within multiple alternative designs.
Drift	Mining terminology for a horizontal underground passage.
Drip Shield	A corrosion-resistant engineered barrier that is placed above the waste package to prevent seepage water from directly contacting the waste package for thousands of years. The drip shield also offers protection to the waste package from rockfall.
Emplacement Area	That part of the geologic repository in which radioactive waste would be placed.
Engineered Barrier System	Those engineered features of the geologic repository that contribute to containing radioactive wastes and preventing or delaying them from escaping the geologic repository. Engineered barriers are items such as waste packages and drip shields.
Fault	A fracture in crustal rock along which movement of one side relative to the other has occurred.
Fault Zone	An area composed of many small, closely spaced rock fractures that show evidence of movement.
Flexible Design	Repository design that provides operational and control flexibility that allows repository operations for various heat loading scenarios by adjusting heat removal ventilation rates and duration so as to limit the maximum postclosure surface temperatures of the waste packages and the temperatures in the emplacement drift walls to values that will reduce uncertainty in coupled thermal-hydrological-mechanical-chemical process.
Geologic Repository	A facility designed for the disposal of radioactive waste in excavated geologic media. A geologic repository includes the engineered barrier system and the portion of the geologic setting that provides isolation of the radioactive waste.
Hydraulic Conductivity	A measure of the ability of a soil or rock material to transmit water through its connected pores or fractures.
Important to Safety	With reference to structures, systems, and components (SSCs), those engineered features of the geologic repository operations area, whose function is to (1) provide reasonable assurance that high-level waste can be received, handled, packaged, stored, emplaced, and retrieved without exceeding the proposed radiological exposure limit, or (2) prevent or mitigate design basis events that could result in doses equal to or greater than the proposed radiological exposure limit to any individual located on or beyond any point on the boundary of the site.

Glossary Item	Definition or Explanation
Key Technical Issues	The ten issues identified by the U.S. Nuclear Regulatory Commission that must be resolved before the nuclear waste repository can be issued a license. Specifically, these issues relate to: Unsaturated Zone, Igneous Activity, Container Life and Source Term, Structural Deformation and Seismicity, Saturated Zone, Radionuclide Transport, Evaluation of the Near Field, Thermal Effects on Flow, Repository Design and Thermal Mechanical Effects, and TSPA Integration.
Longitudinal Dispersivity	A measure of the ability of a soil or rock material to spread a solute moving through it, by elongating the solute plume in the direction of the flow lines.
Model	A depiction of a system, phenomenon, or process including any hypotheses required to describe the system or explain the phenomenon or process. The depictions may be conceptual or numerical.
Natural Barrier System	Those natural features of the geologic repository that individually and collectively contribute to containing radioactive wastes and preventing or delaying them from leaving the geologic repository. Natural barriers are items such as the rocks above and below the emplacement area.
Near-Field Environment	The zone of environmental conditions that directly impacts the waste package container materials and the waste form.
Niche	A relatively shallow excavation in the side of a drift where scientific experiments can be conducted.
Perched Water	Small bodies of water held above the water table and supported by a relatively impermeable layer of unsaturated rock.
Performance-Based Approach	A requirement that relies on measurable or calculable outcomes, with some flexibility in meeting those outcomes. A performance-based regulatory approach establishes performance and results as the primary basis for regulatory decision-making.
Performance Confirmation	The program of tests, experiments, and analyses that are conducted to evaluate the adequacy of the information used to demonstrate compliance with the performance of objectives of 10 CFR 63.
Permeability	A measure of the degree to which a given material (e.g., rock or soil) will transmit air or water.
Porosity	The fraction of the total volume of soil or rock occupied by void spaces. The "effective porosity" is a measure of the fraction of soil or rock occupied by connected void spaces and can be determined from tracer testing.
Postclosure	The period of time after the repository is closed (contrast with preclosure).

Glossary Item	Definition or Explanation
Preclosure	The period of time before the repository is closed (contrast with postclosure).
Process Model Report	A report that documents a synthesis of the necessary and sufficient technical information that the Project will be relying upon to support its site suitability evaluation and the licensing safety analysis pertaining to a particular process model.
Quality Assurance	All those planned and systematic actions necessary to provide adequate confidence that the geologic repository and its subsystems or components will perform satisfactorily.
Recharge	Water that flows into an aquifer to replace water that is lost from the aquifer by natural discharge or by pumping.
Repository Block	The geologic structure (i.e., block of rock) inside Yucca Mountain that would house the waste emplacement area.
Risk-Informed Approach	An approach to regulatory decision-making whereby risk insights (results and findings from risk assessments) and other factors are considered together to establish requirements that focus licensee and regulatory attention on design and operational issues commensurate with their importance to public health and safety.
Repository Horizon	The stratigraphic horizon in which the potential repository might be constructed.
Saturated Zone	The subsurface zone below the water table in which all void spaces are completely saturated with water.
Sensitivity Studies	An analytic or numerical technique for examining the effects of varying specified parameters in a computer model. Shows the effects that changes in various parameters have on model outcomes and illustrates which parameters have a greater impact on the predicted behavior of the system being modeled.
Specific Flux	The flow rate of water per unit cross-sectional area of soil or rock material resulting from a known hydraulic gradient. (The specific flux divided by effective porosity yields the average flow velocity.)

Glossary Item	Definition or Explanation
Sufficiency	"…the preliminary comments of the U.S. Nuclear Regulatory Commission concerning the extent to which the at-depth site characterization analysis and the waste form proposal for Yucca Mountain seem to be sufficient for inclusion in any application to be submitted by the Secretary for licensing of the site as a repository…" (Nuclear Waste Policy Act of 1982, §114(a)(1)(e). The NRC sufficiency comments are required to be included as part of the Site Recommendation package to be submitted by the Secretary to the President.
Transmissivity	The hydraulic conductivity multiplied by the aquifer thickness.
Tuff	Igneous rock formed from compacted volcanic fragments from pyroclastic (explosively ejected) flows with particles generally smaller than 4 mm (0.16 in.) in diameter.
Unsaturated Zone	The volume of earth below the ground surface, and above the water table, in which the void space contains water and humid air.
Vitric	Any pyroclastic material containing at least 75 percent glass.
Waste Form	A generic term that refers to radioactive materials and any encapsulating or stabilizing matrix.
Waste Package	A sealed container containing waste that is ready for emplacement. The waste package includes the waste form and any containers, spacing structures or baskets, and other absorbent materials immediately surrounding an individual waste container placed internally to the container or attached to the outer surface of the disposal container.
Water Table	The top of the saturated zone below which the rocks are saturated with water, and above which the rocks are not saturated (i.e., the interface between the saturated and unsaturated zones).

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