CHAPTER 7 - EXPLORATORY STUDIES FACILITY DESIGN AND CONSTRUCTION

INTRODUCTION

The Exploratory Studies Facility (ESF) is being designed and constructed to allow the performance of a program of in situ exploration and testing above, at, and below the depths at which waste might be emplaced. This work will be used to determine the suitability of the Yucca Mountain site for the construction of a potential underground high-level nuclear waste repository. This work also addresses the 10 CFR 60.15(b) requirement for in situ exploration and testing at the depths at which waste would be emplaced. Generally, the ESF will provide access to underground tuff horizons to obtain technical data.

For discussion purposes, ESF work can be divided into two parts. The first part is design of the equipment and processes necessary to perform the ESF functions. Basically, this is design to support excavation activities, including design of utilities and support equipment. The second part is the construction and excavation that implements the design. This chapter reports progress in these areas. Testing and analysis activities conducted in the ESF during this reporting period are described in Chapters 3 and 5 of this progress report.

Background

> Title I refers to preliminary design, Title II refers to the definitive design that follows Title I, and Title III refers to construction engineering design that provides sufficient detail to support field work.

The Site Characterization Plan, (DOE, 1988), described an Exploratory Shaft Facility that would be used to gather site data through testing in a localized subsurface facility accessed by two vertical shafts. This facility would have been located in the northeast quadrant of the primary area identified for potential repository construction. In consultation with the U.S. Nuclear Regulatory Commission and the Nuclear Waste Technical Review Board, U.S. Department of Energy (DOE) management subsequently decided to study alternative configurations for the ESF and the Geologic Repository Operations Area. The results were documented in a report entitled ESF Alternatives Study: Final Report (Dennis, 1991). One alternative configuration, called Option 30, was judged to be the most desirable overall concept. After several minor modifications, detailed in a document entitled Documentation of the Evaluation of Findings of the ESFAS Used to Develop a Reference Design Concept (DOE, 1991), the revised Option 30 configuration was used to form the basis for a revised Title I ESF design effort. At that time, the facility was renamed the Exploratory Studies Facility. The Title I design was described in the Title I Design Summary Report for the Exploratory Studies Facility (DOE, 1992a). This configuration was also described in Sections 1.3.1 and 2.1.2 of Progress Report #8 (DOE, 1993b).

Title II ESF design began in fiscal year (FY) 1992. Early activities centered on the design of north portal surface facilities. Underground ESF Title II design began in FY 1993, concurrent with the start of repository advanced conceptual design. Early in repository and Title II ESF design, the ESF Option 30 layout was adjusted. This adjustment resulted in access ramps with flatter grades to support underground facility access by rail, flat-lying emplacement drifts, and emplacement drift arrangements that to a great extent avoid the Ghost Dance fault. The change to this configuration was detailed in Section 2.1.9.3 of Progress Report #9 (DOE, 1994g).

Title II ESF design was divided into design packages to allow phased design and construction. These design packages are referenced throughout Chapter 7. Where applicable, design elements have been subdivided further to meet the needs of the constructor. Plans for development of design packages for the Thermal Test Area adjacent to the north ramp extension, Calico Hills level north ramp, and Calico Hills level main and cross drifts were deleted with the implementation of the Civilian Radioactive Waste Management Program Plan, Revision 1 (DOE, 1996a). Table 7-1 gives the package identification, lists the elements of each design package, and provides the completion status of each package as of the end of this reporting period. Figure 7-1 shows the general physical locations within the ESF of the work supported by the design packages.

A common nomenclature was previously established for existing and planned ESF alcoves. This nomenclature will be used for testing and other purposes. Previously, alcoves were identified by planned physical construction sequence. The new identification system replaces the numerical identifier system with a functional test-based nomenclature. The new ESF alcove names, given in Table 7-2, have been incorporated into the design package identification and descriptions provided in Table 7-1 and will be used in future documentation.

Summary of Activities During this Reporting Period

The main focus of ESF work during this reporting period was to continue tunnel boring machine excavation and test alcove excavation, while constructing only the surface support facilities necessary to support subsurface construction. By the end of this reporting period, tunnel boring machine excavation was 132 m and 32 calendar days behind the schedule promulgated in Revision 1 of the Civilian Radioactive Waste Management Program Plan (DOE, 1996a). The excavation was behind schedule because of less-than-favorable ground conditions encountered in the south ramp.

Design work continued on the Thermal Testing Facility and the Northern Ghost Dance Fault Alcove. Designs for the excavation of the Thermal Testing Facility heated drift and associated test support features, and the drill/test room for the Northern Ghost Dance Fault Alcove were issued for construction.

Table 7-1. Design Package Identification and Description

Design Package	Design Package Description	Status
1	**North Portal Site Preparation and Surface Facilities**	
1A	Elements include • North portal pad • Topsoil storage area • ESF access road • Sewage collection and treatment system • North portal pad water supply system • Tunnel boring machine starter tunnel • Rock storage area • Switchgear building • Modifications to switchgear building for the integrated data and control system • North portal pad power distribution system (partial) • Local controls for water system	Issued
1B	Elements include • Change house building • Shop building • Sanitary sewer system • Power distribution system • Water distribution system • Subsurface wastewater system • H-road, site grading, and paving • Site grounding • Redesigned north portal pad drainage • Reconfiguration of north portal pad for surface rail • Completion of grading and paving plan and surface rail • North portal pad perimeter fencing • North portal lightning protection	Issued
1C	Elements include: • Compressed air system • Standby power system • Site lighting (partial) • Site grounding (partial)	Issued

Table 7-1. Design Package Identification and Description (continued)

Design Package	Design Package Description	Status
1D	Elements include • Site grounding (continuation) • Muck storage area • Conveyor maintenance access road • Fuel storage system • Site lighting (continuation) • Equipment foundations • Compressed air system condensate collection system	Issued
1E	Elements include • Standby/auxiliary power • Site grounding (continuation) • ESF electrical distribution (continuation) • Revised fuel storage system	Issued
Integrated Data and Control System	Elements include • Procurement specification for the complete integrated data and control system • Fiber-distributed data interface for first phase of integrated data and control system • Data Collection System	 Issued Issued FY 1997
2	**North Ramp Excavation - Starter Tunnel to Topopah Spring Level**	
2A	Elements include • Surface and subsurface conveyor • Electrical switchgear, transformers, and power centers	Issued
2B	Elements include • Utility systems • Tunnel ventilation specifications and drawings • Rail haulage system • Mapping platform procurement specification • Excavation, ventilation, and muck storage trade studies • Control system specification and drawings • Life safety monitoring and warning system	Issued

Table 7-1. Design Package Identification and Description (continued)

Design Package	Design Package Description	Status
2C	Elements include • North ramp to Topopah Spring level excavation and ground support • Remaining utility systems for north ramp • Electrical power, lighting, and grounding • Associated test and operational support alcoves	Issued
(a)	Topopah Spring level main drift	Issued
(a)	Ghost Dance fault accesses (at Topopah Spring level) • Northern Ghost Dance Fault Alcove (Alcove #6) - Northern Ghost Dance Fault Access Drift (first 95 meters of excavation) - Northern Ghost Dance Fault Drill/Test Room (remaining 110 meters of excavation) • Southern Ghost Dance Fault Alcove (Alcove #7) - Southern Ghost Dance Fault Access Drift (first 120 meters of excavation) - Southern Ghost Dance Fault Drill/Test Room (remaining approximately 60 meters of excavation)	 Issued Issued Issued FY 1997
(a)	North ramp extension (Referred to as "ESF East-West Drift" in Draft Civilian Radioactive Waste Management System Program Plan, Revision 1 and planned for FY 1999. The DOE recently accelerated schedule to FY 1999)	FY 1998
(a)	Thermal testing area • Thermal Testing Facility (Alcove #5) - Thermal Testing Facility (access/observation drift) - Thermal Testing Facility (thermomechanical alcove) - Thermal Testing Facility (cross drift to beginning of heated drift) - Thermal Testing Facility (heated drift) * Layout and Ground Support * Thermal Bulkhead * Invert * Cast-in-place Liner Test System * Drill Bay - Cable Trays - Power Distribution System - Ventilation System	 Issued Issued Issued Issued FY 1997 Issued Issued Issued Issued FY 1997 FY 1997

Table 7-1. Design Package Identification and Description (continued)

Design Package	Design Package Description	Status
(a)	Topopah Spring level south ramp	Issued
(a)	South portal pad and facilities - South portal pad - South portal highwall and boxcut - South portal lightning protection system - South portal ventilation system	 Issued Issued Issued FY 1997
New	Drift scale flux test niches	FY 1997

(a) The package number designations for these packages were previously deleted as discussed in Progress Report #12 (DOE, 1995g). Since then, these packages have been referred to by their names only.

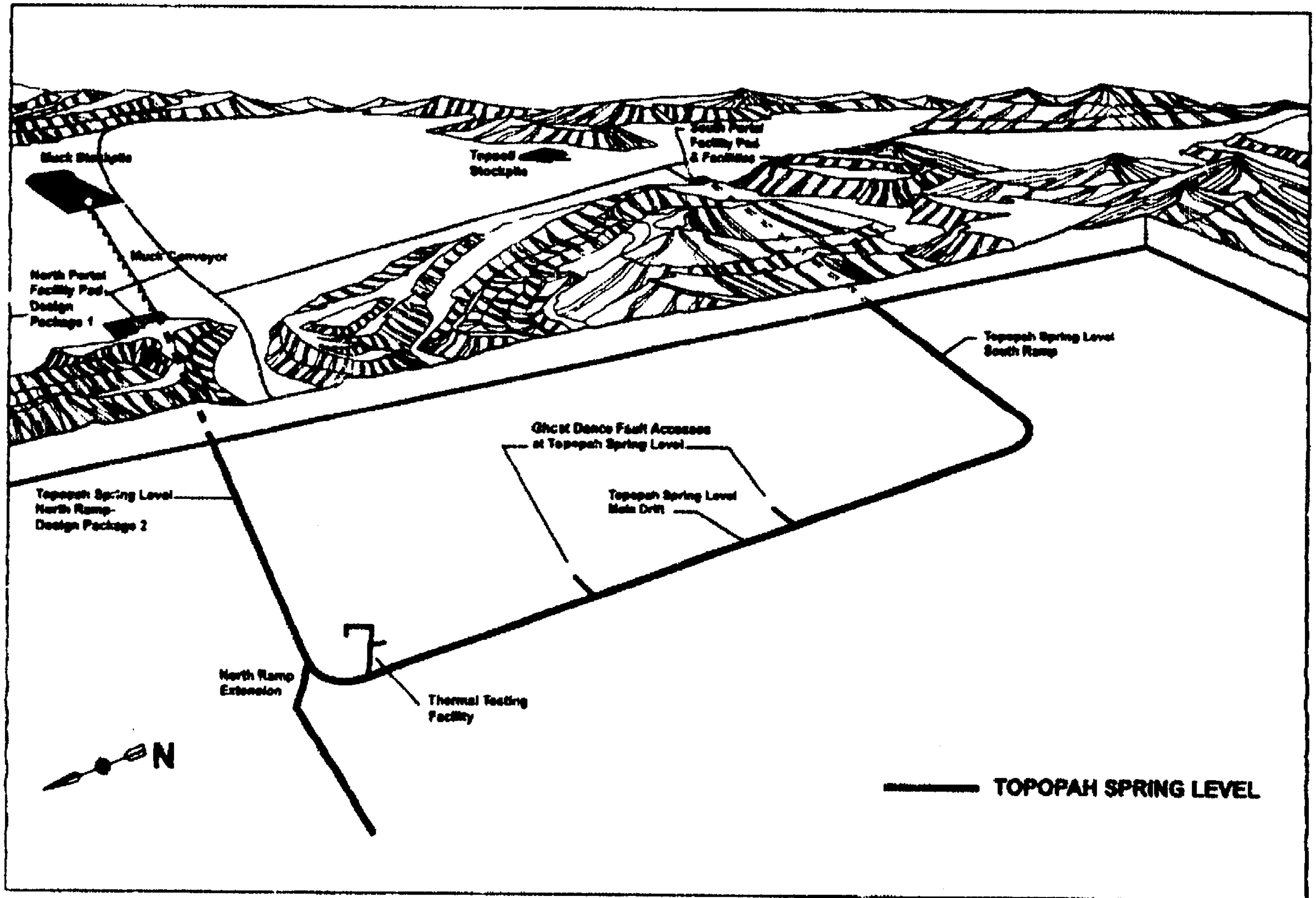

Figure 7-1. Exploratory Studies Facility Design Package Locations

Table 7-2. Exploratory Studies Facility Nomenclature

Alcove name	Accepted alcove acronym	Construction sequence alcove number (for informal reference)
Upper Tiva Canyon Alcove (Anisotropic)	UTCA	Alcove #1
Bow Ridge Fault Alcove	BRFA	Alcove #2
Upper Paintbrush (Non-Welded) Contact Alcove	UPCA	Alcove #3
Lower Paintbrush (Non-Welded) Contact Alcove	LPCA	Alcove #4
Drill Hole Wash Fault Alcove (Deferred)	DWFA	Deferred
Thermal Testing Facility	TTF	Alcove #5
Northern Ghost Dance Fault Alcove	NGDFA	Alcove #6
Southern Ghost Dance Fault Alcove	SGDFA	Alcove #7

The Yucca Mountain Site Characterization Project (Project) initiated a systematic process in the second quarter of FY 1997 to determine the activities necessary to complete construction of the 25 ESF systems. These evaluations may conclude that (a) the system must be completed to the approved design, (b) the system as currently constructed is acceptable, or (c) the system requires additional upgrading to a configuration between the currently constructed design and the approved design. If necessary, the ESF Design Requirements (DOE, 1996h) and the as-built design documentation will be updated to capture the final as-built field configuration and associated requirements.

Construction of underground support and utility facilities continued at a rate needed to support the progress of the tunnel boring machine. Excavation of the Thermal Testing Facility was completed in February 1997, which satisfied a Project milestone. Also, Phase 1 excavation (Northern Ghost Dance Fault access drift) of the Northern Ghost Dance Fault Alcove was completed. The initial phase (approximately 134 m of excavation) of the Southern Ghost Dance Fault access drift portion of the Southern Ghost Dance Fault Alcove was completed.

7.1 EXPLORATORY STUDIES FACILITY DESIGN

ESF design activities proceeded in support of ESF construction and tunnel boring machine operations. The following subsections describe the initiatives and other activities on the various design packages that occurred during this reporting period.

7.1.1 Quality Assurance Activities

Two specifications covering the maintenance and operations of surface facilities and the storage, handling, and operation of materials and equipment were revised to capture the changes made to requirements in the latest revision of the Determination of Importance Evaluation for Surface ESF. The specification revisions maintain traceability to determination of importance evaluation requirements, clarify inspection requirements, and ensure that field operations will have minimum impact on the site and ongoing testing activities. Table 7-3 summarizes ESF design quality assurance activities during this reporting period.

Table 7-3. Exploratory Studies Facility Deficiencies

Graded Deficiencies Received by the Exploratory Studies Facility Design Organization - Issuing Organization	Deficiencies Outstanding as of 10-1-96	Deficiencies Outstanding as of 3-31-97
Corrective Action Requests (most significant)	None	None
Deficiency Reports - Yucca Mountain Quality Assurance Division	4	3
Deficiency Reports - Management and Operating Contractor Quality Assurance	1	1
Performance Reports (least significant--isolated) - Yucca Mountain Quality Assurance Division	0	0
Performance Reports (least significant--isolated) - Management and Operating Contractor Quality Assurance	1	0
TOTALS	**6**	**4**

7.1.2 Design Progress

The following paragraphs report progress made during this reporting period in completing ESF design.

Design Package 1 (North Portal Site Preparation and Surface Facilities)

Two design modifications for Design Package 1 were completed, baselined, and issued for construction by Engineering Change Request: (1) clarification of the specification requirements covering asphalt/concrete surface courses and (2) clarification of the specification requirements covering the sanitary sewer collection system.

Integrated Data and Control System

The data collection system portion of the integrated data and control system equipment purchase order was delivered to the Project in March 1997. The system consists of approximately 10,000 channels of data acquisition hardware housed in 5 cabinets, capable of collecting, storing and transferring data collected from instruments that will be installed in the drift-scale test. The cabinets are currently being configured to accept the types of instrument outputs that will feed data to them.

Design Package 2 (North Ramp Excavation - Starter Tunnel to Topopah Spring Level)

The ESF North Portal Stability Analysis (CRWMS M&O, 1997w) was completed and issued. This analysis examined the stability of existing structural systems at the ESF north portal boxcut and starter tunnel opening. The analysis presents two alternatives for future work in this area (a permanent replacement structure at the north portal or additional testing and analysis of the boxcut and starter tunnel) to ensure the integrity of the system under in situ loadings and possible seismic events.

Topopah Spring Level Main Drift and South Ramp

The analysis for ground support for alcoves was revised. The revision of this analysis established the extent of shotcrete required at the intersections of the ESF main loop and the various test alcoves to supplement the existing rockbolt and steel set ground-support systems to ensure long-term stability of the facility. This revision also removed a large number of To Be Verified (TBV) issues found in the previous revision. Application of shotcrete in the tunnel will begin after tunnel boring machine exits the south portal to avoid interference with ongoing construction activities.

South Portal Pad and Facilities

Final designs for the south portal and pad were released in the previous reporting period. ESF design personnel continued to monitor ongoing construction of the south portal to ensure that the actual ground conditions encountered were within the assumptions made for the design analysis. ESF design personnel were also responsible for monitoring the blasting activities at the south portal

The design package for the south portal lightning system was completed and issued for construction. This system will provide for personnel protection and will be in place before the tunnel boring machine is removed from the tunnel.

Thermal Testing Facility (at Station 28 + 27 (2827 m))

The Thermal Testing Facility is being designed in phases to meet the needs of the testing organizations. The following design activities for the heated drift portion of the Thermal Testing Facility were completed in this reporting period

- **Layout and Ground Support Drawing Package.** This design package covered the general arrangement of the drift excavation and special ground support details.

- **Cast-in-place Liner Test System Design Package.** The cast-in-place liner will become part of the drift scale test and will allow for monitoring of the effects of high heat loads on concrete liners in an environment similar to the potential repository emplacement drifts during the test. The data collected will be crucial in any future designs for structural liners required in the potential repository. The cast-in-place liner design package consisted of a design analysis and two detail drawings of the liner. The design analysis was a cooperative effort with the Repository Design Group. The analysis provides the basis for selection of critical cast-in-place lining construction, configuration, materials, and controls to ensure that the test results can be qualified for use as a design input of potential repository lining systems.

- Concrete Invert design drawings. This design package covered detailed designs for the concrete floor system required in the heated drift.

- Cable Tray Installation Sketches. A set of four sketches showing the cable tray installation inside and outside the heated drift was transmitted to the ESF Test Coordination Office for inclusion in the appropriate Field Work Package. While not a formal design package, these sketches were prepared to assist the testing organization in developing the arrangement of the Thermal Testing Facility.

Northern Ghost Dance Fault Alcove [at Station 37 + 37 (3737 m)]

The design drawings for the Northern Ghost Dance Fault Alcove were revised to incorporate the Northern Ghost Dance Fault Drill/Test Room and issued for construction near the end of this reporting period. This revision included plan and section drawings for the extension of the drift though the fault and creation of a drill/test room on the far side of the fault. Completion of this excavation will support ongoing testing of the Ghost Dance fault structure.

Southern Ghost Dance Fault Alcove [at Station 50 + 64 (5064 m)]

Design of a drift extension and drill/test room, similar to that designed for the Northern Ghost Dance Fault Alcove, will be completed later in FY 1997.

Other Design Activities

A Technical Document Preparation Plan for the Construction Completion Evaluations on the alternate construction utilities was completed and issued. Alternate construction utilities are those utility systems (e.g., power, compressed air, lighting, ventilation, etc.) that were designed and installed by the constructor to support excavation of the ESF. These evaluations will examine each alternate construction utility system of the ESF and will define the minimum design and/or construction modifications required for these systems to continue supporting the requirements of ongoing ESF testing.

Forecast: The following activities are scheduled for second half of FY 1997:

- Approval and issuance for construction of the south portal "flow through" ventilation system. This system will be designed as a modification to the existing construction ventilation system to support ongoing testing in the ESF after tunnel boring machine exit at the south portal.

- Approval and issuance for construction of drawings and specifications for the remaining portion of the Thermal Testing Facility. Areas of work remaining include completion of the thermal bulkhead, ventilation system, and power distribution system designs.

- Revision of the design drawings for the Southern Ghost Dance Fault Alcove to include the drift extension and planned drill/test room layouts.

- Completion of configuration of the data collection system cabinets and shipment to the ESF north portal pad for installation, scheduled for May 1997. Wiring of the instruments to the data collection system and pre-operational checkout are scheduled to begin in June 1997.

- Completion of 13 Architect/Engineering Construction Completion Evaluations with associated as-constructed documentation and system descriptions. These evaluations will examine each alternative construction utility system of the ESF and will define the minimum design and/or construction modifications required to ensure these systems to continue supporting the ongoing ESF testing program. The construction report for the "Q" ground support will begin in FY 1997 but will not be completed until FY 1998.

- Continuation of the ground support confirmation process. The ESF ground-support systems will be evaluated to assess and confirm their adequacy. These evaluations will be based on the comparison of the design with the results of ESF construction monitoring. Confirmation reports covering ground support up to Station 56 + 00 (5600 m) are scheduled to be released in FY 1997.

- Support of completion of ESF change house construction. Any additional design document revisions required to allow completion of the ESF change house will be prepared.

- Approval and issuance for construction of design layout drawings for the drift-scale flux test niches. The niches will be designed to support testing requirements. The niches, due to location on the right rib of the Topopah Spring main drift, will be located to minimize impact on potential repository emplacement drifts.

7.2 EXPLORATORY STUDIES FACILITY SEISMIC DESIGN

The purpose of this activity is to report on progress in ESF seismic design.

No further work occurred during this period in this area. Seismic design basis requirements for the ESF permanent and temporary items are documented in Appendix A of the ESF Design Requirements (DOE, 1996h). Seismic design basis requirements applicable to ESF permanent items are shown in this document as "to be verified." ESF items were designed using the appropriate seismic design basis requirements in the ESF Design Requirements.

Forecast: No activities are planned in FY 1997. Over the long term, engineering analysis based on the methodologies of the two seismic topical reports developed to date will be used to verify the seismic design basis requirements for the permanent items provided in the ESF Design Requirements document. The engineering analysis and the removal of the "to be verified" items from the ESF Design Requirements document are expected to be completed in FY 1998. Upon completion of this task, the design of the ESF permanent items will be evaluated for any impacts.

7.3 EXPLORATORY STUDIES FACILITY CONSTRUCTION

Significant progress was made on the construction of the ESF. Figure 7-2 provides a schematic view of tunnel boring machine progress as of March 31, 1997. The "scheduled" progress in Figure 7-2 reflects the schedule promulgated in Revision 1 of the Civilian Radioactive Waste Management Program Plan (DOE, 1996a). This schedule was revised at the time the Program Plan revision was made to reflect the very large distance by which the tunnel boring machine was ahead of the previous schedule.

Less-than-favorable ground conditions during December and January of this reporting period resulted in slower than expected ESF tunnel advancement. The Northern Ghost Dance Fault Alcove was under construction at the end of the reporting period, along with the Topopah Spring level south ramp

7.3.1 Tunnel Boring Machine Operations

The tunnel boring machine continued excavating in the TSw1, crystal-poor upper lithophysal unit of the Topopah Springs unit, until encountering the Tiva Canyon, Tpcpv, at approximately Station 74 + 37 (7437 m) in late February 1997. The tunnel boring machine is expected to remain in the Tiva Canyon unit until it exits at the south portal at Station 78 + 78 (7878 m).

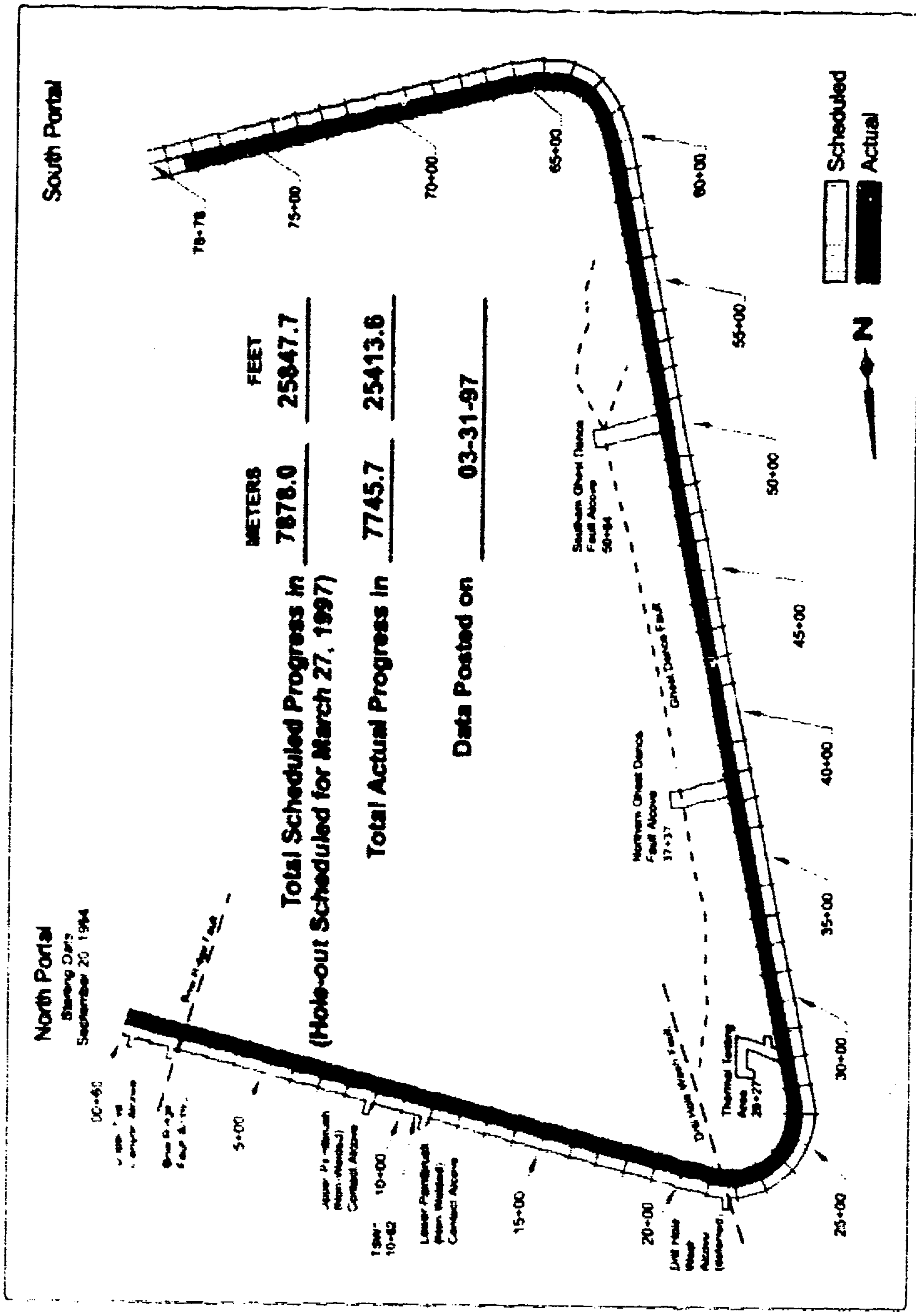

Figure 7-2. Tunnel Boring Machine Progress

At the beginning of this reporting period, the tunnel boring machine was at Station 64 + 78 (6478 m), which was 174 m and 27 calendar days ahead of the revised Program Plan schedule. The tunnel boring machine advanced 1268 m during this reporting period and at the end of the period was at Station 77 + 46 (7746 m), 32 calendar days and 132 m behind schedule. During this reporting period, 42 m and 59 calendar days were lost against the revised Program Plan schedule. As mentioned in Progress Report #15, the project adopted a new Project baseline in June 1996. This 1996 baseline schedule placed the tunnel boring machine exit date at March 27, 1997.

During the first two months of this reporting period, the tunnel boring machine advanced at an average rate of 21.6 m per excavation day until highly fractured rock was encountered in late November that significantly reduced progress. During December and January the average advance rate fell to 2.5 m per excavation day in highly fractured rock that required extensive hand mucking of material around the tunnel boring machine before the installation of invert segments and also required almost continuous steel sets for ground support. In early February ground conditions improved significantly, allowing the tunnel boring machine advance rate to average 20 m per excavation day for the month.

7.3.2 Tunnel Boring Machine 500-Hour Maintenance

At the beginning of the first quarter of FY 1997, the tunnel boring machine was shut down for seven days to perform the fourth 500-hour maintenance. The tunnel boring machine is equipped with an hour meter that operates while the cutter head is rotating; this meter is used to determine the 500 hours of machine use. The maintenance was performed to ensure continued reliable operation and to meet the manufacturer's warranty requirements. As with the previous 500-hour maintenance activities, the fourth 500-hour maintenance generally revealed conditions expected for equipment subjected to the type of material that has been encountered. The main requirement was for hard facing and installing wear plates on the cutter head.

7.3.3 Test Alcove Construction

Test alcoves are being excavated to provide the project with dedicated testing areas free of construction influences to acquire data on the geologic, hydrologic, geochemical, and geothermal characteristics of the site. These alcoves are located at predetermined sites along the north ramp and the Topopah Spring level main drift. The general locations correspond to specific test requirements (such as the need to investigate a fault structure). The specific locations chosen are those expected to provide maximum relevant test data acquisition while minimizing test interference. The tests conducted in these alcoves are described in Chapters 3 and 5 of this progress report.

Three test alcoves were under construction during the reporting period: the Thermal Testing Facility located at Station 28 + 27 (2827 m), the Northern Ghost Dance Fault Alcove located at Station 37 + 37 (3737 m) and, the Southern Ghost Dance Fault Alcove located at Station 50 + 64 (5064 m). Excavation of the Thermal Testing Facility was completed in early February 1997. Completion of excavation of the Thermal Testing Facility satisfied the Program milestone to complete excavation of the alcove. Construction is continuing in the Thermal Testing Facility to support the planned drift-scale test scheduled to start in the first quarter of FY 1998.

Characterization of the Northern Ghost Dance Fault Alcove was completed during this reporting period, and Phase II (Northern Ghost Dance Fault Drill/Test Room) excavation resumed in March 1997.

Construction of the Southern Ghost Dance Fault Alcove began in October 1996 and was completed to Station 1 + 34 (134 m) in late February 1997. At this time, excavation was halted to allow for planned test drilling and instrumentation to be installed to support fault characterization. Excavation to complete Phase I (Southern Ghost Dance Fault Access Drift) of the Southern Ghost Dance Fault Alcove resumed in mid-March 1997.

7.3.4 Surface Facilities and Utilities Construction

Construction of the change house on the north portal pad, which was deferred during the first quarter of FY 1996 because of budgetary constraints, resumed during this reporting period.

The south portal road, pad, and boxcut construction was completed during the reporting period. This task included stripping the topsoil for the road and the pad, excavating the boxcut, constructing the demobilization pad for the tunnel boring machine, and setting up the utility needs for the demobilization of the tunnel boring machine operation.

Forecast: The rate of tunnel boring machine advancement is expected to decrease as it nears the ground surface and encounters increasingly weathered rock resulting in an increased need for installation of steel set ground support. The tunnel boring machine is scheduled to exit at the south portal early in the third quarter of FY 1997.

Phase II (Northern Ghost Dance Fault Drill/Test Room) excavation of the Northern Ghost Dance Fault Alcove is scheduled to be completed in the third quarter of FY 1997.

Phase I (Southern Ghost Dance Fault Access Drift) excavation of the Southern Ghost Dance Fault Alcove is scheduled to be completed in the third quarter of FY 1997. Phase II (Southern Ghost Dance Fault Drill/Test Room) excavation of the Southern Ghost Dance Fault Alcove is scheduled to start in the fourth quarter of FY 1997 and be completed in the first quarter of FY 1998.

Completion of conversion of the tunnel ventilation system after tunnel boring machine exit and construction of the change house on the north portal pad is scheduled for the fourth quarter of FY 1997

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Completion of the switchgear building and potable water system on the north portal pad and the north portal pad drainage is scheduled for FY 1998.

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APPENDIX A

Documentation of Changes to the Program Since the Site Characterization Plan was Issued and Status of Site Investigations, Performance Assessment and Design Activities

PROGRESS REPORT #16

CONTENTS OF APPENDIX A

APPENDIX A

Documentation of Changes to the Program Since the Site Characterization Plan was Issued and Status of Site Investigations, Performance Assessment and Design Activities

INTRODUCTION

The 1988 Site Characterization Plan (SCP) (DOE, 1988) was developed in accordance with the Nuclear Waste Policy Act of 1982 (NWPA, 1983), as amended (NWPAA, 1987), and has been the basis for the site characterization phase of the geologic repository program. In 1989, the U.S. Department of Energy (DOE) assessed the progress and needs of the repository program and established a schedule that would result in a suitability determination for Yucca Mountain in fiscal year (FY) 2001, and if the site were suitable, would result in start of disposal operations in FY 2010. In parallel with the DOE assessment, the approach to underground characterization changed as vertical shaft and drift accesses were replaced by inclined ramps and drifts. From 1989 to 1994, the DOE planned for and then conducted a comprehensive program of site investigations based on the SCP.

By 1994, external and internal factors had tended to broaden, rather than focus the program; Congress had also begun to express concern about continuing growth in the estimated cost of site characterization. Thus in 1994, the DOE issued a revised Program Plan (DOE, 1994a) that was designed to show early observable progress with the financial resources likely to be available. The plan recognized that a great deal of site characterization information had been obtained since the SCP was issued, and that therefore, completing the entire SCP was no longer technically necessary and would have required more resources than could reasonably be expected to be available before the submittal of a license application in 2001. As a result, a new, more flexible approach was developed, and site investigations were phased in such a manner that some of the original planned tests could be de-emphasized and others could be shifted to confirmatory status. Previous progress reports have reported these changes as they affected study plans, design activities, and performance assessment plans. The Civilian Radioactive Waste Management Site Characterization Program (Program) intends to continue evaluations and adjustments of work scopes as information needs evolve.

Congress endorsed the 1994 Program Plan and provided a 37 percent increase in funding for FY 1995; subsequently, important progress was made. However, guidance from Congress and a significant funding reduction in FY 1996 required another revision to the Program Plan, which was issued in May 1996 (DOE, 1996a). Under the funding reductions, the 1994 Program Plan was no longer sustainable. The Yucca Mountain Site Characterization Project (Project) was refocused to emphasize core scientific activity which had continued to develop site characterization data and models throughout this period, excavation of sections of the Exploratory Studies Facility (ESF) necessary for scientific study, and completion of the repository and waste package conceptual designs. Activities supporting preparation and filing of a license application for the repository were deferred. In FY 1997, the program was further focused on an assessment of the viability of geologic disposal at Yucca Mountain in 1998. The revised program strategy is designed to maintain momentum in scientific investigations and regain target dates for determining site suitability and submitting a license application. The new date for recommending the repository site to the President is 2001 if the site is found suitable, and the current plan is to submit a license application to the U.S. Nuclear Regulatory Commission (NRC) in 2002.

Reflecting these top-level program redirections in detailed annual and long-range plans was a major task during FY 1996. With a baselined program in place at the beginning of FY 1997, documenting changes from the original plans presented in the SCP is now a priority. Previous progress reports have provided linkages from the SCP to the requirements or planning documents that provide the basis for the ongoing programs and have also documented changes to the site study and activity structure in the SCP. This appendix is intended to extend the documentation to provide a status and rationale for changes in the design and performance assessment programs. Most changes to the program will be found in the approaches to, amount of, and sequencing of field data collection activities.

While there have been noticeable changes to the repository and waste package design concepts since the SCP Conceptual Design (SNL, 1987), there has not been a correspondingly large number of substantial changes in the technical information needed to design the repository and waste package. The most significant change to the original conceptual design plans described in the SCP is the waste package. That waste package was a thin walled container designed to be emplaced in boreholes; current plans, driven in part by DOE goals for earlier waste acceptance, have shifted to a large, double-walled waste package that will be emplaced in large drifts. A number of changes in the waste package design program are linked to this change.

Similarly, as additional information about the geotechnical character of the site has become better understood, and as system studies have examined alternative approaches to address 10 CFR Part 60 requirements, the repository design concept has evolved to be responsive to this information. For example, the SCP conceptual repository design was interfaced with the ESF design that used vertical shafts for access. Current repository designs are integrated with the drift-based approach that has been used for the ESF. These changes to the current repository design, while appearing to be substantially different from the conceptual design that served as the basis for the SCP, have resulted in few substantive changes in the definition of the technical information needed to design the repository. While maturation in the understanding of constraints and design solutions has resulted in designs that are more responsive to 10 CFR Part 60 requirements, there has not been a concomitant large number of significant changes in the approaches embodied in the issue resolution strategies developed to address these regulatory requirements.

For performance assessment, changes in the regulatory framework together with new site and design information have increased our knowledge base so that improved approaches can be defined. Many of these improved approaches have been discussed with NRC staff during technical interactions or summarized in previous progress reports.

PROGRESS REPORT #16

This appendix provides a systematic review and documents the changes since the SCP was issued at a level of detail that is commensurate with the current planning basis. Following this introduction, the changes in site investigations, repository design, waste package design, and performance assessment are discussed in turn. The discussions first outline the background preceeding the changes and then provide the current status for each study.

This appendix will be updated in future progress reports as additional changes to the program are made. Progress Report #15 summarized changes in the program since the issuance of the SCP in 1988. Additional detailed documentation of the rationale and justification for changes has been provided in this progress report. As part of the ongoing annual and long-range planning efforts, we continue to evaluate our work plans to ensure that the scope and schedule for activities will support the major milestones of the Program, which are (1) viability assessment in 1998, (2) site recommendation in 2001, and (3) license application in 2002. Future semiannual progress reports will provide rationale and justification for changes to the program as performance and design information matures. Ultimately, the adequacy of the revised site characterization program will be judged on the basis of whether sufficient engineering and scientific information has been developed at each stage of the program to provide the technical basis for the approval required to continue the program.

Documents cited in this appendix are included in the consolidated reference list for this progress report (Appendix L).

A.1 SITE PROGRAMS (SCP SECTION 8.3.1)

The Nuclear Waste Policy Act and the High-Level Radioactive Waste Disposal Regulations found in 10 CFR Part 60 specified that DOE develop an SCP before beginning any activities to characterize potential repository sites. The SCP (DOE, 1988) presents the initial general plan for the Yucca Mountain site and was based on then-available information about the site, and on then-current conceptual designs for the repository and the waste package. The SCP was intended to provide the framework for all the site programs, but it was also intended to provide program flexibility. The framework was to be augmented by study plans that were to be developed for each study and were intended to supply site-specific requirements for each study. These plans were intended to describe the specific objectives of each study, specify the approaches and methods to be used to collect data, describe the accuracy and precision requirements for the data, and identify the uses for which the data were needed.

The SCP envisioned an extensive program of data collection designed to characterize the natural features and processes of the site, and reduce, or at least bound, the uncertainties associated with the various characterization parameters. At the outset, the DOE recognized that it was initially committing to conduct a very large number of studies and that many of them would later be shown to be redundant or possibly unnecessary. Thus the SCP contemplated periodic revisions as the site characterization program matured. The purpose of the program was originally to provide the scientific data needed to support the evaluation of site suitability and develop the license application for construction authorization. As discussed in the introduction to this appendix, although the original purpose of the Project has been maintained, the Project has been refocused to emphasize core scientific studies and excavation of those parts of the ESF needed for in situ scientific studies. The revised program strategy was designed to maintain momentum in scientific investigations, provide data needed to support the viability assessment, determine site suitability, and submit a license application.

In planning the program described in the SCP, the DOE adopted an approach that began with identifying the regulatory requirements that must be satisfied in siting and licensing the repository, identifying the performance and design information needed to address those requirements, and then developing specific investigations to obtain the needed information. This approach was embodied in an issue resolution strategy which was discussed in some detail in Section 8.1 of the SCP. An important part of this strategy was an issues hierarchy (discussed in Section 8.1.1 of the SCP) and in the DOE Mission Plan (DOE, 1985) that consisted of key issues, related issues, and information needs. The key issues and related issues were based on the requirements in the disposal regulations. The information needs defined the data and analytical techniques that were needed to resolve each issue.

The issues hierarchy stated questions about the performance of the disposal system and identified the information that would be required before a site could be selected and licensed. The issues hierarchy was developed as a three-tiered framework consisting of key issues, related issues, and information needs. On the highest tier were four key issues which embodied the principal requirements established by the regulations governing geologic disposal. Each of the key issues was expanded, in the next tier, into a group of related issues that elaborated on the requirements stated in the parent key issue. The lowest tier consisted of still more detailed sets of requirements called "information needs" that were associated with each issue. This framework provided a convenient means to distinguish broad questions of overall performance and suitability (key issues) from more specific questions about the characteristics of the site, the design of the repository and the waste package, and the performance of the total geologic disposal system. The framework also distinguished the key issues and related issues from the requirements for basic information needed to resolve the issues.

The investigations for the site characterization program have evolved based on the technical information obtained from the laboratory and field studies, model development and data application activities. Rapidly increasing scientific understanding, along with periodic total system performance assessments, have enabled focusing the ongoing site characterization program on the remaining uncertainties that are significant to the design, operation and safety performance of the proposed repository. Reevaluation and prioritization of Project needs has been a continuous process based on scientific judgment and resource availability, governed by scientific criteria to (a) ensure that data needed for site description, performance assessment, and design purposes were collected and analyzed, and (b) eliminate data-collection that is redundant or no longer relevant. The data-collection needs have been further analyzed and refined as additional knowledge has been gained through years of site characterization activities and analysis of site data.

In addition, major technical revisions to the repository program including reconfiguration of the ESF from a shaft-and-main configuration to a ramp-and-main configuration, mechanical excavation of the ESF using a large diameter tunnel boring machine, and reconfiguration of the repository from vertical borehole emplacement to in-drift emplacement required major revisions to the site programs. The ramp-and-main configuration provided increased opportunities for observation of changes in stratigraphic, lithologic, and structural characteristics of the host rock. As a result, the strategy and methods for in situ mapping of fracture networks, faults, and lithostratigraphic features have changed considerably. Most notable of these changes has been the acquisition of a large volume of data collected through detailed line surveys and full periphery mapping of the ESF. Some questions about geohydrologic features and processes, inferred from the results of surface-based tests, could be answered by direct observation. Because of the increased opportunities for direct underground observation and sampling, it was possible to reduce the scope of some surface-based testing activities.

Section A.1 of this appendix is organized by individual site characterization programs. For each program, background and SCP plans are summarized by study within each investigation. Subsequently, changes that have occurred, the basis for the changes, and the current status of each study are described.

A.1.1 Geohydrology Program (SCP Section 8.3.1.2)

The geohydrology program was developed to provide an understanding of the geohydrologic environment that is essential to assessing the viability and suitability of the site. Ground water is expected to be the major transport medium of radionuclides to the accessible environment. The general SCP strategy to accomplish the geohydrology program was to conduct investigations that would result in complete and accurate descriptions of the pertinent components of the hydrologic system. The descriptions would reflect understanding of the hydrologic properties, initial and boundary conditions and processes, and their interrelationships. The results of the geohydrology program were to be combined with the results of other site programs to produce a site model, or a complete description of the site.

The geohydrology program consisted of the data collection and evaluation activities that were to result in hydrologic models that describe two distinct regimes of the hydrologic system: the unsaturated zone and the saturated zone. Each of these regimes was to be characterized to provide input to the hydrologic models. The unsaturated zone hydrologic model was to be developed only at the site scale, whereas the saturated zone models were to be developed at both site and regional scales. The hydrologic regimes described by these models were to be those that significantly affect the resolution of hydrologic-related design and performance issues; these regimes, therefore, were to be the principal subjects of investigation in the geohydrology program.

The investigations included in the geohydrology program are summarized in the following sections.

A.1.1.1 Studies to provide a description of the regional hydrologic system (SCP Investigation 8.3.1.2.1)

Background and SCP Plans. The objectives of this investigation were (a) to develop a conceptual model of the regional hydrologic system to help assess the ability of the site to contain and isolate waste, and (b) to construct a consistent, regional, numerical model of ground-water flow so that reliable boundary conditions could be assigned to the more critical site area embedded within the regional model. This investigation included four studies developed to accomplish the following:

1. Study 8.3.1.2.1.1 (characterization of meteorology for regional hydrology): This study was to (a) characterize precipitation in the area surrounding Yucca Mountain and its relationship to surface runoff, with particular emphasis on the Fortymile Wash drainage basin; and (b) provide site-specific information on storm precipitation at and near the network streamflow-measurement sites as input to precipitation-runoff models and to infiltration studies.

2. Study 8.3.1.2.1.2 (characterization of runoff and streamflow): This study was to (a) collect data on the characteristics, magnitudes, frequencies, and timing of surface-water runoff at, and peripheral to, Yucca Mountain; (b) develop an understanding of the relationships between specific runoff events and the characteristics of the storms; (c) provide calibration data for precipitation-runoff models for the regional study area; (d) provide data and interpretations of surface-water runoff for evaluations of the amount and processes of ground-water recharge;

and (e) document both quantitatively and qualitatively the characteristics of debris transported by intense surface runoff and assess the potential for flood hazards and related fluvial-debris hazards.

3. Study 8.3.1.2.1.3 (characterization of the regional ground-water flow system): This study was to (a) prioritize data needs for use in the regional ground-water flow description; (b) determine the regional potentiometric distribution, including the cause of the large hydraulic gradient; (c) characterize the regional hydrogeologic framework to support reliable estimates of ground-water flow direction and magnitude; (d) use hydrologic, hydrochemical, and heat-flow data to determine the magnitude and direction of ground-water flow; (e) determine to what extent (quantitatively, if feasible) Fortymile Wash has been a source of recharge to the saturated zone under present and past conditions; and (f) improve estimates of ground-water discharge by evapotranspiration in the Amargosa Desert to provide boundary-condition data for regional ground-water flow models.

4. Study 8.3.1.2.1.4 (regional hydrologic system synthesis and modeling): This study was to (a) synthesize available data and identify ground-water flow system boundaries, hydrogeologic units, structural controls, and other hydrogeologic features pertaining to the regional ground-water flow system; (b) update an existing two-dimensional, subregional, parameter-estimation model; (c) perform subregional, two-dimensional cross-sectional modeling to estimate ground-water flow direction and magnitude along a potential flow path through the repository block to the accessible environment and extending into the region; (d) develop a comprehensive, regional, three-dimensional numerical ground-water flow model; and (e) use the regional model to test the impacts of possible future tectonic activity and climatic changes on the saturated hydrologic system.

Changes and Status. The primary objectives of this investigation have not changed since the SCP was issued. The SCP, however, described a more extensive program of data collection. The studies for this investigation have evolved based on the technical information obtained from the laboratory and field studies, and model development and data application activities of the site characterization program. Rapidly increasing scientific understanding, along with periodic total system performance assessment, have enabled focusing the ongoing site characterization program on the remaining uncertainties that are significant to the design, operation and safety performance of the proposed repository. Reevaluation and prioritization of Project needs has been a continuous process based on scientific judgment and resource availability, governed by scientific criteria (a) to ensure that data needed for site description, performance assessment, and design purposes were collected and analyzed, and (b) to eliminate data-collection redundancy and overlap. The data-collection needs have been further analyzed and refined as additional knowledge has been gained through years of site characterization activities.

1. In the meteorology study (8.3.1.2.1.1), rainfall-runoff models were not developed because direct relationships between precipitation and both infiltration (Hudson and Flint, in prep.; Flint et al., in prep.) and recharge (Hevesi and Flint, in press;

D'Agnese et al., in press[a]) were developed for hydrologic models using methods that did not require simulation of the runoff component. Also, because runoff occurs so infrequently, it was determined to be infeasible to maintain readiness for runoff monitoring with available Project resources. Instead, the emphasis of the meteorology study was focused on analyzing regional and synoptic-scale weather patterns that impact infiltration at Yucca Mountain and on statistically analyzing the spatial variability of average annual precipitation as it relates to estimates of ground-water recharge for the regional saturated zone flow model. Meteorological data collection and analysis activities were focused on determining the seasonality, duration, intensity, and spatial variability of storms that produce net infiltration in the many small watersheds that compose the Yucca Mountain site area. To accomplish this, a network of full weather stations and tipping-bucket precipitation gauges was maintained through FY 1995 and then reduced in FY 1996 (CRWMS M&O, 1995f). A reduced-intensity, site-area, meteorological data-collection effort will continue after being transitioned to the Radiological and Environmental Field Programs. The DOE believes that the site-area data collection effort will be adequate to provide data needed for the viability assessment and license application. The determination of whether additional data are needed will be based on analyses of the sensitivity of total system performance assessment.

2. In the runoff and streamflow study (8.3.1.2.1.2), regional-runoff studies and data collection for precipitation-runoff modeling were terminated before being fully implemented because the data were not needed for the regional ground-water-flow model (D'Agnese et al., in press[a]). Regional ground-water modeling did not require runoff data for model calibration because data describing a direct relationship between precipitation and ground-water recharge was used. In recent years, the emphasis of the streamflow study shifted to measuring the runoff component of the water balance in small watersheds at Yucca Mountain in support of the unsaturated zone infiltration study (8.3.1.2.2.1) [Progress Report #9, Section 2.2.1.2 (DOE, 1994g); Progress Report #13, Section 3.1.2 (DOE, 1996f)]. However, because the net-infiltration component is so small compared with the runoff component and because runoff occurs so infrequently, this approach was abandoned after instrumenting only a few watersheds [Progress Report #14, Section 3.1.2 (DOE, 1996g); CRWMS M&O, 1995f). Because flooding and fluvial-debris transport were shown by the preclosure hydrology program (8.3.1.16) to pose little or no threat to the ESF, the potential repository, or surface facilities at Yucca Mountain (DOE, 1995d), studies to document transport of debris by severe runoff were terminated before being fully implemented.

3. In the regional ground-water system characterization study (8.3.1.2.1.3), the drilling program designed to resolve uncertainties in the regional potentiometric distribution (including the large hydraulic gradient) has not been implemented. In particular, a deep hole in the Amargosa Desert intended to establish geologic control and obtain potentiometric-head data for the Paleozoic carbonate aquifer was not drilled. Instead, data from sources outside the Project have been relied upon almost exclusively to characterize the regional hydrogeologic framework and the regional potentiometric

surface for input to the three-dimensional. regional ground-water-flow model. Despite the almost exclusive use of outside data, the three-dimensional ground-water-flow model has been successfully developed and calibrated (D'Agnese et al., in press[a]). Although possible causes of the large hydraulic gradient have been identified through analyzing available geologic and geophysical data (Fridrich et al., 1994; Luckey et al., 1996) and through hydraulic testing in well USW G-2, the cause of this feature remains an unresolved issue (Luckey, 1996). However, data currently under review and field activities planned for FY 1997 and FY 1998, may result in additional characterization of the large hydraulic gradient. The large hydraulic gradient is a conceptual uncertainty because there is no obvious geologic explanation, and deep geologic information is sparse in this area north of Yucca Mountain. Although reconnaissance-level studies have determined that ground-water recharge to the saturated zone occurs in upper Fortymile Wash (Savard, 1996; Luckey, 1996; Savard, in prep.), the field studies to quantify this recharge have not been conducted because they were determined to be of low priority (CRWMS M&O, 1995f). Similarly, although evapotranspiration feasibility and prototype work was performed [Progress Report #11, Section 3.1.3 (DOE, 1995b)], the field studies to improve estimates of ground-water discharge by evapotranspiration in the Amargosa Desert have not been conducted. Instead, estimates of regional ground-water recharge and discharge were improved using a modification of the Maxey-Eakin method. This method uses a geostatistically derived distribution of average annual precipitation and a regional distribution of recharge potential based on elevation, vegetation, slope-aspect, and rock and soil permeability data obtained using remote-sensing and Geographic Information System techniques (D'Agnese et al., in press[a]). With this approach, the three-dimensional ground-water-flow model has been successfully developed and calibrated.

4. In the regional hydrologic system synthesis and modeling study (8.3.1.2.1.4), updating of an existing two-dimensional, subregional, parameter-estimation model, developed in 1984, and two-dimensional cross-sectional modeling along a potential flow path have not been performed as separate activities. However, much of the work scope intended for these activities is being accomplished by the development and testing of the regional, three-dimensional ground-water flow model (Activity 8.3.1.2.1.4.4). The distribution of estimated values of hydraulic conductivity from parameter-estimation simulations of the model are well within the range of field data for the region (D'Agnese et al., in press[a]), but the model still contains uncertainty. This is because field values of hydraulic conductivity range over two to three orders of magnitude for each rock type. Overall, the range of hydraulic conductivity values for the entire model is more than seven orders of magnitude. Furthermore, there are only about 20 potentiometric-level control points for the lowest layer of the model where most of the Paleozoic carbonate aquifer is represented. Note that the hydraulic conductivity of the Paleozoic carbonate aquifer was the most sensitive parameter in the parameter estimation calibration of the model (D'Agnese et al., in press[a]). Also, model results indicate that flow in the Paleozoic carbonate aquifer has substantially influenced flow in the overlying volcanic rocks. However, overall confidence in simulation of the

Paleozoic carbonate aquifer is strengthened by good control on discharge from the aquifer through well-documented spring discharge data (D'Agnese et al., in press[a]).

The overall regional saturated zone flow system in the vicinity of Yucca Mountain appears to be controlled by the deep Paleozoic carbonate aquifer. From a postclosure performance perspective, however, the overlying tuffaceous aquifers are more significant because they would contain any likely travel paths for radionuclides moving between the potential repository and the accessible environment. In addition, any future use of ground water in the region would likely concentrate on the shallower tuffaceous aquifers rather than on the deeper, albeit more transmissive, carbonate aquifer. The uncertainty in the overall saturated zone flow system and the potential transport of radionuclides will be assessed in the total system performance assessments.

Although large-scale anisotropy has not been characterized by field tests, regional structural features (major faults and fault zones) have been included in the regional model to improve its performance (see Section 3.1.4 of this progress report under Activity 8.3.1.2.1.4.4). The results from ongoing sensitivity analyses will determine whether any further data collection would significantly increase confidence in the regional saturated zone model.

A.1.1.2 Studies to provide a description of the unsaturated zone hydrologic system at the site (SCP Investigation 8.3.1.2.2)

Background and SCP Plans. The objective of this investigation was to develop a model of the unsaturated zone hydrologic system at Yucca Mountain that would help assess the suitability of the site to contain and isolate waste. Developing this model requires an understanding of the manner in which water and gases move through the unsaturated zone, including the directions, paths, and rates in which flow occurs. This information was to be provided through studies of the characterization of infiltration, percolation, gaseous-phase movement, and hydrochemistry. Flow and transport modeling designed to simulate the natural system would provide sensitivity analyses to help prioritize additional data collection. This investigation includes nine studies. Of these, the first seven were data-collection studies; the last two were system-modeling studies. These studies were developed to accomplish the following:

1. Study 8.3.1.2.2.1 (characterization of unsaturated zone infiltration): This study was to (a) characterize the infiltration-related hydrologic properties and conditions of the surficial soils and rocks covering Yucca Mountain; (b) characterize present-day, natural infiltration processes and net-infiltration rates; (c) characterize the range and spatial variability of infiltration rates, flow velocities, and flow pathways in the near-surface unconsolidated surficial material and consolidated bedrock using double-ring infiltrometer and ponding studies (artificial infiltration activity); (d) characterize the relationship between precipitation, soil thickness, runoff, infiltration, evapotranspiration, and development of perched water tables in the near-surface unconsolidated surficial material in each representative hydrogeologic surficial unit using small-plot

and large-plot rainfall simulation tests (artificial infiltration activity); and (e) estimate the future spatial distribution of infiltration rate over the repository block.

Study 8.3.1.2.2.2 (water-movement tracer tests): This study was to characterize the percolation of precipitation into the unsaturated zone at Yucca Mountain and the movement of water through the unsaturated zone using chloride and chlorine-36 measurements.

3. Study 8.3.1.2.2.3 (characterization of percolation in the unsaturated zone—surface-based studies): This study was to (a) characterize and statistically describe the flux-related, matrix hydrologic properties of major unsaturated zone hydrogeologic units and structural features as functions of moisture content or potential through laboratory testing of geologic samples obtained from surface-based boreholes and from the ESF; (b) determine the present vertical and lateral variation of percolation flux through the hydrogeologic units and structural features by measuring the potential field and determining the in situ bulk permeability of the unsaturated media in vertical boreholes throughout the site; (c) evaluate the hydrogeologic significance of fracturing, brecciation, and gouge development within the Solitario Canyon fault zone by drilling and testing a horizontal borehole; and (d) investigate the relationships between present flux and past climatic conditions.

4. Study 8.3.1.2.2.4 (characterization of percolation in the unsaturated zone—ESF studies): This study was to (a) perform ESF hydrologic tests to supplement and complement the surface-based hydrologic information needed to characterize the Yucca Mountain site and to provide information for analyzing fluid flow and the potential for radionuclide transport through unsaturated tuff; (b) combine the integrated results from the ESF hydrologic tests with data from the surface-based studies to provide an overall understanding of the unsaturated zone hydrologic system (ESF tests were designed to provide phenomenological information about water flow through unsaturated fractured tuffs, in addition to providing basic hydrogeologic data) and (c) conduct ten sets of hydrologic tests in the ESF:

   - Intact-fracture testing to evaluate fluid-flow and chemical-transport properties of single, relatively undisturbed fractures

   - Percolation testing to determine the hydrologic conditions that control the occurrence of fluid flow within fractures and matrix

   - Bulk-permeability testing to determine "representative" characteristics of fracture networks for model simulations at the scale at which the fractured host rock behaves as an equivalent porous medium

   - Radial-borehole testing to determine rock mass hydrologic properties (including bulk air permeability) and to detect vertical movement of liquid water and/or vapor within hydrogeologic units and along contacts

- Excavation-effects testing to monitor changes to both the stress state and fractured-rock permeability caused by excavating and lining the ESF and to calibrate a coupled hydraulic-mechanical model

- Testing of the Calico Hills nonwelded unit to determine hydrologic processes, conditions, and properties under both present and expected future conditions

- Perched-water testing to detect any occurrence of perched-water zones, estimate hydraulic properties of the zones, and determine the implications of perched water on flux, flow paths, and travel times

- Hydrochemistry testing to understand the gas transport processes; provide independent evidence of flow direction, flux, and travel time of gas and water; and determine the extent of water-rock interaction and the geochemical evolution of water

- Multipurpose-borehole testing near the ESF to monitor potential interference of ESF construction with ESF tests, identify perched water, and confirm engineering and hydrogeologic properties of the rock before ESF construction

- Testing of hydrologic properties and flow conditions of major faults encountered in the long drifts at the main test level of the ESF.

5. Study 8.3.1.2.2.5 (diffusion tests in the ESF): This study was to determine in situ the extent to which nonsorbing tracers diffuse into the water-filled pores of the tuffs of the Topopah Spring welded unit and the Calico Hills nonwelded unit in the ESF.

6. Study 8.3.1.2.2.6 (characterization of gaseous-phase movement in the unsaturated zone): This study was to (a) describe the pre-waste emplacement gas-flow field and its effect on net water-vapor transport from the unsaturated zone; (b) identify structural controls on gas-phase flow; (c) determine conductive and dispersive properties of the unsaturated zone for gas flow to assess potential transport of gaseous radionuclides (e.g., carbon-14); and (d) provide the parameters necessary for modeling gas flow; perform model simulations of gaseous flux of moisture affecting deep percolation and transport of tracers in the gas phase.

7. Study 8.3.1.2.2.7 (characterization of the unsaturated zone hydrochemistry): This study was to (a) perform hydrochemical investigations to understand gas-transport mechanisms and provide evidence of gas-flow direction, flux and travel time within the unsaturated zone; (b) design and implement methods for extracting pore fluids from the tuff; (c) provide independent evidence of flow direction, flux, and travel time of water in the unsaturated zone; and (d) determine the extent of the water-rock interaction and model geochemical evolution of water in the unsaturated zone.

8. Study 8.3.1.2.2.8 (fluid flow in unsaturated fractured rock): This study was to (a) develop and validate (through ESF testing) detailed conceptual and numerical models of fluid flow and transport within unsaturated, fractured rock; (b) apply these models to volumes of fractured rock at or below the dimensions at which the rock can be replaced conceptually by an equivalent porous medium; and (c) use the models to help design and interpret hydrologic and pneumatic tests and provide information about model parameters that can be incorporated into site-scale models (Study 8.3.1.2.2.9).

9. Study 8.3.1.2.2.9 (site unsaturated zone modeling and synthesis): This study was to: (a) develop appropriate conceptual models for the site unsaturated zone hydrogeologic system; (b) select, modify, or develop numerical hydrologic models capable of simulating the hydrogeologic system and its component subsystems; (c) construct appropriate hydrologic models for the natural site hydrogeologic system to simulate and investigate the present state of the system and predict probable future and past states of the system under changes in the environmental conditions; (d) evaluate the accuracy and uncertainty of the models using stochastic modeling, conventional statistical analyses, and sensitivity analyses; and (e) integrate data and analyses to synthesize a comprehensive, qualitative, and quantitative description of the site unsaturated zone hydrogeologic system under present as well as probable, or possible, future conditions.

Changes and Status. The primary objectives of this investigation have not changed since the SCP was issued. The SCP, however, described a more extensive program of data collection. The studies for this investigation have evolved based on technical information obtained from the laboratory and field studies, model development and data application activities of the site characterization program. Rapidly increasing scientific understanding, along with periodic total system performance assessment, have enabled focusing the ongoing site characterization program on the remaining uncertainties that are significant to the suitability of the proposed repository site (DOE, 1994a). Reevaluation and prioritization of Project needs has been a continuous process based on scientific judgment and resource availability, governed by scientific criteria (a) to ensure that data needed for site description, performance assessment, and design purposes were collected and analyzed, and (b) to eliminate data-collection redundancy and overlap that would result from completion of all the studies in the SCP (DOE, 1994a). The data-collection needs have been further analyzed and refined as additional knowledge has been gained through years of site characterization activities. This process has resulted in the following changes to the investigation.

1. In FY 1995, the unsaturated zone infiltration study (8.3.1.2.2.1) was reconfigured and accelerated [Progress Report #12, Section 3.1.5 (DOE, 1995g)] in response to the site suitability initiative described in the Civilian Radioactive Waste Management System (CRWMS) Program Plan (DOE, 1994a), which was implemented "to support a stepwise evaluation of the suitability or unsuitability of the Yucca Mountain site" (DOE, 1994a, Vol. 2, p. 15). Under the Program Plan, key evaluations were to be accelerated (compared to the SCP schedule) to focus more effectively on site

suitability apart from all the considerations associated with the license application (DOE, 1994a, Vol. 1, p. 20). In support of the suitability initiative, a Technical Basis Report on geohydrology and transport was scheduled for completion in FY 1998, requiring completion of an intermediate, integrated geology/hydrology/geochemistry model in FY 1997 (DOE, 1994a, Vol. 2, Fig. 2-3). Because the infiltration study was responsible for developing the upper boundary condition for site-scale models of unsaturated zone flow and transport, the study had to be accelerated and reconfigured. As a result, the artificial-infiltration tests described in the SCP were deferred, even though their primary purpose was to validate the numerical infiltration model that has been developed. Consequently, although the numerical infiltration model is technically valid, it contains uncertainty with respect to important rock properties and processes at the alluvium-bedrock interface. Should these uncertainties prove to be critical to the accuracy of determinations of overall performance of a repository, it may be necessary to conduct additional field studies to refine and validate the infiltration model.

The primary goal of the reconfigured study was to define the spatial and temporal distribution of moisture flux for the upper boundary condition for site-scale models of unsaturated zone ground-water flow and transport. In this context, the boundary condition was developed as a conceptual and numerical model using arid-land watershed processes. The model has provided a dynamic link between infiltration flux and known climatic variability, potential climatic trends, potential changes in the surface environment (such as loss of vegetation), and sporadic but extreme meteorologic events. The integration of hydrologic-process models for the surface and near-surface environments with mapped surficial-material hydrologic properties and mapped present-day net infiltration rates (as measured in the neutron-access boreholes) has resulted in a stochastic-deterministic simulation of future upper-boundary conditions, including the probability and magnitude of potential fast pathways of net infiltration.

A surficial-materials infiltration-properties map of the Yucca Mountain area showing the spatial distribution of eight statistically significant soil units was developed, but the field and laboratory measurements used to produce the map were reduced both in number and in scope from that envisioned in the SCP because of the prioritization and accelerated schedule for the infiltration study. The effects of the reduction on data representativeness and utility of the properties map have not yet been determined. Moisture monitoring in the network of neutron-access boreholes was discontinued at the end of FY 1995 after 10 years of monitoring because sufficient data had been collected for this phase of the Program (CRWMS M&O, 1995f, Vol. 1, p. 6.3). A synthesis report was prepared in FY 1996 using existing data to assess the current status of the study and to provide input for the viability assessment. A multiple linear regression model was developed to correlate annual shallow-infiltration estimates measured in 69 neutron-access boreholes to annual precipitation, depth to bedrock, and other hydrogeologic factors (Hudson and Flint, in prep.), but the series of double-ring-infiltrometer and ponding studies intended to determine the range and spatial variability of infiltration rates (artificial infiltration) were not conducted. Similarly, although one detailed water-balance study of Split Wash was initiated to develop and calibrate the evapotranspiration component of the infiltration model, the number and scope of watershed-scale studies was reduced considerably. Further, the artificial infiltration control-plot studies were not implemented. These studies would have measured water-potential gradients in the shallow subsurface (<15 m) under ambient conditions to determine the direction of water flow and the extent to which barometric pumping might be removing water in the vapor phase from the system. Finally, although a numerical model was developed to simulate the interaction of critical processes that result in net infiltration, the small- and large-plot rainfall-simulation tests (artificial infiltration) were not conducted; these tests were intended to validate the model with respect to temporal and spatial distribution of infiltration under both current-climatic and wetter conditions. Specifically, these tests would have provided field data on rock properties and processes of the alluvium-bedrock interface to replace the available data that were collected from the alluvial surface and from deeper within the bedrock units. Presently, the Project has no plans to collect these data on rock properties and processes at the alluvium-bedrock interface.

One of the objectives of the artificial infiltration experiments described in the SCP was to approximate the increased infiltration that might result from potentially wetter climatic conditions in the future by simulating those conditions in the field. Even though the artificial infiltration experiments have not been conducted, monitoring of moisture flux in the neutron-access boreholes over the last 10 years has afforded an opportunity to observe a significant range of natural infiltration events. Termination of the neutron-moisture monitoring at the end of FY 1995 has precluded measurement of the subsurface redistribution of water that infiltrated during the larger events, which may require several years. Nonetheless, as a result of several El Niño winter storm events over the last few winters (especially 1992, 1993, and 1995), unusually large precipitation events have, in fact, occurred and have provided useful insights about the potential effects of wetter conditions on infiltration rates. These El Niño events are estimated to be analogous to the expected precipitation during global warming (due to increases in greenhouse gases) and possibly wetter pluvial periods in the future (Hevesi et al., in prep.). Although monitoring the vertical moisture profiles immediately following these events provided direct, qualitative evidence of the increased infiltration, in the absence of quantitative information on water potentials and fracture-matrix interactions at the alluvium-bedrock interface, longer term direction of flow (up or down), and therefore net infiltration, is not known with certainty.

2. The water movement test study (8.3.1.2.2.2) was expanded considerably in scope and complexity from that outlined in the SCP. The expanded scope was intended to provide corroboration of borehole data which indicated that the pore waters were on the order of hundreds of thousands of years old. Corroboration, if provided, was expected to support low-flux arguments. The SCP indicated that sampling of tuffs for chlorine-36 would focus primarily on obtaining a profile in what was then planned to

be a vertical shaft ESF. Additional chlorine-36 measurements were to be performed on samples collected after a survey of Yucca Mountain to determine areas of active percolation. Since that time, the set of targets for sampling has expanded to include (a) soil samples within the "perimeter-drift boundary" and from pits in Midway Valley, (b) drill cuttings from the last set of neutron-access holes and deep systematic drilling, unsaturated zone and north ramp geologic boreholes, (c) pore water extracted from cores of deep unsaturated zone and north ramp geologic boreholes, (d) rain water and water from the bottom of neutron holes, (e) perched water from several deep boreholes near the ESF, (f) water samples from several deep saturated zone holes, (g) water from springs and shallow wells in the Amargosa Valley and Death Valley, and (h) packrat middens [Progress Reports #6 through #15 (DOE, 1992b, 1992c, 1993b, 1994g, 1994e, 1995b, 1995g, 1996f, 1996g, and 1997e)]. With the reconfiguration of the ESF into the ramp and drift configuration, the number of samples from the ESF has increased substantially through systematic sampling along the tunnel and sampling of exposed discrete structural features that are potential fast-transport paths. The complexity of the study also has increased by using the chlorine-36 method to investigate the spatial frequency of fracture flow, residence times of infiltrating water, and ground-water travel times. In addition, the chlorine-36 results have been used in connection with the site-scale unsaturated zone transport model to estimate percolation flux at the repository horizon.

3. The percolation in the unsaturated zone—surface-based study (8.3.1.2.2.3) has been reduced in scope in accordance with the priorities and planning assumptions for site investigations implemented for FY 1996 (CRWMS M&O, 1995f, Vol. 1). The SCP indicated that 17 vertical boreholes would be drilled, tested, and instrumented in support of this study, 9 holes would penetrate to just above the proposed repository horizon, and 8 holes would penetrate the unsaturated zone below the proposed repository horizon. Monitoring of pneumatic pressure, temperature, and water potential was to be performed in each hole for a minimum of 3 to 5 years. Although 15 holes have been drilled and used by this study, four of these were drilled along the alignment of the north ramp of the ESF rather than in the feature-based locations originally planned. Of the 15 holes drilled, 8 terminated above the repository horizon and 7 penetrated below the repository horizon. However, no deep borehole has been drilled, or excavation made, to characterize the Ghost Dance fault in the Calico Hills Formation below the repository horizon. No additional surface-based drilling is scheduled in this study in the Long-Range Plan (CRWMS M&O, 1996a) except that which might be a part of confirmatory testing.

   Of the 15 holes drilled, 7 have been instrumented as planned to monitor pneumatic pressure, temperature, and water potential, while 2 holes were instrumented for pressure and temperature (Nye County), 2 for pressure only (flexible borehole liners), and 1 for vertical seismic profiling. A significant change in the study has been increased emphasis on the effects of ESF construction on the natural gaseous-phase system. This occurred because of commitments made to the NRC to perform "pneumatic instrumentation and data collection in the vicinity of the ESF, prior to the passage of the tunnel boring machine, to characterize the pneumatic pathways of the mountain before the ESF cuts across possible pneumatic barriers" (CRWMS M&O, 1995f, Vol. 1, p. 6.3-1). Air-injection tests to determine gas-phase permeability have been conducted in 4 of the holes, only one of which penetrated below the repository horizon. Air-permeability testing in surface-based boreholes was suspended because sufficient data have been collected to support this phase of the program. Further, no cross-hole pneumatic or gas-tracer tests have been conducted, and no additional pneumatic tests are planned. Contrary to the SCP, no boreholes have been drilled and tested on opposite sides of the Solitario Canyon fault or at the southern end of Yucca Mountain. Further, no boreholes at the crest of Yucca Mountain have been instrumented for hydrologic monitoring or for vertical seismic profiling. Water-injection tests in instrumented boreholes and the Solitario Canyon horizontal borehole study have been deleted from the testing program, consistent with the revised program strategy described in the Program Plan (DOE, 1994a, Vol. 1, App. A, p. A-4). However, many of the objectives of the Solitario Canyon horizontal borehole study may be met by planned hydrologic testing in a drift driven southwest from the ESF through the Solitaro Canyon Fault (CRWMS M&O, 1996a).

Although there are no additional surface-based boreholes planned to intersect the Ghost Dance fault, two test alcoves off the main ESF tunnel are being constructed, and horizontal boreholes drilled from these alcoves are intended to intersect the Ghost Dance fault. The hydrogeologic testing that will be conducted from these boreholes will allow characterization of the hydrologic conditions in the vicinity of the fault at the repository horizon. These hydrologic conditions will then be used to constrain the unsaturated zone flow and transport models.

4. In the percolation in the unsaturated zone—exploratory studies facility study (8.3.1.2.2.4), a number of changes in testing strategy resulted from reconfiguration of the ESF from vertical shafts to ramps and drifts. The multipurpose-borehole testing was deleted because of its association with vertical shafts and was replaced by the series of north ramp geologic holes and other boreholes. The intact-fracture and excavation-effects tests have been terminated consistent with the strategy described in the Program Plan (DOE, 1994a, Vol. 1, App. A, p. A-4) because they would not lead to a reduction in residual uncertainty in hydrologic parameters at the site scale. Although the percolation tests on blocks of intact rock were deleted from the testing program, a reconfigured series of in situ field tests are being planned to estimate the flux of water moving downward through the repository horizon in the ESF under present-day conditions. Further, a test not anticipated in the SCP involving moisture monitoring in the ESF is under way. This test is intended to develop a water mass balance for the ESF and to determine how much naturally occurring water is being removed from the ESF by the ventilation system. The in situ testing for the bulk-permeability test has been combined with the radial-boreholes and major-faults tests, both of which are ongoing, consistent with the work-consolidation efforts implemented as part of FY 1996 planning (CRWMS M&O, 1995f). The modeling part of the bulk-permeability test is being accomplished under Study 8.3.1.2.2.8 (fluid flow in

unsaturated fractured rock). Discrete testing of the Calico Hills nonwelded (CHn) hydrogeologic unit in the ESF was deleted from the study plan in Revision 9 of the Site Characterization Program Baseline (DOE, 1995a) (see Appendix H of this progress report). Testing in the CHn may be conducted as part of other future ESF testing activities

5. No diffusion tests have been conducted in the ESF (Study 8.3.1.2.2.5), and plans to conduct such tests have been suspended indefinitely. Natural radioisotopes have been encountered in samples collected at several locations from the ESF and surface-based boreholes. The occurrence of these naturally occurring (albeit anthropogenically enhanced) tracers will continue to be used in conjunction with laboratory testing of matrix diffusion processes and parameters to define the role of matrix diffusion in the unsaturated zone radionuclide transport model. In addition, tracer testing in the saturated zone at the C-hole complex will provide additional information, at the scale of several tens of meters, about the role of matrix diffusion in the tuffaceous rocks at Yucca Mountain.

6. Although the gaseous-phase movement study (8.3.1.2.2.6) has collected and used data from about a dozen more boreholes than was expected, the scope of work planned for key locations and boreholes has been reduced because not as many surface-based boreholes were drilled as anticipated by the SCP, and because of a judgment that sufficient data have been collected to support this phase of the program. Accordingly, the study was requested to produce a synthesis report in FY 1996 using existing data to assess the status of the study and provide input to the viability assessment. Examples of reduced technical scope include the fact that neither the two vertical boreholes planned to straddle the Solitario Canyon fault nor the horizontal borehole to penetrate it were drilled. Also, the cross-hole tracer tests planned for the USW UZ-9 borehole complex have not been conducted because this cluster of boreholes has been deleted from the testing program. Further, the extensive sampling of boreholes for chlorofluorocarbons to determine residence time of gas in the Tiva Canyon welded (TCw) hydrogeologic unit and to investigate possible breaches in the Paintbrush nonwelded (PTn) hydrogeologic unit was not conducted. The results of this study provide input to evaluation of barometric pumping, which is potentially an important mechanism for water vapor and heat removal. Sensitivity analyses will be necessary to determine the extent to which barometric pumping must be characterized for performance assessment purposes.

   A significant change from the original study strategy has been use of the effects of ESF construction on the gaseous-phase system to estimate pneumatic properties of the unsaturated zone. This occurred because of commitments made to the NRC to perform "pneumatic instrumentation and data collection in the vicinity of the ESF, prior to the passage of the tunnel boring machine, to characterize the pneumatic pathways of the mountain before the ESF cuts across possible pneumatic barriers" (CRWMS M&O, 1995f, Vol. 1, p. 6.3-1). This was new work, identified since the SCP was issued. The work was done to take advantage of the opportunity to use barometric responses to estimate large-scale pneumatic diffusivity in the ESF. Specifically, a numerical gas-flow model of the ESF north ramp was constructed to simulate the progressive effects of excavating the north ramp as detected in nearby surface-based boreholes (Patterson et al., in prep.) A parameter-estimation technique was used to determine horizontal and vertical permeabilities of the Topopah Spring Tuff (see Section 3.1.10 of this progress report). Although this preliminary, three-dimensional gas-phase modeling of the ESF north ramp area was done for this study, all remaining site-scale, gas-phase modeling will be done under Study 8.3.1.2.2.9.

An additional activity was added to this study involving use of a water-vapor RAMAN-LIDAR system to investigate preferred pneumatic pathways that have surficial expression. This activity, however, has not progressed beyond the prototype stage and has been suspended indefinitely because of the low priority assigned to this activity, consistent with the strategy described in the Program Plan (DOE, 1994a, Vol. 1, App. A, p. A-4).

7. In the unsaturated zone hydrochemistry study (8.3.1.2.2.7), pore water has been extracted for hydrochemical and isotopic analysis from the cores of 9 of the 15 boreholes drilled to support deep unsaturated zone studies (see item 3 above). The scope of the hydrochemistry study was reduced because sufficient data have been collected to support this phase of the program. Accordingly, a synthesis report was produced in FY 1996 using existing data to provide input for the viability assessment. Detailed, time-series gas-composition and isotopic-content data has been collected from borehole USW UZ-1, which is north of the repository. Gas samples have been collected from 8 other boreholes, but in two instances the sampling was very limited (Yang et al., 1996). Further, gas samples have been collected from below the repository horizon in the Calico Hills Formation in one borehole (Yang et al., in prep.). Overall, although inferences and conclusions regarding fluid movement have had to be based on fewer data from fewer locations in the vicinity of Yucca Mountain the data collected are sufficient to meet the basic objectives and strategy for this study.

   Significant additional information on naturally occurring radioisotopes has been collected from the ESF. These data have increased confidence in the unsaturated zone flow and transport models. These data from the ESF combined with the borehole hydrochemical and isotopic data have been used to constrain these models. Assessment of the sufficiency of the data will be made after the data have been analyzed and a reaction mass-balance model has been developed.

8. Because of significant changes in the ESF testing strategy (see item 4 above), the flow in unsaturated fractured rock study (8.3.1.2.2.8) has de-emphasized the development of conceptual and numerical models solely for design and interpretation of small-scale ESF tests. Instead, the study has concentrated on using all data available from the ESF to construct representative fracture-flow models at about the drift scale. These models, particularly of the Topopah Spring welded (TSw) hydrogeologic unit, are expected to provide significant insight into the possible spatial distribution and magnitude of

fracture flow that might occur into drifts of the proposed repository. In addition, the study has developed a series of modeling approaches for small-scale flow phenomena that can be applied directly to the unsaturated zone site-scale model. These include fracture-matrix interaction modules, a hysteresis model, and an equivalent for unsaturated fracture-network models. These approaches and models provide the theoretical and applied basis for evaluating various complex processes within the site-scale model.

- The site unsaturated zone modeling and synthesis study (8.3.1.2.2.9) has exceeded expectations for simulation of the site-scale unsaturated zone system. This has occurred, in part, because of significant advances in the numerical code and computer technology used in the modeling effort [Progress Report #15, Section 3.1.13, Activity 8.3.1.2.2.9.2 (DOE, 1997e); Progress Reports #7, #8, and #9, Section 2.2.1.13, Activity 8.3.1.2.2.9.2 (DOE, 1992c, 1993b, and 1994g)]. In addition, construction of the ESF ramp-and-drift configuration during the time that the site-scale model was being developed has afforded an unexpected opportunity to calibrate the gaseous-phase part of the model. Although it has been necessary to develop and calibrate the model with data from fewer surface-based boreholes than originally expected, data from instrumented boreholes documenting atmospheric-pressure fluctuations from ESF construction on the gaseous-phase system has made possible enhanced, large-scale, transient-state modeling of gas-pressure propagation through the mountain (Ahlers et al., 1995). These data have led not only to the enhanced simulation of the gaseous phase but also to improved understanding and representation of fracture and fault diffusivities and permeabilities in the site-scale model. Further, using temperature-gradient and heat-flow data for the unsaturated zone has led to an enhancement of the ability of the model to simulate and predict moisture flow [Progress Report #15, Section 3.1.13, Activity 8.3.1.2.2.9.3 (DOE, 1997e); Bodvarsson and Bandurraga, 1996)]. The non-uniqueness of model calibration based on pressure-response alone has been recognized, and the model will need to be further constrained by information that explains pneumatic diffusivity in terms of gas-transport pathways. Additional methods contributing to calibration of the unsaturated zone model include environmental isotopes, perched water occurrences, analysis of fracture coatings, and saturation and water potential data. As calibration of the model continues, determinations of whether sufficient data have been collected to validate the model are being made using sensitivity analysis.

A.1.1.3 Studies to provide a description of the saturated zone hydrologic system at the site (SCP Investigation 8.3.1.2.3)

Background and SCP Plans. The objective of this investigation was to develop a model of the saturated zone hydrologic system of Yucca Mountain that will help assess the suitability of the site to contain and isolate waste. Developing this model requires an understanding of ground water flow. This understanding will be provided through studies focusing on the determination of boundary conditions imposed by structure, recharge, and discharge; hydraulic gradients in three dimensions; and bulk aquifer properties of units. Modeling activities will use the resulting information to calculate ground-water flow paths, fluxes, and velocities within the saturated zone. This investigation included three studies developed to accomplish the following:

1. Study 8.3.1.2.3.1 (characterization of the site saturated zone ground-water flow system): This study was to (a) determine the hydrogeologic nature of the Solitario Canyon fault in the saturated zone; (b) refine the spatial and temporal distribution of the potentiometric surface at the site to determine hydraulic gradients and ground-water flow magnitudes and directions; (c) analyze water-level fluctuations to determine their causes and to estimate formation properties; (d) analyze previously completed single- and multiple-well hydraulic-stress tests conducted in the C-holes to determine type of flow, hydraulic boundaries, and bulk hydraulic properties; (e) conduct multiple-well interference testing in the C-holes to determine hydraulic properties, the appropriateness of anisotropic porous-media or fracture-network models, and the appropriateness of single-well or multiple-well tests; (f) conduct single- and multiple-well conservative tracers tests at the C-holes and throughout the site to determine transport properties; and (g) conduct reactive tracer tests in the C-holes and throughout the site to determine properties of the geologic media that will affect retardation of radionuclides in the saturated zone.

2. Study 8.3.1.2.3.2 (characterization of the saturated zone hydrochemistry): This study was to (a) describe the spatial variations in chemical composition of saturated zone ground waters in the regional and site areas through analysis of representative water samples collected from wells and springs; (b) describe the chemical and isotopic composition of the upper part of the saturated zone through analysis of representative water samples collected from the upper 100 m of the saturated zone; (c) conduct geochemical modeling to identify chemical and physical processes that influence ground-water chemistry; and (d) aid in the identification and quantification of ground-water travel times, climatic conditions during periods of recharge, and fluxes to and from the saturated zone by analyzing the chemical and isotopic compositions of interstitial-water and gas samples collected from immediately above the water table.

3. Study 8.3.1.2.3.3 (saturated zone hydrologic system synthesis and modeling): This study was to (a) synthesize available data into a conceptual model and make a qualitative analysis of how the site saturated zone hydrogeologic system was functioning; (b) develop fracture network models for simulating ground-water flow and conservative solute transport and relate results of hydraulic and conservative-tracer tests in wells to fracture network characteristics; and (c) develop a comprehensive site scale model of ground-water flow and transport to simulate ground-water flow direction and magnitude for input into travel-time calculations and evaluate the appropriateness of the porous-media and fracture-network concepts.

Changes and Status. The primary objectives of this investigation have not changed since the SCP was issued. The SCP, however, described a more extensive program of data collection. The studies for this investigation have evolved based on the technical information obtained from the laboratory and field studies, model development and data application activities of the site characterization program. Rapidly increasing scientific understanding, along with periodic total system performance assessment, have enabled focusing the ongoing site characterization program on the remaining uncertainties that are significant to the suitability of the proposed repository site (DOE, 1994a). Reevaluation and prioritization of Project needs has been a continuous process based on scientific judgment and resource availability, governed by scientific criteria (a) to ensure that data needed for site description, performance assessment, and design purposes were collected and analyzed, and (b) to eliminate data-collection redundancy and overlap that would result from completion of all the studies in the SCP (DOE, 1994a). The data-collection needs have been further analyzed and refined as additional knowledge has been gained through years of site characterization activities. This process has resulted in the following changes to the investigation:

1. In the site saturated zone ground water flow system study (8.3.1.2.3.1), the study of the Solitario Canyon fault in the saturated zone has not been conducted and is not included in the long-range plan. This is a result of the judgment (CRWMS M&O, 1996a) that Solitario Canyon fault is not considered as crucial to predicting movement of radionuclides in the saturated zone as are hydrogeologic features and conditions down gradient from the repository area. Although 14 of the planned 22 water table boreholes were drilled in the early 1980s, none of the additional 8 water table holes have been drilled, including the two for the Solitario Canyon fault study and the two to investigate the large hydraulic gradient. Although some hydraulic tests have been conducted in borehole USW G-2, these tests resulted in no new major understanding, and the nature and cause of the large hydraulic gradient remain unresolved. Two possible hydrogeologic models for the large hydraulic gradient have been described by Fridrich et al. (1994). As a result, estimates of saturated zone flux, flow velocities, and dilution beneath the site may differ considerably for different explanations of the cause of the large hydraulic gradient (Luckey, 1996). The need for additional drilling to investigate the nature of the large hydraulic gradient has been recognized by the Project. Current plans are to drill and test borehole USW WT-24 in late FY 1997.

   Although the C-holes multiple-well interference and tracer tests are being conducted mostly as planned, not as many of the high-producing flow zones will be tested as planned, and testing of the low-producing zones will probably be limited to one zone. (See Forecast in Section 3.1.14 of this progress report.) C-holes testing was reduced in scope in accordance with the priorities and planning assumptions for site investigations implemented for FY 1996 (CRWMS M&O, 1995f, Vol. 1). In addition, the sequencing of testing has been modified in that hydraulic, conservative-tracer, and reactive-tracer tests are being conducted sequentially in a single flow zone before conducting any tests in the next flow zone. Although single-well hydraulic tests have been conducted in two water table holes (USW WT-10 and UE-25 WT#12), the results are of limited value (O'Brien, in press) because (1) storativity data were not obtainable from the tests, and (2) well-bore losses imparted additional uncertainties to the test results. Therefore, no other single-well hydraulic or tracer tests are planned. Instead, a second multiple-well test site is planned along a flow path south of the repository footprint. There hydraulic and tracer tests will be conducted to determine hydrologic properties and to measure the reduction in concentration of solutes as they move through the saturated zone.

2. In the saturated zone hydrochemistry study (8.3.1.2.3.2), the SCP called for intensive water and gas sampling from discrete intervals in 22 water table holes, 14 existing and 8 new holes. Hydrochemical testing was to include the clean out of all the existing water table holes, extraction and analysis of interstitial water from cores of the new holes, and multielement geochemical analyses of selected samples. Although a few mixed-interval samples have been collected from two water table holes, the C-holes, and USW G-2, the site saturated zone hydrochemistry study remains only partially implemented. Subsequent to the SCP, a plan was devised for in situ determinations of pH, Eh, and temperature in all 22 water table holes using a sophisticated downhole hydrochemical tool. However, this plan was abandoned because of its high cost, uncertain potential for increasing knowledge gain, and the need to support critical saturated zone modeling efforts. Although a limited number of water samples have been collected for chemical and isotopic analyses from springs during the regional study near Death Valley, the regional hydrochemistry study also remains only partially implemented. The saturated zone hydrochemistry study has not been implemented as planned because of the programmatic judgment (DOE, 1994a, Vol. 1, App. A, p. A-4) that saturated zone hydrochemistry studies would have less impact on site suitability determinations than other studies and were therefore assigned a lower priority. This is consistent with the strategy described in the Program Plan (DOE, 1994a, Vol. 1, App. A, p. A-4) that not all studies in the SCP would be completed before the suitability of Yucca Mountain is evaluated. It should be kept in mind that the primary purpose of the saturated zone hydrochemistry study was to use hydrochemical and isotopic data to corroborate purely hydrogeologic evidence of regional and site-scale ground-water sources, recharge, fluxes, flow paths, and travel times. Hydrochemical "corroboration" for regional flow paths probably has been adequately accomplished, as described below. However, a similar evaluation at the site scale probably is not possible at the present time because of a lack of hydrochemical data from existing boreholes in the immediate vicinity of Yucca Mountain. The importance of the hydrochemical corroboration at the site scale is debatable and does not currently have a high priority. However, because the standard for disposal at Yucca Mountain is repromulgated, the Project has reevaluated the need for Eh and Ph investigations in the saturated zone and plans to implement testing in the WT wells in FY 1998.

Regional hydrogeochemical information has been collected by other programs along the likely flow paths of regional ground-water flow. The regional data, combined with the limited data collected under this study, have been used to enhance confidence in the regional ground-water flow model (F. A. D'Agnese, U.S. Geological (USGS) Survey, oral communication February 1997). The geochemical "signatures" of greatest interest are distributions of major dissolved ions and stable isotope ratios that occur over large scales and are indicative of general mixing and geochemical evolution of water along regional flow paths. Accordingly, following calibration of the regional ground-water flow model. general flow-path maps were generated from model output and superimposed over a series of maps depicting regional hydrochemical data. Apparent hydrochemical evolution along major flow paths was evaluated qualitatively to corroborate the possibility or likelihood of the flow path generated by the model. These evaluations were performed along general flow paths from major recharge areas (i.e., Spring Mountains, Pahute Mesa, Sheep Range) to major discharge areas (i.e., Ash Meadows, Oasis Valley, Furnace Creek Ranch). Even though the hydrochemical-data sets along these major flow paths are somewhat incomplete and discontinuous, in general, the hydrochemical evaluation corroborated the flow paths generated by the flow model. An activity to document and publish the results of the hydrochemical evaluation of regional flow paths has been included in the FY 1998 work package "Regional Flow-Path Evaluation and Validation." This activity will result in a USGS-series publication.

3 In the site saturated zone hydrologic system synthesis and modeling study (8.3.1.2.3.3), construction and calibration of a site-scale, porous-media-equivalent flow model is proceeding generally as planned. However, because of the application of sophisticated Geographic Information System and geologic-modeling techniques, the geologic framework model on which the flow model is based may be more rigorous and detailed than was envisioned when the SCP was issued.

Although not yet calibrated, the final saturated zone, site-scale model will contain uncertainty for several reasons: (a) limited field tests have been completed to characterize the large-scale anisotropy because of a sparsity of hydraulic-test locations to serve as control points for model calibration; (b) uncertainty persists about the cause of the large hydraulic gradient; (c) uncertainty persists about fluxes at the northern model boundary because no potentiometric data are available in the Timber Mountain area to calibrate the regional model from which boundary fluxes are derived for the site-scale model; (d) hard data are sparse on the geometry and hydraulic properties of the Paleozoic carbonate aquifer underlying Yucca Mountain; and (e) high quality chemical and isotopic data from the saturated zone are not sufficient to corroborate flow patterns. The degree to which these uncertainties in the saturated zone flow model affect the relevant output from the model used in total system performance assessment will be ascertained by a range of sensitivity analyses. These analyses are planned as part of the abstraction of this model in the total system performance assessment. Although uncertainties are expected to remain, the impact of these uncertainties on total system performance assessment will be evaluated.

Although "generic" fracture-network-modeling techniques have been developed, a fracture-network model of the C-hole complex has not yet been developed because the extensive data that would have been required exceeded the data that could be collected. The need to develop a fracture network model will be determined by performance assessment and sensitivity analyses.

A.1.2 Geochemistry Program (SCP Section 8.3.1.3)

The geochemistry program was intended to characterize and evaluate the effectiveness of the geochemical "barriers" that are expected to inhibit the transport of radionuclides away from the potential repository. The program of geochemical testing described in the SCP concerned characterizing those areas of the site that lie beyond the "altered zone" (see Section A.1.15 of this appendix). The major purpose of the geochemistry program was to quantify the radionuclide retardation factor. This factor was expected to be greater than one, and values greater than one were expected to provide added confidence to the calculations of transport to the accessible environment based on advective and dispersive transport calculations.

A.1.2.1 Studies to provide information on water chemistry within the potential emplacement horizon and along potential flow paths (SCP Investigation 8.3.1.3.1)

Background and SCP Plans. The objectives of this investigation were to provide a ground-water chemistry model that would explain the present ground-water composition as a result of interactions of the ground water with minerals and be able to predict future variations in ground-water chemistry (under anticipated and unanticipated conditions) that could alter radionuclide flux through the saturated and unsaturated zone. This investigation included one study developed to accomplish the following:

> Study 8.3.1.3.1.1 (ground-water chemistry modeling): This study was to develop pre- and postemplacement ground-water chemistry models that would integrate the unsaturated and saturated zone data with the processes of water infiltration, water flow, and mineralogic changes to develop a mechanistic description of the current and future ground-water chemistry. The study was also intended to consider changes in infiltration as influenced by climatic conditions; long-term mineralogic changes, particularly those influenced by the thermal pulse from emplaced waste; and changes in the material properties caused by the emplaced waste, or possible igneous activity. These models have been integrated with several investigations in the geochemistry program.

Changes and Status. The primary objectives of this investigation have not changed since the SCP was issued. The SCP, however, described a more extensive program of data collection. The studies for this investigation have evolved based on the technical information obtained from the laboratory and field studies, model development and data application activities of the site characterization program. Rapidly increasing scientific understanding, along with periodic total system performance assessment, have enabled focusing the ongoing site characterization program on the remaining uncertainties that are significant to the design, operation and safety performance of the proposed repository. Reevaluation and prioritization of Project needs has been a continuous process based on scientific judgment and resource availability, governed by scientific criteria to (a) ensure that data needed for site description, performance assessment, and design purposes were collected and analyzed, and (b) eliminate data-collection redundancy and overlap. The data collection needs have been further analyzed and refined as additional knowledge has been gained through years of site characterization activities. This process has resulted in changes to the investigation.

In the ground-water chemistry modeling study (8.3.1.3.1.1), the number of laboratory experiments on water-rock interaction has been decreased, resulting in increased remaining uncertainty about the quantitative models of the processes that control water chemistry in the saturated and unsaturated zones. Uncertainties involve the rate and manner in which volcanic glass is altered when it comes in contact with different water compositions. Alteration of glass can strongly influence pH and the concentrations of other constituents in solution.

Information has been provided to studies of radionuclide retardation and transport. Additional information on the solid phases involved in the alteration of volcanic glass would be needed to develop detailed deterministic models of ground-water chemistry. The solid phases buffer the dissolved concentrations of major solutes which, in turn, influence the distribution of dissolved actinide species. A range of possible water and rock compositions, which may change with time, are expected to be encountered along the likely paths of radionuclide transport in the unsaturated and saturated zones. Some of the compositional variation is caused by the natural variability in the water chemistry and rock mineralogy in the different hydrogeologic units. Some of the variation is the result of uncertainty in the hydrochemical model. The extent to which this variability and uncertainty affect radionuclide transport will be bounded in the total system performance assessments.

A.1.2.2 Studies to provide information on mineralogy, petrology, and rock chemistry within the potential emplacement horizon and along potential flow paths (SCP Investigation 8.3.1.3.2)

Background and SCP Plans. The purpose of this investigation is to provide the baseline set of data and a basic understanding of the natural environment in which geochemical and other processes interact. The objectives of this investigation are to determine the three-dimensional distribution of mineral types, compositions, and abundances in rocks beyond the host rock that provide pathways to the accessible environment; determine the timing, temperatures, and hydrologic conditions of past alteration at Yucca Mountain; study experimentally the dehydration of smectite, zeolite, and glass; and use the results to develop descriptive and predictive models of mineral distributions along potential pathways to the accessible environment. This investigation includes two studies developed to accomplish the following:

1. Study 8.3.1.3.2.1 (mineralogy, petrology, and chemistry of transport pathways): This study is to (a) determine the petrologic variability within the devitrified Topopah Spring Tuff at Yucca Mountain and define the stratigraphic distribution of variability, (b) determine the three-dimensional distribution chemistry and the total abundance of all major rock-matrix minerals between the host rock and the accessible environment; and (c) determine the distributions of minerals within fractures at Yucca Mountain.

2. Study 8.3.1.3.2.2 (history of mineralogy and geochemical alteration at Yucca Mountain): This study is to (a) determine past temperatures from alteration mineral assemblages as a means to estimate the long-term thermal stabilities of important sorptive phases, such as clinoptilolite, and of the silica polymorphs that can influence water composition, precipitation, and the stabilities of other silicate minerals; and (b) determine how minerals and glasses in the rocks at Yucca Mountain will dehydrate and transform under expected thermal loads and investigate the ability of zeolites and smectites to rehydrate after the peak in temperature.

Changes and Status. The primary objectives of this investigation have not changed since the SCP was issued. The SCP, however, described a more extensive program of data collection. The studies for this investigation have evolved based on the technical information obtained from the laboratory and field studies (Vaniman et al., 1996; Levy et al., 1996), model development and data application activities of the site characterization program. Rapidly increasing scientific understanding (Robinson et al., 1995), along with periodic total system performance assessments, have enabled focusing the ongoing site characterization program on the major uncertainties that are significant to the design, operation and safety performance of the proposed repository. Reevaluation and prioritization of Project needs has been a continuous process based on scientific judgment and resource availability, governed by scientific criteria to (a) ensure that data needed for site description, performance assessment, and design purposes are collected and analyzed, and (b) eliminate data-collection redundancy and overlap. The data-collection needs have been further analyzed and refined as additional knowledge has been gained through years of site characterization activities (Vaniman et al., 1996; Levy et al., 1996). This process has resulted in the following changes to the investigation:

1. In the mineralogy, petrology, and chemistry of transport pathways study (8.3.1.3.2.1), the textural features within the devitrified Topopah Spring Tuff are no longer being quantified as a guide to determining variability within the potential host rock. The method was cumbersome and prone to variability between operators conducting the activity. However, quantitative x-ray diffraction and chemical data are still being obtained. The technique of microautoradiography has been added both to the determination of mineral distributions between the host rock and the accessible environment and to the work on fracture mineralogy. This addition has been made to provide the needed detailed information on partitioning between minerals in specific rock samples of retardation potential for radionuclides, both for tuff matrix samples and for fracture samples.

2. In the history of mineralogic and geochemical alteration of Yucca Mountain study (8.3.1.3.2.2), the basic objectives have not changed, but there is now greater emphasis on determining the interrelationship between alteration and hydrology (e.g., Levy and Chipera, in prep.). A relative chronology of alteration has been established, and the study is focused on some of the less well understood alteration, not explicitly identified in the SCP, but responsible for the distribution of existing hydrologic properties, particularly in the Paintbrush nonwelded (PTn) hydrogeologic unit (Levy and Chipera, in prep.). Mineralogic characterization of PTn samples that have been used for

hydrologic-property measurements makes it possible to evaluate differences in moisture content as determined by different methods because these differences are likely to correlate with hydrous mineral content. Progress has been made on a conceptual model of alteration in the PTn that will be used to predict the distribution of hydrologic properties within the unit, based on mineralogic and hydrologic-property variations resulting from alteration processes. The ramp-and-main configuration of the ESF has provided greater underground exposure of this unit than the vertical shaft design referenced in the SCP. The role of analytical geochronology has been less than originally planned because apparent ages determined by exploratory potassium-argon studies of zeolites are ambiguous. Similarly, the use of electron spin resonance dating has been minimal for lack of a satisfactory commercial source of analytical services, but this technique may yet be used to confirm the timing of mineral deposition along ground-water flow paths. Plans for petrofabric studies of zeolitic tuffs below the potential repository horizon, predicated on the availability of large oriented-block samples from an underground exploratory facility, had to be adapted to the use of drill core samples, which limits the data to cm-scale domains (Levy, in prep.), and evaluation of drill core samples. Studies of the smaller samples revealed limited evidence for the channelization of fluid flow in partially zeolitized tuffs (Levy, in prep.), and the techniques developed for these studies will be available if large samples are obtained in the future. The adaptions were necessary because the tunnel boring machine did not enter the Calico Hills Formation and no oriented-block samples were available

Heating studies of mineral and glass dehydration and transformation have proceeded largely as described in the SCP, with a few exceptions. Smectite, zeolites, and glasses are being studied, but few data have been collected for manganese minerals. The natural manganese minerals at Yucca Mountain have highly complex and variable chemical compositions and occur as intricate intergrowths of more than one mineral. Efforts to date have emphasized studies of the volumetrically more abundant clays and zeolites, yielding results that can be incorporated into numerical models of site thermal behavior and water budget. Planned experiments to heat minerals in a steam environment could not be maintained on a long-term basis with existing laboratory apparatus. The heating tests will be done by Project participants having more suitable equipment

A.1.2.3 Studies to provide information required on stability of minerals and glasses (SCP Investigation 8.3.1.3.3)

Background and SCP Plans The goal of this investigation is to determine the stability of minerals and glasses along the flow paths to the accessible environm[illegible] to assess impacts of waste emplacement on mineral stability and the resulting effect on radionuclide retardation. The objectives of this investigation include testing the capabilities of the EQ3/6 geochemical code, improving the reliability of long-term predictions regarding hydrothermal rock alteration in devitrified welded ash flow tuff, and improving the understanding of the origin of alteration mineral assemblages found in Yucca Mountain; investigating the kinetics of glass and silica polymorph transitions and their relationships to aqueous silica activity, and providing thermodynamic data for clinoptilolite-heulandite, albite and analcime; and developing a conceptual model of mineral evolution. This investigation included three studies developed to accomplish the following:

1. Study 8.3.1.3.3.1 (natural analog of hydrothermal systems in tuff): This study will improve the reliability of long-term predictions regarding hydrothermal rock alteration in devitrified welded ash-flow tuff using studies of occurrences of natural analog hydrothermal systems in tuffs.

2. Study 8.3.1.3.3.2 (kinetics and thermodynamics of mineral evolution): This study will (a) predict the rates of possible transformation of silica polymorphs in Yucca Mountain and the effects such transformations would have on aqueous silica activity; (b) determine the end-member free energies from solubility measurements of clinoptilolite-heulandite, albite, and analcime; and (c) describe the thermodynamics of the clinoptilolite-heulandite and analcime solid solutions in support of development of the mineral stability model.

3. Study 8.3.1.3.3.3 (conceptual model of mineral evolution): This study will produce a conceptual model to explain the observed distributions of minerals in Yucca Mountain, address the general chemical evolution of vitric tuffs, and predict future mineral evolution in the mountain caused by both natural processes and as a result of an emplacement of radioactive waste in a repository.

Changes and Status. The primary objectives of this investigation have not changed since the SCP was issued. The SCP, however, described a more extensive program of data collection. The studies for this investigation (Study Plan 8.3.1.3.3.2) have evolved based on technical information obtained from the laboratory and field studies, model development and data application activities of the site characterization program (Carey et al., 1996). Rapidly increasing scientific understanding, along with periodic total system performance assessment, have enabled the ongoing site characterization program to prioritize the remaining uncertainties that are significant to the design, operation and safety performance of the proposed repository. Reevaluation and prioritization of Project needs has been a continuous process based on scientific judgment and resource availability, governed by scientific criteria to (a) ensure that data needed for site description, performance assessment, and design purposes were collected and analyzed, and (b) eliminate data-collection redundancy and overlap. The data-collection needs have been further analyzed and refined as additional knowledge has been gained through years of site characterization activities (see Study Plan 8.3.1.3.3.2, and Carey et al., 1996). This process has resulted in the following changes to the investigation:

1. The natural analog of hydrothermal systems in tuff study (8.3.1.3.3.1) has not been initiated as described in the SCP. The potential performance-related implications of possible hydrothermal alteration of tuffaceous rocks would be on the flow and transport characteristics along the likely paths of radionuclide transport between the potential repository and the water table. The resultant change will be on the

hydrologic properties of the altered rocks (permeability and porosity) and the retardation characteristics of the mineral assemblages. In addition, repository-induced alterations of the host rock could result in changes to the mechanical properties of the rocks. Initial indications are that such alterations cause insignificant changes in the retardation coefficients along potential transport pathways. These changes are outside of the expected natural variability observed in the characterization program for rocks along potential flow paths to the water table (Carey et al., 1996; Bish et al., in prep.). Given that the changes are outside the bounds of natural variability, the need to confidently determine the reliability of any particular water-rock interaction model using natural analogs continues.

2. The kinetics and thermodynamics of mineral evolution study (8.3.1.3.3.2) was combined with the study on conceptual model of mineral evolution (previously 8.3.1.3.3.3) (see Study Plan 8.3.1.3.3.2). These studies were combined to integrate the experimental and modeling aspects of mineral evolution and to create the necessary ties between experiment and performance models. There is a feedback between these two studies, with kinetics and thermodynamics experimental results providing input into the conceptual model, which subsequently influences the experimental program. The conceptual model integrates results of the kinetics and thermodynamics studies with the Project's three-dimensional mineralogic model to predict the long-term effects of a repository on the rocks and minerals at Yucca Mountain. Efforts to investigate glass reactions are no longer planned because these studies are now parts of Studies 8.3.1.20.1.1 (altered zone characterization) and 8.3.4.2.4.1 (characterize chemical and mineralogic changes in the postemplacement environment). Studies on the dissolution and precipitation kinetics of zeolites have been expanded to include an experimental component because insufficient site- and mineral-specific data are available in the literature. These studies now include clinoptilolite, mordenite, illite-smectite, and analcime. Solubility studies to provide zeolite free energies have been augmented to include mordenite, but these studies will no longer consider albite because sufficient data now exist. The data reduction codes listed in the SCP under this activity will not be used, because more modern and comprehensive codes exist; instead Yucca Mountain Site Characterization Office (YMSCO)-approved codes such as EQ3/6 will be used (see Study Plan 8.3.1 3.3.2). Efforts to describe the thermodynamics of zeolite equilibria have been expanded to include mordenite and other minor zeolites at Yucca Mountain such as erionite, chabazite, and phillipsite.

3. The study on conceptual model of mineral evolution (previously 8.3.1.3.3.3) was combined with the kinetics and thermodynamics of mineral evolution study (8.3.1.3.3.2). See description under item 2 above.

A.1.2.4 Studies to provide the information required on radionuclide retardation by sorption processes along flow paths to the accessible environment (SCP Investigation 8.3.1.3.4)

Background and SCP Plans. The purpose of this investigation was to obtain data on the sorption behavior of key radionuclides (americium, carbon, cesium, curium, iodine, neptunium, plutonium, strontium, technetium, uranium, and zirconium). The objectives of this investigation were to obtain sorption coefficients for key radionuclides as functions of the composition of ground water, substrate compositions and structures, acidity (pH), reduction-oxidation potential (Eh), and other parameters; evaluate effects of microorganisms on the movement of radioactive waste, and determine if microbial activities play a role significant enough to be included in performance calculations; and model the sorption experiments on rocks and minerals representing the proposed repository block and derive a capability to predict sorption coefficients for key radionuclides under water-rock conditions not included within the experimental program. This investigation included three studies developed to accomplish the following:

1. Study 8.3.1.3.4.1 (batch sorption studies): This study was to (a) determine sorption coefficients for radionuclides on tuffs of the Calico Hills Formation zeolitic and vitric units, on devitrified tuffs, and on pure minerals representative of the minerals present in the rocks and fractures of the repository block; (b) characterize the dependence of sorption coefficients upon the concentration of the element being sorbed by developing isotherms for the radionuclides; (c) measure sorption coefficients as functions of ground-water compositions anticipated along potential travel paths and determine if the values of K_d were above specified values; (d) determine if sorption of important radionuclides occurs along particulates or colloids that may be present in ground waters along potential transport pathways; and (e) produce statistical correlations and error estimates.

2. Study 8.3.1.3.4.2 (biological sorption and transport): This study was to quantify the locations and characteristics of past and potential future organic materials used at the site and their susceptibilities to microbiologic degradation by determining the growth of microorganisms in fluids such as drilling fluids, evaluating the influence of microorganisms on the movement of actinides by mechanisms such as colloidal agglomeration and chelation, and determining the binding constants of microorganisms to actinides.

3. Study 8.3.1.3.4.3 (development of sorption models): This study was to (a) model the sorption experiments on rocks and minerals representing the proposed repository block and to derive a capability to predict sorption coefficients for key radionuclides under water-rock conditions not included within the experimental program; and (b) develop the best possible capability for predicting sorption coefficients for key radionuclides in the proposed repository block using the available data.

Changes and Status. No significant changes in these studies have been made since the SCP was issued.

1. The batch sorption study (8.3.1.3.4.1) is more than three-quarters complete, and the work is generally consistent with the description in the SCP. Work remains to complete the data set for plutonium. This work on plutonium has been complicated by the multiple oxidation states of plutonium and by difficulties in obtaining ground waters with different compositions. However, the focus of the study is shifting to synthesis and integration of the sorption data to support identification of optimal sorption models that will be used in performance assessment.

2. For the biological sorption and transport study (8.3.1.3.4.2), since the SCP was issued, study progress and developments in the field of subsurface microbiology have been used to change the focus of the study. Changes to the study are discussed in detail in the study plan, but no substantive changes to the study have been made since the study plan was approved in 1993. Most of the changes identified in the study plan are simple reorganizations of the SCP tasks. However, one study (v-max and actinide speciation) has been deleted because the work was determined to be beyond the needs of the program. Remaining work includes support for the development of process models for site-scale unsaturated zone transport and waste package degradation, site-scale saturated zone transport, and parts of the waste containment and isolation strategy that use container corrosion estimates and actinide concentrations.

3. The development of sorption models study (8.3.1.3.4.3) remains relatively incomplete because of resource constraints over the past several years. The work that has been accomplished has generally progressed consistently with the description in the SCP. At this time, it appears that it may be necessary to resolve three remaining technical questions to produce defensible sorption models for performance assessment. These questions are: (a) oxidation state of plutonium sorbed into tuffs, (b) speciation of neptunium sorbed onto zeolitic tuffs, with emphasis on the roles of clinoptilolite and clay, and (c) speciation of neptunium sorbed onto fracture coatings such as mineral oxides and calcite. The focus of this study has shifted from sorption model development to evaluation of the mechanistic sorption models, and identification and selection of the optimal sorption model for use in performance assessment.

A.1.2.5 Studies to provide the information required on radionuclide retardation by precipitation processes along flow paths to the accessible environment (SCP Investigation 8.3.1.3.5)

Background and SCP Plans. The objective of this investigation was to collect data needed to evaluate potential radionuclide retardation by precipitation processes. Data about dissolved species concentration limits were intended to provide information on solubility or concentration limits for dissolved species of important waste elements under conditions that were characteristic of the repository and along flow paths to the accessible environment. Data about colloid behavior would be used to determine the stability of waste element colloids under expected site-specific conditions that might be encountered at the repository or along flow paths to the accessible environment. This investigation included two studies developed to accomplish the following:

1. Study 8.3.1.3.5.1 (dissolved species concentration limits): This study was to (a) specify the conditions under which solubility experiments would be performed and then measure solubilities or concentration limits of important waste elements under these conditions; (b) identify important aqueous species of waste elements under conditions specified and determine the formation constants for those species; and (c) develop the thermodynamic models and data needed to calculate waste element solubilities over a range of conditions expected at the site.

2. Study 8.3.1.3.5.2 (colloid behavior): This study was to (a) determine the formation and stability of waste element colloids, particularly plutonium and americium; (b) determine the conditions for formation, stability, and break up of colloids, including pH, reduction-oxidation state, temperature, and concentration of the element; (c) determine the effect of these conditions on colloid size, density, composition, charge, and chemical reactivity; and (d) develop models and model parameters to calculate natural colloid concentrations and stability and describe the disposition of the waste element species as the colloids break up.

Changes and Status. The primary objectives of this investigation have not changed since the SCP was issued. The SCP, however, described a more extensive program of data collection. The studies for this investigation have evolved based on the technical information obtained from the laboratory and field studies, model development and data application activities of the site characterization program. Rapidly increasing scientific understanding, along with periodic total system performance assessment, have enabled focusing the ongoing site characterization program on the remaining uncertainties that are significant to the design, operation and safety performance of the proposed repository. Reevaluation and prioritization of Project needs has been a continuous process based on scientific judgment and resource availability, governed by scientific criteria to (a) ensure that data needed for site description, performance assessment, and design purposes were collected and analyzed, and (b) eliminate data-collection redundancy and overlap. The data-collection needs have been further analyzed and refined as additional knowledge has been gained through years of site characterization activities. This process has resulted in the following changes to the investigation.

1. The dissolved-species concentration limits study (8.3.1.3.5.1) has essentially remained unchanged since the SCP was issued. Emphasis has been placed on identifying the solubility-limiting solids and oxidation states and on developing a thermodynamic data base for neptunium and plutonium. The strategy for sorption studies and subsequent performance assessments generally supported an emphasis on neptunium and plutonium as key radionuclides. The interest in investigating oxidation states resulted from the realization that these elements are much less soluble under reducing conditions.

2. In the radiocolloid behavior study (8.3.1.3.5.2), a letter report on plutonium (IV) colloids was written to document the literature data base (Clark, 1994). All other work on radiocolloids has been deferred because it is not needed to support the long-range plan. Uncertainties in radiocolloid formation, stability, and mobility will be addressed as part of the total system performance assessment. Reasonable ranges in naturally occurring colloid and radiocolloid properties will be derived from literature surveys and other direct and indirect sources.

A.1.2.6 Studies to provide the information required on radionuclide retardation by dispersive, diffusive, and advective transport processes along flow paths to the accessible environment (SCP Investigation 8.3.1.3.6)

Background and SCP Plans. The objective of this investigation was to experimentally determine the rate of movement and effective retardation of radionuclides by dispersive, diffusive, and advective processes. The dynamic transport column experiments were intended to measure the breakthrough or elution curves for tracers through tuff columns. The diffusion study was intended to measure the diffusivity and kinetics of adsorption in a purely diffusive system (i.e., no advection) using beakers fabricated from tuff wafers and rock slabs. This investigation included two studies developed to accomplish the following:

1. Study 8.3.1.3.6.1 (dynamic transport column experiments): This study was to (a) measure the rate of movement of radionuclides through crushed tuff columns relative to tritiated water and other well-defined chemical species or colloids; (b) determine the elution rate of radionuclides as a function of water velocity for crushed tuff columns (homogeneous system), for solid rock columns (heterogeneous system), and for pure mineral samples; (c) measure the relative migration rate of radionuclides through partially unsaturated rock columns; (d) measure the transport and diffusion of radionuclides through naturally fractured tuff; and (e) quantify the filtration of colloids and particulates by the tuff as a function of particle or pore size.

2. Study 8.3.1.3.6.2 (diffusion): This study was to (a) measure the uptake of radionuclides by rock beakers as a function of time; (b) measure the diffusion of radionuclides in a purely diffusive system (i.e., no advection); and (c) determine the distribution of radioactivity in the unsaturated tuff matrix using an unsaturated tuff block of the Topopah Spring Tuff or Calico Hills Formation.

Changes and Status. There have been no significant changes in these studies since the SCP was issued.

1. The dynamic transport column experiments study (8.3.1.3.6.1) is about three-quarters complete. Questions remain about the validity of using batch sorption distribution coefficients (K_ds) for unsaturated zone transport calculations. An encouraging, but limited set of data, including data from experiments with uranium and selenium,

indicate that K_ds can be used to make conservative predictions of radionuclide transport through unsaturated tuff.

2. The diffusion study (8.3.1.3.6.2) is about four-fifths complete. Diffusion coefficients have been determined for a fairly comprehensive set of radionuclides, tuff types, and water compositions. Diffusion as a function of saturation in tuffs remains to be determined.

A.1.2.7 Studies to provide the information required on radionuclide retardation by all processes along flow paths to the accessible environment (SCP Investigation 8.3.1.3.7)

Background and SCP Plans. The objectives of this investigation were to (a) provide a baseline set of input data from geochemistry, mineralogy-petrology, hydrology, and other studies needed for the integrated radionuclide transport calculations; and (b) outline the strategy that would be used to demonstrate the validity of the laboratory generated geochemical data and the validity of transport calculations using that data. This investigation included two studies developed to accomplish the following:

1. Study 8.3.1.3.7.1 (retardation sensitivity analysis): This study was to (a) analyze the processes that may affect transport, including geochemical and physical processes, particulate transport, heat-load effects, and coupled phenomena; (b) develop, using this analysis, laboratory experiments to examine the physical and geochemical processes affecting radionuclide transport and other diffusion experiments; (c) correlate and validate results obtained from laboratory, ESF, and field experiments with transport calculations; (d) perform calculations of radionuclide transport from the repository to the accessible environment using, as a basis, an integrated conceptual geochemical-geophysical model of Yucca Mountain; and (e) verify computer codes and validate the models used in this study to identify important contributors to uncertainties in the retardation calculations (sensitivity analyses).

2. Study 8.3.1.3.7.2 (demonstration of the applicability of laboratory data to repository transport calculations): This study was to outline the strategy that would be used to demonstrate the validity of the laboratory-generated geochemical data and of transport calculations using that data including modeling and a combination of large-scale laboratory experiments, field studies, consideration of natural analogs, information from processes in the soil zone, and peer review.

Changes and Status. The primary objectives of this investigation have not changed since the SCP was issued and there have been no significant changes in the studies. The studies for this investigation have evolved based on technical information obtained from the laboratory and field studies, model development and data application activities of the site characterization program. Rapidly increasing scientific understanding, along with periodic total system performance assessment, have enabled focusing the ongoing site characterization program on the remaining uncertainties that are significant to the design, operation and safety performance of the proposed repository. Reevaluation and prioritization of Project needs has been a continuous process based on scientific judgment and resource availability, governed by scientific criteria to (a) ensure that data needed for site description, performance assessment, and design purposes were collected and analyzed, and (b) eliminate data-collection redundancy and overlap. The data-collection needs have been further analyzed and refined as additional knowledge has been gained through years of site characterization activities. This process has resulted in the following changes to the investigation.

1. The retardation sensitivity analysis study (8.3.1.3.7.1) has proceeded generally as described in the SCP.

2. The study to demonstrate applicability of laboratory data (8.3.1.3.7.2) has not evolved beyond the planning stages because insufficient hydrologic information has been developed to determine the location suitable for such a test. However, the C-hole tracer tests include a suite of tracers which, because of their properties, would be expected to help quantify fracture flow and adsorption in the saturated zone. The results of the C-hole tests are needed to evaluate a variety of models ranging from analytical (close-form) solutions to three-dimensional numerical models. The modeling exercise using the C-hole data is expected to provide important information needed to determine the level of complexity needed in the site-scale model. For example, dual permeability models may be required to explain the C-hole data.

A.1.2.8 Studies to provide the information required on retardation of gaseous radionuclides along flow paths to the accessible environment (SCP Investigation 8.3.1.3.8)

Background and SCP Plans. The purpose of the investigation was to supply input data for calculations of gaseous radionuclide transport from the repository to the accessible environment at the Yucca Mountain site. The objectives of this investigation included: (a) calculating the rates of transport of gaseous radionuclide species between the repository and the accessible environment considering the various driving forces and retardation mechanisms that may exist, and (b) experimentally verifying existing models of gaseous radionuclide transport and retardation that were used to assess radionuclide release to the environment. This investigation included one study developed to accomplish the following:

Study 8.3.1.3.8.1 (gaseous radionuclide transport calculations and measurements): This study was to (a) determine the manner in which gaseous species were transported in the unsaturated zone and calculate transport rates without retardation; (b) identify the retardation mechanisms that can affect the transport of gaseous species through the unsaturated zone and model these processes so that the effects on transport rates can be evaluated; and (c) measure experimentally gas transport rates under typical unsaturated zone conditions to verify calculational models of gas transport and retardation if they exist.

Changes and Status. The primary objectives of this investigation have not changed since the SCP was issued. The SCP, however, described a more extensive program of data collection. The studies for this investigation have evolved based on technical information obtained from the laboratory and field studies, model development and data application activities of the site characterization program. Rapidly increasing scientific understanding, along with periodic total system performance assessment, have enabled focusing the ongoing site characterization program on the remaining uncertainties that are significant to the design, operation and safety performance of the proposed repository. Reevaluation and prioritization of Project needs has been a continuous process based on scientific judgment and resource availability, governed by scientific criteria to (a) ensure that data needed for site description, performance assessment, and design purposes were collected and analyzed, and (b) eliminate data-collection redundancy and overlap. The data-collection needs have been further analyzed and refined as additional knowledge has been gained through years of site characterization activities.

This investigation has not been funded during FY 1997 [see Long Range Plan/Integrated Project Schedule (CRWMS M&O, 1996a)].

A.1.3 Rock Characteristics Program (SCP Section 8.3.1.4)

The rock characteristics program was intended to provide the information needed to develop a three-dimensional model of the physical properties of the rocks at the Yucca Mountain site. That is, the program would determine the geometries associated with the various material properties of the rocks at the site. The purpose of the three-dimensional model was to provide a computer-based representation of the physical properties of the rocks at the site. The model was intended to include data defining the distribution of parameters (physical properties) within specified property-dependent units. The model data were also intended to provide input for numerical computer analyses that involve hydrologic, thermal, thermomechanical, and geochemical processes.

The three-dimensional physical properties model was intended to be a representation of the Yucca Mountain repository site containing various kinds of data on assorted geologic, geohydrologic, thermal, mechanical, and geochemical properties. One of the purposes of the model was to allow predictions of how a physical property changes spatially within and across the boundaries of the model. The relevant model boundaries would represent distinct changes in the property of interest.

The investigations included in the rock characteristics program are summarized in the following sections.

A.1.3.1 Development of an Integrated Drilling Program and Integration of Geophysical Activities (SCP Investigation 8.3.1.4.1)

Background and SCP Plans. The objective of this investigation was to provide a mechanism for the overall integration of the surface-based activities to be conducted during site characterization. The SCP and early study plan drilling programs provided for drilling the following holes: (a) 12 systematic drilling (SD) program boreholes supporting the rock properties investigations; (b) 25 additional unsaturated zone neutron (UZN) access boreholes for study of shallow infiltration in the site area; (c) 17 new unsaturated zone (UZ) boreholes supporting the characterization of the deeper part of the unsaturated zone; (d) at least 5 deep water table (WT) holes, and a southern tracer complex of 3 boreholes to test the saturated zone; (e) 3 volcanic (V) boreholes; and (f) 3 additional deep geologic (G) boreholes. This program is described in the Catalog of Planned Boreholes (CRWMS M&O, 1993a).

The geophysical integration activity was intended to review and evaluate planned geophysical surveys for (a) consistency with results from past surveys, (b) direct or supportive uses of the data for licensing, (c) the likelihood that useful data would be generated, (d) the need for the planned effort with respect to alternate methods for obtaining the data, and (e) scheduling with respect to other studies and the overall priorities for site characterization.

1. Activity 8.3.1.4.1.1 (development of an integrated drilling program): This activity was to (a) ensure data collected during surface-based testing activities were representative of phenomena and structural characteristics; (b) integrate and prioritize surface-based activities; and (c) maintain a system of technical element baseline approval and control.

2. Activity 8.3.1.4.1.2 (integration of geophysical activities): This activity was to provide a mechanism for information exchange, data analysis, and overview of planned geophysical site characterization activities.

Changes and Status. At the DOE-NRC Technical Exchange in April 1995, a list of 35 boreholes was presented to the NRC as exemplification of the Program Plan of December 1994. The list was generally consistent with plans outlined in the SCP and early study plans, as described above. Of the holes on this list, three boreholes have been drilled since 1995, and three other listed holes plus one new borehole are included in the current long-range plan. However, the remaining 29 listed boreholes identified are unlikely to be drilled. Currently, two boreholes associated with the Enhanced Characterization of the Repository Block (formerly the East-West Drift) are under consideration by DOE. The drilling of a borehole at the USW WT-24 pad is also under consideration. However, as noted below, supplemental data have been developed from other sources.

1. For the integrated drilling program (8.3.1.4.1.1), although the plans for additional boreholes have been reduced compared with the plans described in the SCP, 11 additional north ramp geologic boreholes were drilled in support of ESF design. Three of these boreholes supplemented SCP drilling and provided core from the potential

repository horizon that originally was intended to be provided by the proposed (and subsequently canceled) systematic drilling and unsaturated zone boreholes. While the lack of additional boreholes may reduce confidence in the process models, the data from the revised drilling program is sufficient for purposes of the viability assessment. Conservative concepts of parameter values may be used to compensate for the absence of information in process modeling. Discussions are in progress concerning the need to drill at least one more SD hole (e.g., SD-6).

2. In the activity to integrate geophysical activities (8.3.1.4.1.2), a comprehensive geophysical testing program (regional- and repository-scale, surface and subsurface, ground-based and aerial surveys) was conducted. Since 1991, 40 boreholes have been cored at Yucca Mountain, and 24 new and existing boreholes were logged (under subcontracts to private sector geophysical corporations) with industry-standard wireline geophysical tools. To date 20 of the post-1991 boreholes have been logged, and 4 pre-1991 boreholes have been re-logged with modern wireline geophysical tools.

   Nearly 23 miles of deep regional seismic reflection profiling, 35 miles of high-resolution shallow seismic reflection profiling in the repository area, and coincident magnetic and gravity profile data have been collected. The aeromagnetic and ground gravity regional potential field data sets have been synthesized, and final interpretations and subsurface structural models are being generated by further analysis to support the tectonics, volcanism, and hydrologic investigations. Follow-up documentation for many of the geophysical activities and proposed testing programs were presented in the 1990 and 1995 Geophysics White Papers (DOE, 1990; Oliver et al., 1995). Most of the standard and prototype testing programs outlined in DOE (1990) were conducted during the past five years. Enhancements to the 1990 proposals included completion of vertical seismic profiling investigations to repository depths in three boreholes near the potential repository. These investigations are summarized in Majer et al. (1996) and Brocher et al. (1996).

A.1.3.2 Geologic Framework of the Yucca Mountain Site (SCP Investigation 8.3.1.4.2)

Background and SCP Plans. The three objectives of this investigation generally covered those studies and activities that would further allow an understanding of the large-scale variations in stratigraphy and structure needed to support design and performance assessment calculations. First, this investigation was to provide primary data on the lateral and vertical variations in site stratigraphy through the acquisition of borehole cores and cuttings and from surface geologic mapping. Second, the investigation was to provide information that would allow three-dimensional modeling (through the use of borehole and surface geophysical surveys) of the variations in properties of interest between points of primary data. Third, information was to be provided on the lateral and vertical variations of structural elements that may affect in situ properties of interest (e.g., fracture-related flow) in conjunction with site characterization investigations on geohydrology, geochemistry, postclosure tectonics, and seismicity (i.e., preclosure tectonics). This investigation included three studies developed to accomplish the following:

1. Study 8.3.1.4.2.1 (characterization of the vertical and lateral distribution of stratigraphic units within the site a ea): This study was to (a) determine the vertical and lateral variability, emplacement history, and characteristics of stratigraphic units and lithostratigraphic subunits within the Paintbrush Group, tuffaceous beds of Calico Hills Formation, Crater Flat Group, and possibly older volcanic rocks; (b) improve confidence in stratigraphic models by drilling three additional deep geologic boreholes and by incorporating results from surface-based and borehole geophysical surveys and petrophysical properties testing; (c) determine the distribution of rock properties within lithostratigraphic units; (d) provide magnetic-property data to help interpret volcanic stratigraphy and structure and to assess the rotation of rock units in relation to the geologic structures; and (e) integrate geophysical activities.

2. Study 8.3 1.4.2.2 (characterization of the structural features within the site area): This study was to (a) determine the frequency, distribution, characteristics, and relative chronology of structural features within the Yucca Mountain site area; (b) extend the 1:12,000 scale mapping of zonal features and variations in exposed tuffs of the Paintbrush Group in the site area to help identify structural displacements of 10 m or less and to detect subtle changes in structural styles; (c) conduct surface-fracture network studies to provide measurements and analyses for hydrologic-flowpath modeling of the unsaturated zone and to help develop tectonic models and determine mechanical response of fractured rock to excavation and thermal loading; (d) conduct borehole evaluations of faults and fractures to assess reliability and usefulness of borehole techniques, determine vertical and lateral variability and characteristics of subsurface fractures, and identify subsurface characteristics of fault zones; (e) conduct geologic mapping of the FSF to determine vertical and horizontal variability of fracture networks and lithostratigraphic features, characterize major faults and fault zones, and assist in evaluation of test locations; and (f) conduct seismic tomography and vertical seismic profiling to detect and characterize subsurface fracture networks by extrapolating the relation between seismic-propagation characteristics and observed fracture patterns to unexplored volumes of rock.

3. Study 8.3 1.4 2.3 (three-dimensional geologic model): This study was to develop a three-dimensional geologic model of the site area that incorporates stratigraphic, structural, geophysical, and rock properties information pertinent to site characterization, design, and performance assessment activities.

Changes and Status. The objectives of the investigation remain the same as defined in the SCP. The scope of the investigation has, for the most part, followed that described in the SCP, and in some instances has exceeded that scope. The notable exception is the decision not to drill the additional deep geologic (G) holes. Overall, the purpose of the investigation has been fulfilled, resulting in the generation of information sufficient to achieve the original objectives of each study as presented in the SCP. Changes that have occurred in the investigation are summarized below:

1. In the distribution of stratigraphic units study (8.3.1.4.2.1), the drilling of three deep geologic holes proposed in the SCP has not occurred. These holes were intended to investigate lithostratigraphic and structural conditions associated with the large hydraulic gradient in the saturated zone just north of the site area in Yucca Wash, to provide data on the thickness of key lithostratigraphic units in the vicinity of Windy Wash, and to provide data on the thickness of the Paintbrush Group southwest of Busted Butte. The three geologic holes were to be targeted at the corners of the site area and serve as control points for geologic modeling and interpretations of seismic-reflection profiles. Although the Project has completed an important set of boreholes not anticipated by the SCP (eleven north ramp geologic boreholes), and successfully implemented an extensive surface and borehole geophysical studies program, additional work may be needed to determine (a) the depth to the top of the Paleozoic rocks and the configuration of the Tertiary-Paleozoic contact underlying Yucca Mountain, and (b) stratigraphic and structural controls on the large hydraulic gradient north of the site. These features have potentially important implications for flow of water under the repository area in the saturated zone and the possible migration of radionuclides away from the potential repository. For the Tertiary-Paleozoic contact, the uncertainty in configuration results in a range of possibilities regarding the relative volumes of Tertiary volcanic tuffs and Paleozoic sedimentary rocks in the saturated zone through which potentially radionuclide-carrying water would pass on its route from the repository to the accessible environment. Because the Tertiary and Paleozoic rocks have significantly different hydrologic and geochemical properties, their presence or absence affects flow paths, velocities, dilution, and sorption. Similarly, for the large hydraulic gradient, the uncertainty results in estimates of saturated zone flux, flow velocities, and dilution beneath the site that likely will differ considerably for different explanations of the cause of the large hydraulic gradient (Luckey, 1996). Once uncertainty in the most representative explanation for each of these features has been determined, the potential implications of these features for long-term containment and isolation of radionuclides at the Yucca Mountain site can be evaluated. When these uncertainty analyses have been completed, the importance of additional characterization of these features to reduce uncertainty in performance predictions can be ascertained.

   The SCP scope has been exceeded in the measurement and verification of stratigraphic sections, revision of the stratigraphic nomenclature, and development of a detailed microstratigraphy for characterization of features observed in core holes. In addition, although not all the areas and features targeted in the SCP were covered, an extensive surface-based geophysical-survey program has been completed, including nearly 23 miles of deep regional seismic-reflection profiling, 35 miles of shallow high-resolution seismic-reflection profiling in the site area, and coincident magnetic and gravity surveys of the site area. The integration of geophysical activities was deleted from this study in Revision 7 of the Site Characterization Program Baseline because the integration is being performed under Investigation 8.3.1.4.1.

2. In the structural features study (8.3.1.4.2.2), recognized inadequacies in available surface geologic maps and changes in criteria for stratigraphic units have resulted in an intensive program to remap and to evaluate existing 1:12,000-scale maps of the site area (Study Plan 8.3.1.4.2.2, Revision 2; Progress Reports #6 through #10, Section 2.2.3.4, DOE, 1992b, 1992c, 1993b, 1994g, and 1994e; Progress Reports #11 through #15, Section 3.3.4, DOE, 1995b, 1995g, 1996f, 1996g, and 1997e). Emphasis in the remapping effort was placed on the central block area of Yucca Mountain (Day et al., in press). Geologic mapping at a scale of 1:6,000 has been performed in an area extending from Comb Peak in the north to Busted Butte in the south, and from Jet Ridge on the west to Midway Valley on the east (see Progress Reports #6 through #15). Although 1:12,000-scale geologic mapping of zonal features was not extended southward to U.S. Highway 95 as originally planned (see SCP, p. 8.3.1.4-67; see Progress Reports #6 through #15), detailed 1:6,000-scale mapping was extended northeast of Yucca Wash in the Paintbrush Canyon area to include several faults that affect the repository-area structure, and to elucidate important stratigraphic-facies issues (Dickerson and Drake, in prep.). Mapping was not extended south of Busted Butte because that is the southern limit of both the geologic framework model and site-scale unsaturated zone flow model.

   Several pavement studies and detailed surface-mapping exercises have generated a wealth of fracture data for the development of site-area fracture models (Sweetkind and Williams-Stroud, 1996). With reconfiguration of the ESF from vertical shafts to ramps and alcoves, the strategy and methods for mapping fracture networks, faults, and lithostratigraphic features have changed considerably (see Study Plan 8.3.1.4.2.2, Revision 2). The most notable of these changes has been the acquisition of a large volume of data collected through detailed line surveys and full periphery mapping of the ESF.

   Although vertical seismic profiling has been completed to repository depths in 10 available boreholes near the potential repository, the scope and strategy for vertical seismic profiling have changed significantly. Initial plans were to test this method in borehole USW G-4 (for vertical seismic profiling) and in the C-holes for the cross-hole tomographic imaging. USW G-4 was selected because of its proximity to the planned vertical shaft of the ESF. When the ESF configuration was modified to ramps and drifts, testing in USW G-4 became less important. Consequently, multi-offset vertical seismic profiling using P- and S-waves were first used in USW NRG-6, a borehole close to the ESF north ramp, and in USW WT-2, a borehole close to the Ghost Dance fault (Progress Reports #8 through #10, Section 2.2.3.4; Progress Report #11, Section 3.3.4). Both surveys met the objectives of the study plan, in that fracture and fault characteristics were inferred from the data. Subsequent vertical seismic profiling surveys in additional holes (USW G-2, USW G-4, USW SD-12, UE-25 RF#7a and UE-25 RF#4) were performed using P- and S-wave sources for defining shallow

S-wave structure for input to site seismic-response models (Progress Report #13. Section 3.3.4).

In addition, vertical seismic profiling data were collected in a state-of-the-art testing program at borehole UE-25 UZ#16 (Progress Reports #13 through #15, Section 3.1.7); data from this investigation are being interpreted. Tomographic studies will not be done at UE-25 UZ#16 because drilling of the additional, closely spaced boreholes at the UZ-16 site, which would have supported gaseous-phase investigations, has been deleted from the Long-Range Plan (CRWMS M&O, 1996a). The tomographic studies were intended to extrapolate observations of structural features and fracture content between surface exposures, underground tunnels and drifts, and boreholes (see Study Plan 8.3.1.4.2.2, Revision 2). However, the development of the detailed system for identifying lithostratigraphic units (Buesch et al., 1996a) and the three-dimensional geologic model (Buesch et al., 1996b; CRWMS M&O, 1996i), have obviated the need for tomographic studies in most Project applications. This is because the detailed system of lithostratigraphic descriptions, which is based on crystal content, phenocryst assemblage, depositional texture, degree of welding, high-temperature crystallization, precipitation from the high-temperature vapor phase, and fracture characteristics, makes it possible to correlate the lithostratigraphic units and properties through regions of sparse data (Buesch et al., 1996c).

Cross-hole tomographic imaging in the C-holes was completed as planned. No additional tomographic work is planned at other locations in the vicinity of Yucca Mountain because of the lack of available closely spaced boreholes that penetrate sufficient intervals in the saturated zone. (The length of the holes beneath the water table must be at least twice the hole separation.) Available seismic sources will not operate in dry holes and give the required data quality. The tomographic imaging of the ESF has not yet been conducted because ESF construction is not complete. The need for tomographic imaging in the ESF will be determined as testing progresses and problems in characterization arise.

3. In the three-dimensional geologic-model study (8.3.1.4.2.3), the SCP strategy has evolved considerably. Whereas the original three-dimensional geologic model was envisioned to be primarily "conceptual" and to encompass a series of isopach and structure contour maps, correlation diagrams, and cross sections, the present model is a three-dimensional, computer-based stratigraphic, structural, and properties model (see Section 3.3.5 of this progress report). Presently, the integrated site model includes a geometric representation of selected rock units and structures (the geologic framework model) and a set of rock-properties models and data sets. The geologic framework model encompasses a 166 km^2 rectangular area around the Controlled Area Boundary (Figure 3-2) and includes more than 30 lithostratigraphic layers between land surface and the top of the Paleozoic rocks as described by Majer et al. (1996). The 42 faults included in the three-dimensional model (Version ISM2.0) are those which (a) lie outside the repository area, are longer than 2 miles (3.2 km), and have offsets greater than 100 ft (30 m), or (b) lie inside the repository area, are longer than one mile

(1.6 km), or have offsets greater than 100 feet (30 m); or (c) their exclusion would produce a mismatch between the model and mapped outcrop patterns (see CRWMS M&O, 1997a for additional information.) Rock properties in the integrated site model include matrix porosity, bulk lithophysal porosity, saturated hydraulic conductivity, density, thermal conductivity, mineralogy, and apparent ages and isotopic ratios for the Topopah Spring Tuff welded interval at the repository horizon.

A.1.3.3 Development of Three-Dimensional Models of Rock Characteristics at the Repository Site (SCP Investigation 8.3.1.4.3)

Background and SCP Plans. The purpose of this investigation was to synthesize and integrate information collected from various laboratory and field investigations into comprehensive three-dimensional, computer-based models of rock characteristics. The studies were intended to document vertical and lateral variations in rock properties, to provide information and statistical testing necessary to permit modeling of properties between control points, and to characterize key rock property variations in the site area. The investigation provides a variety of work products, such as geologic maps and cross sections, to design and performance assessment groups. These work products typically depict variations in physical properties such as rock compressive strength, thermal conductivity, gas permeability, or fracture density.

The SCP and derivative study plans specified that the majority of data for this investigation would be obtained from 7 to 12 systematic drilling boreholes to be drilled in the repository area, and from unsaturated zone boreholes located along the perimeter of the potential repository area. Additional data for the rock properties modeling investigation were to be provided by various unsaturated zone boreholes.

The objectives of this investigation were to characterize the three-dimensional distribution of rock characteristics, and hydrologic and geochemical variables, for the unsaturated zone at Yucca Mountain and to integrate quantitative and semiquantitative data on rock characteristics.

1. Study 8.3.1.4.3.1 (systematic acquisition of site-specific subsurface information): This study was to acquire physical rock samples, analytical data, and basic descriptions of the subsurface geology of the repository site on a systematic basis.

2. Study 8.3.1.4.3.2 (three-dimensional rock characteristics models): This study was to develop computer-based three-dimensional models that integrate quantitative and semiquantitative data on rock characteristics in light of constraining information developed by studies of the geologic framework of the Yucca Mountain site (Investigation 8.3.1.4.2).

Changes and Status. The primary objectives of the investigation remain the same, with minor modifications, and include acquiring rock samples and determining physical properties, presenting the analytical data, providing a basic description of subsurface rock characteristics derived from systematic drilling and unsaturated zone boreholes, and presenting rock properties variations as three-dimensional computer-based numerical models. The investigation objectives require a broad scope of activities. One major enhancement to the SCP program was amplification of the responsibilities for integration of results from Investigation 8.3.1.15.1 (thermal and mechanical rock properties), which was an aspect of the investigation never clearly identified in the SCP. Also, minor task adjustments moved the majority of stratigraphy and structural synthesis and associated model development to Investigation 8.3.1.4.2 (Geologic Framework of Yucca Mountain).

1. In the study to systematically acquire site-specific subsurface information (8.3.1.4.3.1), the Catalog of Planned Boreholes (CRWMS M&O, 1993a) and FY 1994 and 1995 Program plans (DOE, 1994a) presented proposals to drill 12 systematic drilling boreholes and reduced the number of planned unsaturated zone holes to 14. According to current plans, 3 of the 12 systematic drilling boreholes are planned to support the license application. A proposal to drill "SD-6" on Yucca Crest is being evaluated. This hole would, if drilled, reduce some of the uncertainties in material properties estimates. The range of spatial correlation for at least one material property of interest, porosity, now appears to be greater than originally thought (Rautman, in pr ; Rautman, 1991; Istok et al., 1994; McKenna and Rautman, 1995). Hence the results of modeling porosity are more reliable than would have been expected had the correlation been less. The number of systematic drilling boreholes eventually drilled may exceed three depending on the results of characterization and modeling of rock properties and as-built design information obtained from ESF construction.

   Outside the scope of the SCP investigation, Nye County officials are also recording fluid pressure data in boreholes UE-25 NRG#4 and UE-25 ONC#1 supporting long-term and short-term monitoring of drilling and excavation effects on the ambient pressure and thermal system within Yucca Mountain (i.e., changes in ambient conditions induced by the effects of perturbation of the ambient system by the tunnel boring machine are being documented). Larger-scale bulk properties, notably bulk density, are being estimated using sensor responses in these boreholes, and these estimates will provide a level of support to the thermal design process that was not anticipated in the SCP.

2. In the study to develop three-dimensional rock characteristics models (8.3.1.4.3.2), plans are to complete assessment of rock properties data derived from borehole and ESF samples, to prepare models of the various rock properties, and to provide rock properties models to various performance assessment activities. Information needs identified during the development of these models will be used to evaluate the need to drill additional systematic drilling boreholes.

A.1.4 Climate Program (SCP Section 8.3.1.5)

Evaluation of the available data on recent climate, meteorology, and paleoclimate indicated that more data were required than were available on the paleohydrology, paleoclimate, and modern climate of the Yucca Mountain area in order to adequately predict future climate and its possible effects on site hydrology relative to repository performance. The SCP climate program was developed to provide data on past, present, and possible future climate conditions and to determine the effects of climate change on surface, unsaturated zone, and saturated zone hydrology. Specifically, the effects of future climate on geohydrology were to be determined to provide input to performance assessment and design.

The investigations included in the climate program are summarized in the following sections.

A.1.4.1 Studies to provide the information required on nature and rates of change in climatic conditions to predict future climates (SCP Investigation 8.3.1.5.1)

Background and SCP Plans The objective of this investigation was to provide recent meteorologic data and Great Basin historic climate data for use in calibrating (using present conditions) and validating (using past conditions) models of future climate. A paleoclimate-paleoenvironment synthesis was to be developed from data from studies of lake, playa, and marsh sediments, packrat middens, vegetation calibrations, and soil and surficial deposits. This synthesis was to provide time-sequential reconstructions for the modeling activities as well as for Investigation 8.3.1.5.2. These models were to attempt to forecast climatic variables for the next 100,000 years to determine climatic conditions. This investigation included six studies developed to accomplish the following:

1. Study 8.3.1.5.1.1 (characterization of modern regional climate): This study was to (a) characterize modern regional climate to provide a baseline for the interpretation of climatic variation; (b) characterize synoptic climate to determine modern spatial and temporal variations in precipitation, air temperature, cloud cover, and other meteorologic variables; (c) develop modern vegetation-climate calibration relationships, assess lake-climate relationships, and develop and test climate-circulation models to specify relationships between global-scale circulation patterns and the regional and local climate features of relevance to site performance; and (d) determine the climate conditions (i.e., time, temperature, seasonality, and air masses) under which recharge occurs.

2. Study 8.3.1.5.1.2 (paleoclimate study: lake, playa, and marsh deposits): This study was to (a) establish the nature, timing, duration, and amplitude of paleoclimate changes based on analyses of paleontologic, geochemical, and stratigraphic-sedimentologic data obtained from lacustrine sediments in or near southern Nevada; (b) assemble and interpret, in paleoclimatic terms, detailed records of ostracodes, diatoms, and pollen, and other types of fossils to identify, enumerate, and interpret

paleontologic data that emphasize the past 50,000 years in great detail, the past 200,000 years in moderate detail, and the past 1,000,000 years in some detail; (c) identify and characterize the general physical and chemical properties of sedimentary units from outcrops, shore deposits, and cores to determine their physical and relative temporal framework; (d) analyze the chemical and mineralogic characteristics of sediments to determine the chemistry of the water from which the minerals precipitated and to determine sediment provenance; (e) determine the specific environment of deposition for the sedimentary units; and (f) obtain an accurate, precise chronologic framework of the lake, playa, and marsh deposits sampled in this study.

3. Study 8.3.1.5.1.3 (climatic implications of terrestrial paleoecology): This study was to (a) provide quantitative estimates of changes in climatic variables (e.g., precipitation and temperature) for the southern Great Basin; (b) determine the nature, timing, duration, and magnitude of past vegetation change as recorded in plant macrofossil assemblages preserved in ancient packrat middens for the last 50,000 years and in the stratigraphic record of fossil pollen grains for the last 150,000 years; and (c) translate the vegetational records provided by packrat midden and palynological investigations and available dendroclimatological data into quantitative estimates of past climatic variables.

4. Study 8.3.1.5.1.4 (paleoenvironmental history of the Yucca Mountain region): This study was to (a) evaluate the paleoenvironmental record at Yucca Mountain and surroundings in light of the inferred paleoclimate history of the southern Great Basin to distinguish between effects of climate related surficial processes from those produced by tectonic activity; (b) conduct soil-properties modeling studies to determine the relations among late Holocene soils and modern climatic parameters, analyze properties of soils at Pahute Mesa and near Tonopah as analogs to soil formation at Yucca Mountain during pluvial conditions, compare properties of early Holocene and Pleistocene soils to paleoclimatic models that were reconstructed from other lines of evidence, frame climatic scenarios as a function of the depth, distribution, and quantity of pedogenic carbonate and other soil parameters, and to quantify rates of soil development in specific climates for use as a dating tool for Quaternary deposits and ages of fault movements; (c) conduct detailed mapping of surficial deposits in the vicinity of Yucca Mountain to support climate, geomorphic, tectonic, infiltration, engineering, and facilities studies; (d) determine the distribution of major concentrations of calcite-silica vein deposits at or near the ground surface at Yucca Mountain, and (e) document eolian erosion and deposition in the Yucca Mountain area during the last 750,000 years and the associated paleoenvironmental conditions.

5. Study 8.3.1.5.1.5 (paleoclimate-paleoenvironmental synthesis): This study was to conduct a paleoclimate-paleoenvironmental synthesis by comparing paleoclimatic estimates from various proxy data sets and providing summaries of paleoclimatic data in formats required for future climate and paleohydrology investigations.

6. Study 8.3.1.5.1.6 (characterization of future regional climate and environments): This study was to (a) estimate values for regional climatic parameters for the Yucca Mountain area over the next 100,000 years, with special emphasis on the next 10,000 years and provide estimates of future precipitation, temperature, and evapotranspiration for input to hydrologic models; (b) identify and estimate factors controlling global climate over the next 100,000 years, including the extent and climatic effects of ice sheets; (c) provide boundary conditions for regional climate models through the use of general-circulation models; (d) establish the feasibility of using a regional scale numerical climate model for predicting future climatic conditions at Yucca Mountain then calibrate the model against modern climatic data and validate it with paleoclimatic data; (e) conduct linked global-regional climate modeling to formulate scenarios of future climate in the Yucca Mountain area over the next 100,000 years and to determine the associated meteorologic parameters for input to hydrologic and erosion models; and (f) conduct empirical climate modeling to formulate scenarios of future climate in the Yucca Mountain area over the next 100,000 years and to determine the associated meteorologic parameters for input to hydrologic and erosion models.

Changes and Status. The objectives of the paleoclimate work have not changed since the SCP was issued. These studies remain the foundation of the climate program and the studies to estimate bounds on future climatic conditions. Data from different sample suites was to be used to develop numerical transfer functions for using these data sets to quantitatively estimate past climatic parameters such as precipitation and temperature. Collection of data from different sample media was intended to provide independent lines of evidence, and data from one sample suite could be used to corroborate data from another sample suite. The data sources were intended to be sufficiently extensive that data synthesis could provide a robust basis for describing past and current climatic conditions for modeling purposes. Ultimately, the future climate studies may use the linked model output as numerical input for hydrologic process models. Testing activities described in the SCP for this investigation are near completion. Changes that have occurred in the investigation are summarized below:

1. In the study of modern regional climate (8.3.1.5.1.1), the scope has been limited to determining stable and radiogenic isotopes in samples of modern precipitation to establish baseline data against which to compare the isotopic content of lake, playa, marsh, and paleospring deposits (see Study Plan 8.3.1.5.1.1, p. 1-1). Samples of precipitation were collected in the vicinity of Yucca Mountain for 2.5 years and analyzed to determine the relationships among isotopic composition, season and magnitude of precipitation events, and topographic elevation [Progress Report #13, Section 3.4.1, p. 3-112 (DOE, 1996f)]. Meteorological and other climatic data necessary for characterization of modern regional climate have been collected and analyzed in Study 8.3.1.2.1.1 in the geohydrology program and in Investigation 8.3.1.12.1 in the meteorology program.

2. In the study of the paleoclimate of lake, playa, and marsh deposits (8.3.1.5.1.2), efforts have focused on obtaining relevant data sets in all study areas (recent meteorologic,

aquatic, terrestrial, and surficial) and correlating these data with orbital parameters to produce a time-sequential reconstruction. Multiple cores and deposits from relevant lake basins and spring deposits are being used to extract ostracode, diatom, and pollen data sets. A significant difference between the current study and that outlined in the SCP is the period of time selected for the most detailed paleoclimate characterization. The current study is focusing most intensively on the last 400,000 years because this time frame represents a full climate cycle consisting of four 100,000-year subcycles, each containing a glacial-interglacial couplet. More importantly, the interpretation of the relationship between climate change and insolation, which is determined by the earth's orbital properties, indicates the climatic conditions during the next 100,000 years are likely to be most like those that existed between 300,000 and 400,000 years ago (Forester et al., 1996a).

3. In the study of climatic implications of terrestrial paleoecology (8.3.1.5.1.3), terrestrial studies have focused on packrat middens to reconstruct the history of vegetation changes and associated climatic variables. This study has proceeded largely as described in the SCP.

4. In the study of the paleoenvironmental history of the Yucca Mountain region (8.3.1.5.1.4), surficial and soil studies have established depositional and erosional regimes in response to climatic changes. Detailed mapping of surficial deposits was completed as described in the SCP, but primarily to support geomorphic, tectonic, infiltration, and engineering studies rather than climate studies. Soil-properties modeling to determine the relationships between soil formation and climatic parameters has been deleted from the study because characteristics of soil formation are unlikely to provide the millennial-scale climate-change information available from other lines of evidence (R.M. Forester, USGS, Oral Communication, November 1996), such as isotopic compositions of deep calcites. Also, soil-properties modeling will not yield information on changes in mean annual precipitation and temperature, which is critical to developing future climate scenarios based on the past.

   The origins of major calcite-silica vein deposits were determined in Study 8.3.1.5.2.1 (characterization of the quaternary regional hydrology) and are described in Stuckless (1991), Stuckless et al. (1991), National Research Council (1992), and Stuckless et al. (1992).

5. In the paleoclimate-paleoenvironmental synthesis study (8.3.1.5.1.5), current efforts are focused on synthesizing and corroborating the various data sets to reconstruct paleoclimatic conditions. These time-sequenced reconstructions were to be used to estimate the initial bounds for future climatic conditions and to calibrate the future climate-modeling efforts. This study has proceeded largely as described in the SCP.

6. In the characterization of future regional climate and environments study (8.3.1.5.1.6), limitations in numerical-modeling techniques have resulted in the realization that a full 100,000-year simulation of future climate using the regional climate model is not

feasible. Instead, the regional climate model is being used to simulate various possible future climate scenarios (such as the "greenhouse" state) and the conditions of the glacial maximum that occurred about 21,000 years ago) then to produce tallies of precipitation and temperature for two- to five-year periods. These tallies are, in essence, "snapshots" in time for the climate conditions that are simulated by the model for the boundary conditions, such as ice cover, that describe the scenario. The details of this approach are described in Thompson et al. (1996).

A.1.4.2 Studies to provide the information required on potential effects of future climatic conditions on hydrologic characteristics (SCP Investigation 8.3.1.5.2)

Background and SCP Plans. The objective of this investigation was to develop an understanding of the Quaternary regional hydrologic regime by using the reconstructions of past climate from Investigation 8.3.1.5.1, along with past surface-water, unsaturated zone, and saturated zone characterizations. The investigation was to determine the hydrologic conditions during the Quaternary that differ significantly from present conditions because of changes in climate. Data from this investigation were intended to assess the nature and likelihood of episodic climatic changes that could produce changes in the regional flow system during the next 100,000 years. This information, along with models of future climate conditions and estimates of future meteorologic conditions from Investigation 8.3.1.5.1, and models of the unsaturated and saturated zones from the geohydrology program (SCP Section 8.3.1.2), was to be used to determine the effects of climate change on geohydrology. This determination would require development of a relationship between climate, infiltration, and recharge. This investigation included two studies developed to accomplish the following:

1. Study 8.3.1.5.2.1 (characterization of the Quaternary regional hydrology): This study was to (a) characterize the distribution of surface water, unsaturated zone infiltration and percolation rates, and ground-water potentiometric levels during the Quaternary Period in the vicinity of Yucca Mountain; (b) investigate the hydraulic characteristics of paleofloods and compare them with modern flooding and geomorphic processes to improve knowledge of the relationships between climate and flooding; (c) assess the character and severity of potential flood and debris hazards for the repository during the preclosure period; (d) determine the past infiltration and percolation history at Yucca Mountain by analyzing the isotopic and chemical characteristics of water from the unsaturated zone; (e) characterize the hydrogeologic units in the regional ground-water discharge areas of the Amargosa Desert and Death Valley; (f) understand the past quantity and quality of water in the discharge areas of Franklin Lake, Amargosa Desert-River, and Peter's Playa; (g) determine the location and hydrogeologic characteristics of paleospring deposits and the amount of discharge by evapotranspiration that has occurred at past discharge sites; (h) determine past ground-water levels in carbonate caverns as evidence of past hydrologic conditions; (i) use information about past and present discharge areas to help predict the future saturated zone hydrologic system at Yucca Mountain, (j) conduct analog recharge studies to estimate the conditions and rates of ground-water recharge (infiltration) during the

Quaterna Yucca Mountain; and (k) determine the ages, distribution, origin, and paleohydr gnificance of calcite and opaline silica vein deposits along faults and fractures in the vicinity of Yucca Mountain.

2. Study 8.3.1.5.2.2 (characterization of future regional hydrology due to climate changes): This study was to (a) characterize the impacts of potential future climate changes on the regional and site surface-water system, the site unsaturated zone hydrology, and the regional and site saturated zone hydrology; (b) simulate past changes in runoff and surface-water storage (lakes) resulting from past climatic change using precipitation-runoff models calibrated to modern surface-water conditions; (c) use the relationship between paleoclimate and paleo surface-water conditions to predict the impact of future climatic conditions on surface water hydrology at the site; (d) predict quantitatively the potential effects of future climatic conditions on infiltration, percolation, and the degree of saturation of the unsaturated zone at Yucca Mountain; (e) reconstruct paleohydrologic conditions at Yucca Mountain and use these conditions together with the reconstructed paleoclimatic conditions to predict the impact of future climatic conditions on the saturated zone; and (f) use numerical-simulation techniques to synthesize existing paleohydrologic data and to determine the effects of greater recharge on water-table altitude, ground-water flow paths, and hydraulic gradients.

Changes and Status. The objectives of this investigation have not changed since the SCP was issued. However, the investigation has been modified to take advantage of data available from other sources. For example, the objectives of characterizing the hydrogeologic units in the regional ground-water discharge areas and predicting the effects of future climatic conditions are being accomplished through collaboration with SCP Studies 8.3.1.2.1.3 and 8.3.1.2.1.4. In these studies, data from outside sources were used to construct hydrogeologic framework and numerical flow models of the regional ground-water-flow system (see Section A.1.1.1 of this appendix) and those models are being used to investigate the effects of possible future climate scenarios (see Section 3.1.4 of this progress report). Further, the characterization of past discharge areas has been accomplished through collaboration with SCP Study 8.3.1.5.1.2 (Paleoclimate Study: Lake, Playa, and Marsh Deposits). The investigation is intended to determine the effect of past climate change on hydrologic conditions, then use that understanding as the foundation for evaluation of future effects of climate change on hydrologic conditions. Changes that have occurred in the investigation are summarized below.

1. The Quaternary regional hydrology study (8.3.1.5.2.1) has changed significantly since the SCP was issued. For example, the Quaternary unsaturated zone hydrochemical analysis planned originally under this study has been transferred to Study 8.3.1.2.2.7 (characterization of the unsaturated zone hydrochemistry). Further, although a study of paleoflooding and the potential for future extreme flooding was conducted in Coyote Wash at Yucca Mountain (Glancy, 1994), additional, site-specific studies of alluvial deposits in neighboring washes were not conducted, and only limited studies were conducted in the region surrounding Yucca Mountain (Grasso, 1996). This is because there was less concern about flood and debris hazards potentially impacting the ESF or

surface facilities after the ESF was reconfigured from vertical shafts to ramps and drifts and the entrances (portals) were relocated from Coyote Wash to Midway Valley. As reported in the Technical Basis Report for Surface Characteristics, Preclosure Hydrology, and Erosion (DOE. 1995d, p. 2-12), the locations of the ESF north and south portals are outside the flood-prone area for the probable maximum flood. Overall, the report concluded that flooding of the repository by extreme runoff during the preclosure period was extremely unlikely given the location and elevation of the ESF.

Much of the work planned for evaluation of past discharge areas has been completed. This includes remote sensing of pedogenic carbonate deposits, vegetation, and fracture zones; measurement of discharge from springs and seeps; measurement of water levels in wells, caverns, and springs; studies of past water levels in carbonate caverns; chemical and isotopic analysis of hydrogenic deposits; and studies of ostracode ecology. However, some characterization work described in the SCP either has not been conducted or has been accomplished under other studies. For example, a drilling program to sample subsurface materials was not implemented because subsurface sampling also was being conducted under Study 8.3.1.5.1.2 (paleoclimate study: lake, playa, and marsh deposits). Also, characterization of hydrogeologic units in the regional ground-water discharge area has been accomplished using available data under Study 8.3.1.2.1.3 (characterization of the regional ground-water flow system).

In contrast, efforts to characterize surficial pedogenic deposits and the history and origin of paleosprings and lake ecology have expanded significantly in scope and complexity [see Progress Reports #11 and #12, Section 3.4.7, Activity 8.3.1.5.2.1.3 (DOE, 1995b and 1995g)]. The expansion was necessary because of concern that the deposits originated from discharge of ground water from the saturated zone at higher elevations and in more recent times than had been hypothesized at the time the SCP was written [Progress Report #13, Section 3.4.7, Activity 8.3.1.5.2.1.3, (DOE, 1996f)]. Deposits in about 50 playas in the Yucca Mountain region have been sampled for ostracode ecology and for chemical and isotopic analysis [Progress Report #9, Section 2.2.4.7 (DOE, 1994g)]. In addition, for selected sites, interdisciplinary, reconnaissance- level stratigraphic, sedimentologic, geochronologic, isotopic, and paleontologic studies have been conducted (Paces et al., 1996b). Efforts to determine the origin and age of hydrogenic deposits have intensified to determine fluctuations in elevation of the regional water table and the extent of ground-water discharge during the last several glacial cycles (Paces et al., 1996b). Past water-table levels and ground-water discharge are crucial for predicting the probability of such conditions recurring during the repository postclosure period. These studies have been enhanced and advanced considerably through application of state-of-the-science isotopic methods including strontium, uranium-series disequilibrium, and stable carbon and oxygen analyses (Paces et al., in press, Paces et al., 1995).

Although the analog-recharge study was terminated prior to full implementation of the four or five sites envisioned in the SCP, useful results were obtained from two small watersheds in south-central Nevada that were instrumented and studied for several years (Lichty and McKinley, 1995). Results obtained from the 3-Springs/Kawich site (annual precipitation 250-350 mm/yr) and the East Steward Creek site (annual precipitation 500-700 mm/yr) were judged to be sufficient to meet study objectives. Because of the difficulties associated with obtaining sufficient data to support low error precipitation-runoff and chloride-mass-balance modeling at the drier site (Kawich), no additional dry-end analog sites were studied. In addition, a study of an "arid-zone, monsoonal" site in Arizona was initiated but then terminated because of resource constraints before any significant results could be obtained.

Studies of calcite and opaline-silica vein deposits have been expanded substantially in scope and complexity. Whereas the SCP outlined sampling and analysis of fault and fracture fillings found in trenches, natural exposures, drill cores, and spring and pedogenic deposits (Stuckless, 1991; Stuckless et al., 1991; National Research Council, 1992; Stuckless et al., 1992), the current study has undertaken an intensive effort to sample and analyze occurrences of secondary calcite and silica in fractures, fault zones, and lithophysal cavities in the ESF. This expansion was in response to a need to reconstruct the history of percolation in the Topopah Spring Tuff at the potential repository horizon to support performance-assessment and design issues. This work has been facilitated by recent advances in petrographic and isotopic sampling and analytical methods, and by ready access to the rock mass afforded by the ESF ramp and drift configuration. Although the study has focused on the repository horizon, representative samples have been collected from the entire length of the ESF as excavation has proceeded. The study has concentrated on the application of strontium and stable carbon and oxygen isotope ratios to determine the source of water and the mode of mineral deposition, uranium-series and radiocarbon dating methods to determine timing of mineral deposition, and petrographic examination to determine the sequence of mineral deposition. The goal of these studies is to use the history and distribution of secondary-mineral deposition in the deep unsaturated zone to estimate or bound percolation rates through the repository block over the past several hundred thousand years (Paces et al., 1996a).

2. In the study of future regional hydrology due to climate changes (8.3.1.5.2.2), efforts to develop precipitation-runoff models of modern surface-water conditions and basin characteristics were terminated because runoff occurs so infrequently that collecting data sets sufficient to calibrate the models was not feasible. Regional ground water modeling studies (D'Agnese et al., in press[a]) did not require runoff data for calibration because a direct relationship between precipitation and ground-water recharge was used. The impact of future climate on the ground-water system was identified as more important for evaluating repository performance than the impact of future climate on the surface-water system. Consequently, plans to use these models to predict future runoff conditions resulting from hypothesized climatic change also were dropped from the characterization program. The effects of possible future climatic

conditions on the regional ground-water system are being evaluated under Activity 8.3.1.2.1.4.4 (see Section 3.1.4 of this progress report and Section A.1.1.1 of this appendix).

As reported in Revision 9 of the Site Characterization Program Baseline (see Appendix H of this progress report), the analysis of impacts of future climate changes on the unsaturated zone have been deleted from this study and will be performed under Activities 8.3.1.2.2.9.3 and 8.3.1.2.2.9.5. Similarly, the effects of possible future recharge from climate changes on the saturated zone are being evaluated under Studies 8.3.1.2.1.4 (regional hydrologic system synthesis and modeling) and 8.3.1.2.3.3 (site saturated zone hydrologic system synthesis and modeling).

A.1.5 Erosion Program (SCP Section 8.3.1.6)

Data available when the SCP was written suggested that the proposed repository could be constructed deeper than the minimum depth of 200 m and that erosion was unlikely to uncover or affect the repository at the planned depth (DOE, 1986). Long-term average upland and hillslope erosion rates had been established for the southern Great Basin and many of the parameters necessary to estimate erosion rates in the region had been obtained from ongoing scientific studies at the Nevada Test Site. Few of these data, however, were specific to the proposed repository site. Therefore, the erosion program was designed to provide representative, site-specific data about present and past locations and rates of erosion, effects of future climatic conditions and future tectonic activity on locations and rates of erosion, and potential effects of erosion on selected other site features and processes.

The investigations included in the erosion program are summarized in the following sections.

A.1.5.1 Studies to Determine the Distribution and Characterization of Present and Past Erosion (SCP Investigation 8.3.1.6.1)

Background and SCP Plans. The objectives of this investigation were to identify the erosional processes that have been operating in the Yucca Mountain area during the Quaternary Period to identify the specific locations of past erosion and to quantify the rates of the different processes and assess their relative importance. This investigation included one study developed to accomplish the following.

Study 8.3.1.6.1.1 (distribution and characteristics of present and past erosion). This study was to (a) determine the areal distribution of active erosional areas and geomorphically stable areas and determine the spatial distribution of the different types of geomorphic processes and associated deposits, (b) determine stream-incision rates on Fortymile Wash and selected tributaries and determine the cause(s) of the major downcutting episode(s) on Fortymile Wash, and (c) determine the average rates of Quaternary hillslope erosion on

Yucca Mountain in bedrock and surficial deposits and determine the genesis and rates of movement of hillslope deposits.

Changes and Status. The primary objectives of this investigation have not changed since the SCP was issued. The SCP, however, described a more extensive program of data collection. The studies for this investigation have evolved based on technical information obtained from the laboratory and field studies, model development and data application activities of the site characterization program. Rapidly increasing scientific understanding, along with periodic total system performance assessments, have enabled focusing the ongoing site characterization program on the remaining uncertainties that are significant to the design, operation and safety performance of the proposed repository. Reevaluation and prioritization of Project needs has been a continuous process based on scientific judgment and resource availability, governed by scientific criteria to (a) ensure that data needed for site description, performance assessment, and design purposes were collected and analyzed, and (b) eliminate data-collection redundancy and overlap. The data-collection needs have been further analyzed and refined as additional knowledge has been gained through years of site characterization activities. This process has resulted in the following changes to the investigation.

All objectives identified in the SCP have been fulfilled to address the DOE siting guidelines (10 CFR Part 960) and the NRC performance requirements (10 CFR Part 60) as specified in these regulations. Some of this information was reported to the NRC in a topical report (DOE, 1993c) containing the DOE evaluation of the extreme erosion potentially adverse condition, in the responses to the NRC staff comments on the Extreme Erosion Topical Report (DOE, 1995h) and supplemental responses contained in a letter dated June 28, 1996 (CRWMS M&O, 1996dd). Other parts of the information have been (a) presented in the Technical Basis Report for Surface Characteristics, Preclosure Hydrology, and Erosion (DOE, 1995d); (b) forward-referenced to outputs in the Project Integrated Safety Assessment; (c) fulfilled with surrogate information gathered under other SCP Programs; or (d) rendered unnecessary based on early stages of the investigation and evaluation of the need for additional data to support assessments of performance of the potential repository. Quaternary denudation rates on hillslopes and stream incision rates in the major alluvial system at Fortymile Wash confirmed the DOE expectations and indicated that no additional data collection was required. In 1991, DOE decided to document the results obtained in a topical report (DOE, 1993c) as planned in Investigation 8.3.1.6.4, terminate data collection, and not implement Investigations 8.3.1.6.2 and 8.3.1.6.3. The NRC was officially informed that study plans would not to be developed for the erosion program (DOE, 1994h).

Work for the erosion program began in the 1980s under a USGS Survey Scientific Investigation Plan (Whitney, 1987) and later through SCP study plans that had been prepared for other programs of the SCP (the Preclosure Tectonics Program, Study Plan 8.3.1.17.4.6, "Quaternary Faulting in the Site Area," the Preclosure Hydrology Program," Study Plan 8.3.1.16.1.1, "Characterization of Flood Potential at the Yucca Mountain Site;" and the Climate Program Study Plan 8.3.1.5.1.4, "Analysis of the Paleoenvironmental History of the Yucca Mountain Region"). Data gathered under these studies were used to describe erosional processes, measure the extent of erosion, and calculate erosion rates. The erosion rate estimates and information demonstrating the overall stability of the landscape indicated that additional analysis and data collection were unnecessary. These results were documented in the Extreme Erosion Topical Report (DOE, 1993c). Similar interpretations were described in the Technical Basis Report for Surface Characteristics, Preclosure Hydrology, and Erosion which stated: "Studies of erosional processes at the Yucca Mountain Site suggest that the landscape at the Yucca Mountain Site has changed very little during the past several hundred thousand years due to erosion." (DOE, 1995d, p. 5-1).

Because of NRC staff concerns with the age estimation method used by DOE to determine ages of colluvial boulder deposits, the DOE authorized a modest program to collect cosmogenic ages for selected deposits (CRWMS M&O, 1996dd) under Study 8.3.1.5.1.4 (analysis of the paleoenvironmental history of the Yucca Mountain region). Information from this study was expected to corroborate the ages determined previously and support DOE's conclusions about the erosion rates, and the age and stability of the landscape (DOE, 1995d). Given the proposed depth of the potential repository of at least 200 m (DOE, 1995d), and based on the stability of the landscape and the very low rates of hillslope erosion (DOE, 1993c and 1995d), the DOE determined that it is unlikely that hillslope erosion poses a significant risk to repository performance.

In Study 8.3.1.6.1.1 data were obtained from other studies to determine the age of alluvial deposits and stream incision rates in Fortymile Wash and Midway Valley, and the age of colluvial boulder deposits and erosion rates on hillslopes. Information on the depth of stream incision, stream gradients, and lithologic composition of gravels in the Fortymile Wash drainage system was collected under studies in the climate program and is reported in Lundstrom and Warren (1994). Dating of surficial alluvium, soils, and terraces was reported in Paces . . (1995) and is discussed in CRWMS M&O (1996dd).

Volumes of denuded sediment were calculated. An abstract by Coe et al. (1992) estimated volumes of sediment removed from the western slope-face of Yucca Mountain. A volumetr analysis of Quaternary alluvium removed in Midway Valley based on the results of surficial deposits mapping in Study 8.3.1.5.1.4 was reported in CRWMS M&O (1996dd).

A.1.5.2 Potential effects of future climatic conditions on locations and rates of erosion (SCP Investigation 8.3.1.6.2

Background and SCP Plans. The objectives of this investigation were to determine the effects of future climatic conditions on the locations and rates of erosion, especially areas with the potential for increased erosion or stream incision, and apply the results to evaluation of site processes that could degrade the surface marker system. This investigation includes one study to accomplish the following:

Study 8.3.1.6.2.1 (potential effects of future climatic conditions on locations and rates of erosion). This study was to determine the effects of future climatic conditions on the locations and rates of erosion by integrating Quaternary climate conditions and rates of surface erosion with predicted conditions of future climate, and by estimating significant changes in the character, distribution, and rates of surface erosion in the Yucca Mountain region over the next 10,000 to 100,000 years.

Changes and Status. The primary objectives of this investigation have not changed since the SCP was issued. However, on the basis of data collected in other site characterization programs and analyses done for Investigation 8.3.1.6.1, DOE determined that erosion rates are extremely low and that the potential impacts on repository system performance are negligible. Thus, the DOE decided not to implement Investigation 8.3.1.6.2, and the NRC was officially informed that study plans would not be developed (DOE, 1994h).

The present locations and rates of surface erosion and their relationships to present climate are discussed in the Extreme Erosion Topical Report (DOE, 1993c), Coe et al. (1995), and Whitney and Harrington (1993). The distribution and characteristics of past erosion and their relationships to past climatic conditions are discussed in Glancy (1994), Whitney and Harrington (1993), and in CRWMS M&O (1996dd). DOE has concluded that climatic influences on erosion are minimal. Climate fluctuations of the type that can be discerned over the last 10,000 to 100,000 years with proxy data from the geologic record bound the expectation for future conditions. DOE's data and analyses support the conclusion presented in the Extreme Erosion Topical Report (DOE, 1993c) that erosion rates have been very low during the last half of the Quaternary Period. In fact the erosion rate is so low that DOE concluded that the potentially adverse condition, "evidence of extreme erosion during the Quaternary Period" (10 CFR 60.122(c)(16)) is not present at the site (DOE, 1993c), and erosion is unlikely to have any significant impact on performance of the potential repository.

A.1.5.3 Studies to provide the information required to determine the potential effects of future tectonic activity on locations and rates of erosion (SCP Investigation 8.3.1.6.3)

Background and SCP Plans. The objectives of this investigation were to identify the potential effects of tectonic activity on erosion at Yucca Mountain during the postclosure period by defining those components of erosion that were dependent upon tectonic activity, determining how future tectonic adjustment might influence local incision rates, and applying the results to assessment of the potential for degradation of the surface marker system. This investigation included one study developed to accomplish the following:

Study 8.3.1.6.3.1 (evaluation of the effects of future tectonic activity on erosion at Yucca Mountain): This study consists of a single synthesis activity that was intended to estimate (a) the effects of tectonic activity on erosion over the repository postclosure period using probable future tectonic scenarios for the Yucca Mountain region; (b) the locations and rates of present and past erosion for present climatic conditions; and (c) the effects of future climatic conditions on erosion.

Changes and Status. The primary objectives of this investigation have not changed since the SCP was issued. However, on the basis of data collected in other site characterization programs and analyses done for Investigation 8.3.1.6.1, DOE determined that erosion rates are extremely low and that the potential impacts on repository system performance are negligible. Thus the DOE decided not to implement Investigation 8.3.1.6.3, and the NRC was officially informed that study plans would not be developed (DOE, 1994a).

The intent of the study to evaluate the effects of future tectonic activity on erosion at Yucca Mountain (8.3.1.6.3.1) was fulfilled by work performed under Investigation 8.3.1.17.4. The ages of exhumed fault line scarps on the Solitario Canyon and Windy Wash faults were calculated with cosmogenic carbon-14 (Harrington et al., 1994; also pp. 4-15 and 4-16 of DOE, 1995d). Erosion rates are so low at Yucca Mountain that these scarps show only minor modification after a minimum exposure age of 20,000 years. The tectonic model synthesis, including the probability and expected magnitude of faulting in the Yucca Mountain area during the postclosure period was evaluated under Investigation 8.3.1.17.4 and is reported in Whitney (1996).

A.1.5.4 Potential effects of erosion on hydrologic, geochemical, and rock characteristics (SCP Investigation 8.3.1.6.4)

Background and SCP Plans. The objectives of this investigation were to assemble data showing the expected effects of erosion (a) on the hydrologic, geochemical, and rock characteristics of the controlled area and (b) on the ability of the mined geologic disposal system (MGDS) to effectively isolate waste over 10,000 and 100,000 years after disposal. The results of this investigation were intended to be reported in a topical report describing the effects of erosion on the geohydrology, rock characteristics, and geochemistry of the site. This investigation included one study developed to accomplish the following:

> Study 8.3.1.6.4.1 (development of a topical report to address the effects of erosion on the hydrologic, geochemical, and rock characteristics at Yucca Mountain): This study was to assemble data showing the expected effects of erosion (a) on the hydrologic, geochemical, and rock characteristics of the controlled area and (b) on the ability of the MGDS to effectively isolate waste over 10,000 and 100,000 years after disposal.

Changes and Status. The primary objectives of this investigation have not changed since the SCP was issued. Although plans for the studies identified in this investigation were not developed, the main study objectives identified in the SCP have been accomplished as described in the discussions under investigations 8.3.1.6.1, 8.3.1.6.2, and 8.3.1.6.3.

DOE completed the topical report on extreme erosion (DOE, 1993c) and used the report to fulfill the intention described in the SCP. A second topical report will not be developed because of the extremely low erosion rates determined for the arid region and the erosion-resistant rock type at Yucca Mountain. Potential performance impacts from erosion over time were discussed in the supplemental responses to the NRC comments (DOE, 1995h, pp. 2-39 and 2-40) on the

Extreme Erosion Topical Report. Rates of erosion at Yucca Mountain have been shown to be so low (DOE, 1993c; DOE, 1995h, pp. 2-39 and 2-40) that it is extremely unlikely that erosion could remove enough overburden to impact repository system performance.

A.1.6 Rock Dissolution Program (SCP Section 8.3.1.7)

The objective of this investigation was satisfied by the information presented in the Yucca Mountain Environmental Assessment (DOE, 1986).

The investigation included in the rock dissolution program is summarized in the following section.

A.1.6.1 Rates of dissolution of crystalline and noncrystalline components in tuff (SCP Investigation 8.3.1.7.1)

The objectives of this investigation were satisfied by the information presented in the Yucca Mountain Environmental Assessment (DOE, 1986). Therefore, no additional testing was proposed in the SCP. The potential for dissolution to occur in conjunction with thermally driven fluid flow and condensation in the repository environment is being addressed in the altered zone study (see Section A.1.15).

A.1.7 Postclosure Tectonics Program (SCP Section 8.3.1.8)

The postclosure tectonics program specified in the SCP was predicated on performance and design requirements (e.g., 10 CFR 60.122 and 10 CFR 960.4-2-7) to investigate, and provide data about, the probabilities and effects of tectonic "initiating events" that might alter existing conditions at Yucca Mountain and adversely affect repository performance. Five investigations were identified and included in the postclosure tectonics program. As the following discussion indicates, the first four investigations were intended to provide data collection, and the last investigation was intended to provide analysis of the data collected.

Because many elements of these investigations have been consolidated since the SCP was issued (Revision 11, Site Characterization Program Baseline; see Appendix H of this progress report), the summaries for Investigations 8.3.1.8.2, 8.3.1.8.3, and 8.3.1.8.4 have been combined into Section A.1.7.2.

The investigations included in the postclosure tectonics program are summarized in the following sections.

A.1.7.1 Studies to provide information required on direct releases resulting from volcanic activity (SCP Investigation 8.3.1.8.1)

Background and SCP Plans. The purpose of this investigation was to assess the probability of future volcanic activity with respect to siting a repository for storage of high-level radioactive waste at Yucca Mountain and gather data on the effects of a potential volcanic eruption should such an eruption penetrate the site. This investigation included two studies developed to accomplish the following:

1. Study 8.3.1.8.1.1 (probability of a volcanic eruption penetrating the repository): This study was to (a) synthesize the data collected by other activities on the dating, location, and volume of late Cenozoic volcanic events in the region surrounding the site; (b) investigate time-space patterns of past volcanic activity in the Yucca Mountain region and the possible structural controls of volcanic centers and potential future volcanic centers at and adjacent to Yucca Mountain; (c) use statistical methods to evaluate geophysical data to assess the significance of possible local and regional structures on the area ratio of probability calculation; (d) review geophysical and geochemical data collected near the site to assess whether there were any indications of the presence of crustal bodies that could be the source of future volcanic activity; and (e) revise estimates of the probability of volcanic disruption of a repository site at Yucca Mountain.

2. Study 8.3.1.8.1.2 (effects of a volcanic eruption penetrating the repository): This study was to (a) summarize the effects of a Strombolian eruption on a repository; and (b) obtain geologic parameters for disruption of a repository by magmatic activity accompanied by hydrovolcanic (magma-water) explosions.

Changes and Status. The primary objectives of this investigation have not changed since the SCP was issued. The SCP, however, described a more extensive program of data collection. The studies for this investigation have evolved based on technical information obtained from the laboratory and field studies, model development and data application activities of the site characterization program. Rapidly increasing scientific understanding, along with periodic total system performance assessments, have enabled focusing the ongoing site characterization program on the remaining uncertainties that are significant to the design, operation and safety performance of the proposed repository. Reevaluation and prioritization of Project needs has been a continuous process based on scientific judgment and resource availability, governed by scientific criteria (a) to ensure that data needed for site description, performance assessment, and design purposes were collected and analyzed, and (b) to eliminate data-collection redundancy and overlap. The data-collection needs have been further analyzed and refined as additional knowledge has been gained through years of site characterization activities. This process has resulted in the following changes to the investigation.

1. In the probability of a volcanic eruption penetrating the repository study (8.3.1.8.1.1), the main objective (to estimate the probability of disruption of a repository) has remained the same since the SCP was issued. Data on the location and timing of

volcanic events was incorporated into the Probabilistic Volcanic Hazard Analysis (CRWMS M&O, 1996e) (see Section 3.6.2 of this progress report). The study of the presence of magma bodies in the vicinity of the site using geophysical techniques was performed by the geophysics program under Study 8.3.1.4.2.1 and not by the volcanism program. Calculations of the probability of a volcanic eruption penetrating the repository were completed using currently available data. A final set of probability calculations using only qualified data obtained in Study 8.3.1.8.5.1 (characterization of volcanic features) was deferred indefinitely. Probability studies were augmented and tested in 1995 through use of the expert elicitation process. The results of the expert elicitation were reported in the Probabilistic Volcanic Hazard Analysis for Yucca Mountain, Nevada (CRWMS M&O, 1996e) [see Section 3.6.1 of Progress Report #15 (DOE, 1997e)].

2 The effects of a volcanic eruption penetrating the repository study (8.3.1.8.1.2) has changed substantially since the SCP was issued. Studies of the effects of Strombolian and hydrovolcanic eruptions were replaced by three activities (eruptive effects, subsurface effects, and magma system dynamics) when the study plan was drafted in 1993. The eruptive effects activity was only partially completed (not all measurements from analog centers were completed, nor were all data analyzed). However, based on the results of the Probabilistic Volcanic Hazard Analysis (CRWMS M&O, 1996e), there appear to be no significant impacts from only partially completing the measurements of analog centers. The subsurface effects activity, which focuses on the processes that control shallow-level intrusion geometries and on hydrothermal alteration in silicic tuffs near shallow basaltic intrusions, now includes the study of chemical and physical changes around dikes. A third aspect of the subsurface studies, modeling of hydrothermal processes near intrusions and implications for their effects on a repository, has been indefinitely deferred. A new magma system dynamics study activity was added; its objectives were to constrain the physical processes that control magma generation and ascent and to determine how these processes relate to probabilistic estimates of future volcanic activity. Further work on Study 8.3.1.8.1.2 has been deferred indefinitely because based on the results of the Probabilistic Volcanic Hazard Analysis (CRWMS M&O, 1996e), additional work is not needed to support the long-range plan.

The relative importance of precisely evaluating the potential effects of a direct volcanic eruption penetrating the repository are directly related to (a) the probability of having such an event during the time period of regulatory concern, (b) the performance measure of concern, and (c) the significance of these effects. Total system performance assessments conducted to date using bounded estimates of the effects of such events indicate that the probability of occurrence is the most significant aspect of the impact of direct intrusive events on postclosure performance. Therefore, greater effort, including expert elicitation (CRWMS M&O, 1996e), has been devoted to narrowing the probability uncertainty, and the additional work required to refine the estimates of bounds of direct effects has been deferred.

A.1.7.2 Studies to provide information required on rupture of waste packages due to tectonic events (SCP Investigation 8.3.1.8.2); Studies to provide information required on changes in unsaturated and saturated zone hydrology due to tectonic events (SCP Investigation 8.3.1.8.3); Studies to provide information required on changes in rock geochemical properties resulting from tectonic processes (SCP Investigation 8.3.1.8.4)

Background and SCP Plans. The three investigations were intended to determine the hazards posed to the repository by a variety of tectonic initiating events during the postclosure period. Once the hazards were determined, the investigations were designed to examine the potential effects of these hazards on waste package integrity, saturated and unsaturated zone hydrology, and rock mineralogical and geochemical properties during the postclosure performance period. The testing and modeling proposed was intended to provide data to describe and characterize the magnitudes and rates of tectonic processes that have operated in the past. This information was to provide the basic input for geologic, geochemical, tectonic, and hydrologic models of the site. In turn, these models were to provide the mechanisms for analyzing scenarios that portray the potential future effects of tectonic processes and events that could impact repository performance. Initiating events to be modeled included volcanic and igneous intrusion in the control area, faulting, uplift or tilting of rocks, and changes in stress-strain characteristics resulting from related tectonic or igneous events.

In Revision 11 to the Site Characterization Program Baseline (Appendix H), the three investigations were reconfigured into a single study titled "Tectonic Effects: Evaluations of Changes in the Natural and Engineered Barrier Systems Resulting from Tectonic Processes and Events" (Study 8.3.1.8.2.1, see Section 3.6.3 of this progress report). As indicated in Progress Reports #10 and #11 (DOE, 1994e and 1995b), the five studies that composed the three original investigations became the five activities in the reconfigured study, which was designed to accomplish the following:

1. Activity 8.3.1.8.2.1.1 (formerly Study 8.3.1.8.2.1): Collect and synthesize data to assess the probability and effects of tectonic processes and events that could result in waste package rupture and/or adverse impacts on waste-package lifetime and performance.

2. Activity 8.3.1.8.2.1.2 (formerly Study 8.3.1.8.3.1): Analyze and assess the probability and effects of tectonic initiating events that may result in changes in the average percolation flux rate at the top of the Topopah Spring welded hydrogeologic unit.

3. Activity 8.3.1.8.2.1.3 (formerly Study 8.3.1.8.3.2): Analyze and assess the probability that tectonic initiating events could result in significant changes in the elevation of the water table, changes in the hydraulic gradient, the creation of discharge points in the controlled area, or the creation of perched aquifers in the controlled area.

4. Activity 8.3.1.8.2.1.4 (formerly Study 8.3.1.8.3.3): Analyze possible changes in fracture permeability and effective porosity caused by tectonic events and processes.

5. Activity 8.3.1.8.2.1.5 (formerly Study 8.3.1.8.4.1): Assess possible local changes in the distribution of rock geochemical properties resulting from tectonic processes and events.

Changes and Status. The objectives of the investigations (now the reorganized study) have not changed since the SCP was issued. The results of multifaceted studies required as inputs to modeling and assessments needed to determine the impacts of tectonic events on the hydrologic system were items of early focus of the site characterization studies. Studies of volcanic and tectonic effects have been coordinated with performance assessment scenario development and consequence analyses over the past several years. Preliminary geologic, geochemical, tectonic and hydrologic models of the site have been developed. Probabilistic estimates of the magmatic disruption probability have been reported in various progress reports since the 1980s, and in 1996 a Probabilistic Volcanic Hazard Analysis for Yucca Mountain, Nevada, was completed (CRWMS M&O. 1996e). This analysis quantified the probability and uncertainty of volcanic disruption of the repository using formal expert elicitation. As discussed in the description of Investigations 8.3.1.17.3 and 8.3.1.17.4 (Sections 3.13.8 and 3.13.9 of this progress report), characterization of seismic hazards is now complete. In 1997 a probabilistic seismic hazard analysis is intended to provide the basis for assessing the magnitudes and rates of tectonic processes. Event trees that form the basis for scenario development for volcanism and tectonics are now complete. To date, preliminary disruptive scenarios for volcanism, reported in Total System Performance Assessment - 1991 (Barnard et al., 1992; Eslinger et al., 1993) and Total System Performance Assessment - 1993 (Andrews et al., 1994; Wilson et al., 1994), indicate that volcanic effects are not significant to system performance. Changes that have occurred in implementation of the reorganized study are summarized below:

1. In the effect of tectonics on waste-package lifetime and performance activity (8.3.1.8.2.1.1), the potential for basaltic volcanism in the Southwest Nevada Volcanic Field and the implications for Yucca Mountain were analyzed [see Progress Report #10 (DOE, 1994e)]. However, the analysis did not address waste-package lifetime or performance, but a conceptual model of the relation between tectonism and volcanism in the Yucca Mountain region was developed [see Progress Report #11 (DOE, 1995b)]. The model refers to factors that affect the probability of magmatic intrusion through the repository block. No additional work is planned.

2. In the effect of tectonics on percolation flux activity (8.3.1.8.2.1.2), a scoping study of the effect of tectonic activity (principally faulting) on the hydrologic system was initiated in preparation for numerical modeling of tectonic effects [Progress Report #11, Section 3.6.3 (DOE, 1995b)]. Although the numerical modeling of tectonic effects on percolation flux has been deferred [Progress Report #13, Section 3.6.3 (DOE, 1996f)], results of the scoping study and the cross-sectional modeling under Activity 8.3.1.8.2.1.3 are being used to help develop tectonic scenarios that may affect the rate of fluid movement in performance assessment calculations.

3. In the effect of tectonics on the saturated zone and perched water activity (8.3.1.8.2.1.3), a scoping study of the effect of tectonic activity (principally faulting)

on the hydrologic system was initiated in preparation for numerical modeling of tectonic effects. Further, two-dimensional, cross-sectional numerical modeling of coupled fluid and heat flow in the saturated zone was used to analyze three alternative conceptual models for the large hydraulic gradient [see Progress Report #13 (DOE, 1996f)]. In addition, a preliminary scoping study was conducted of the hydrologic setting under Yucca Mountain to assess how occurrences of perched water may be affected by repository thermal loading and tectonic processes [see Progress Report #14 (DOE, 1996g)]. The occurrence of perched water in boreholes USW UZ-1 and USW UZ-14 was analyzed, as well as its possible implications with respect to lateral flow along the top of the basal vitrophyre of the Topopah Spring Tuff beneath the repository area (see Section 3.6.3 of this progress report). Although additional numerical modeling has been deferred, results of the scoping study and the cross-sectional modeling are being used to help develop tectonic scenarios that may affect the rate of fluid movement in performance assessment calculations. For example, G. E. Barr et al. (1996) present a comprehensive set of scenarios that connect tectonic events with radionuclide releases through logical and physically possible combinations or sequences of features, events, and processes. The effects of these tectonic events include a wide range of hydrologic effects such as changes in pathways and flow rates in the unsaturated and saturated zones, changes in the water-table configuration, and changes in the development of perched water. The scenarios are intended to guide performance assessment analyses and ensure that all important aspects of possible system disturbance by tectonic processes are captured in numerical analyses. G. E. Barr et al. (1996) also discuss a number of open issues for which further data and analyses would be necessary to establish their importance. The adequacy of the scenario-development approach will depend on the outcome of performance assessment analyses that capture the tectonic features, events, and processes that are described by the scenarios.

4. In the effect of tectonics on fracture permeability and effective porosity activity (8.3.1.8.2.1.4), possible buried geologic features were analyzed, as well as conditions that may be causing the large hydraulic gradient in the saturated zone just north of Yucca Mountain [see Progress Report #10 (DOE, 1994e)]. Two-dimensional, cross-sectional numerical modeling of coupled fluid and heat flow in the saturated zone was used to analyze these features and conditions [see Progress Report #13 (DOE, 1996f)]. Although additional numerical modeling has been deferred, results of scoping studies and the cross-sectional modeling are being used to help develop tectonic scenarios that may affect the rate of fluid movement in performance assessment calculations. The rationale and methodology for development of tectonic-process scenarios are described in G. E. Barr et al. (1996).

5. In the effect of tectonics on rock geochemical properties activity (8.3.1.8.2.1.5), no work has been performed, and none is planned. Observations of rock geochemical properties indicate a wide spatial variability. Bounded estimates of changes in rock geochemistry induced by potential tectonic events are considered to be well within the bounds of the natural variability. In addition, modified rock geochemistry would

primarily affect the retardation characteristics of the geologic media along likely paths of radionuclide transport. Observations also indicate that tectonic processes or events would be unlikely to significantly change the retardation characteristics; therefore, this work has been deferred.

A.1.7.3 Studies to provide the information required by the analysis and assessment investigations of the tectonics program (SCP Investigation 8.3.1.8.5)

Background and SCP Plans. The objectives of this investigation were to provide refined data on the age, location, and volume of young volcanic rocks in the vicinity of the site; gather data concerning the presence of thermal anomalies in the area and data on the geochemical and physical effects of intrusions on the surrounding rock; and establish the regional pattern and rate of Neogene folding. This investigation included three studies developed to accomplish the following:

1. Study 8.3.1.8.5.1 (characterization of volcanic features): This study was to (a) investigate, through drilling, the origin of four aeromagnetic anomalies found in Crater Flat and the Amargosa Valley that may represent shallowly buried basaltic or silicic volcanic centers or intrusive bodies; (b) establish the chronology of basaltic volcanism and the youngest silicic volcanic activity in the Yucca Mountain region; (c) establish the field geologic relations and the eruptive history of basaltic volcanic centers in the Yucca Mountain region; (d) determine the geochemistry of scoria sequences of different ages at the Lathrop Wells center and older centers in the Crater Flat area; and (e) determine the time-space geochemical variations of the volcanic fields of the southern Great Basin.

2. Study 8.3.1.8.5.2 (characterization of igneous intrusive features): This study was to (a) determine the depth of the curie temperature isotherm by analyses of existing magnetic survey data; (b) collect data on the nature and extent of chemical and physical changes that may occur in the surrounding tuffs as a result of the intrusion of dikes or sills; and (c) evaluate the local ambient heat flow and local heat flow anomalies in relation to Quaternary igneous bodies.

3. Study 8.3.1.8.5.3 (investigation of folds in Miocene and younger rocks of the region): This study was to establish the pattern, rate, amplitude, and wavelength of post-middle-Miocene folding in the region

Changes and Status. The primary objectives of this investigation have not changed since the SCP was issued. The SCP, however, described a more extensive program of data collection. The studies for this investigation have evolved based on technical information obtained from the laboratory and field studies, model development and data application activities of the site characterization program. Rapidly increasing scientific understanding, along with periodic total system performance assessments, have enabled focusing the ongoing site characterization program on the remaining uncertainties that are significant to the design, operation and safety performance of the proposed repository. Reevaluation and prioritization of Project needs has been a continuous process based on scientific judgment and resource availability, governed by scientific criteria to (a) ensure that data needed for site description, performance assessment, and design purposes were collected and analyzed, and (b) eliminate data-collection redundancy and overlap. The data-collection needs have been further analyzed and refined as additional knowledge has been gained through years of site characterization activities. This process has resulted in the following changes to the investigation:

1. The main objectives of the characterization of volcanic features study (8.3.1.8.5.1), to provide field geologic, geochronologic, and geochemical data for volcanism probability calculations, have not changed. However, the methods used to collect the information were modified to take advantage of information available from other sources. Drilling of aeromagnetic anomalies to characterize the composition, age, and volume of possible buried volcanic centers in the Yucca Mountain region has been indefinitely deferred. The study of geochemical variations in basaltic volcanic fields to determine whether volcanism is waxing or waning in the Yucca Mountain region was only partially completed (data were gathered but not analyzed because of resource constraints). The geochronology studies to determine the age of the youngest silicic volcanism in the Yucca Mountain region were not implemented. Instead, the Project will use geochronologic data from non-Project sources.

2. The objectives of the study to characterize igneous intrusive features (8.3.1.8.5.2) have not changed. Sufficient information is available with which to define reasonable bounds on the probability of future magmatic events in the Yucca Mountain region. This information has been used in an expert elicitation to define a probability density function for future events that may intersect the repository region (CRWMS M&O, 1996e). Bounded analyses will be used in assessments of total system performance to evaluate the potential consequence of these low probability events.

3. The study of folds in Miocene and younger rocks of the region (8.3.1.8.5.3) was deferred because active folding was judged not to be a significant factor affecting repository performance.

A.1.8 Human Interference Program (SCP Section 8.3.1.9)

The postclosure human interference program was developed to address (a) the likelihood of inadvertent human intrusion into a MGDS, (b) interference with long-term MGDS performance because of human activities, and (c) the possible consequences of such interference events.

The investigations included in the human interference program are summarized in the following sections.

A.1.8.1 Studies to provide the information required on natural phenomena and human activities that might degrade surface markers and monuments (SCP Investigation 8.3.1.9.1)

Background and SCP Plans. The objectives of this investigation were to provide information on active or potentially active natural processes at Yucca Mountain capable of adversely affecting the long-term-survivability of the surface marker system, and use the data to determine the most suitable locations for the surface markers and monuments. This investigation included one study developed to accomplish the following:

> Study 8.3.1.9.1.1 (an evaluation of natural processes that could affect the long-term survivability of the surface marker system at Yucca Mountain): This study was to (a) identify the potential locations of faulting and volcanic eruption or intrusion that could occur and affect the marker system; and (b) determine the effects of future erosion and deposition on the topographic elements of the controlled area boundary at Yucca Mountain.

Changes and Status. The primary objectives of this investigation have not changed since the SCP was issued. The SCP, however, described a more extensive program of data collection. The studies for this investigation have evolved based on technical information obtained from the laboratory and field studies, model development and data application activities of the site characterization program. Rapidly increasing scientific understanding, along with periodic total system performance assessment, have enabled focusing the ongoing site characterization program on the remaining uncertainties that are significant to the design, operation and safety performance of the proposed repository. Reevaluation and prioritization of Project needs has been a continuous process based on scientific judgment and resource availability, governed by scientific criteria to (a) ensure that data needed for site description, performance assessment, and design purposes were collected and analyzed, and (b) eliminate data-collection redundancy and overlap. The data-collection needs have been further analyzed and refined as additional knowledge has been gained through years of site characterization activities.

> The study to identify natural events that could disrupt or destroy the surface marker system (8.3.1.9.1.1) was completed generally as described in the SCP. Information concerning natural processes that could affect the long-term survivability of the surface marker system at Yucca Mountain has been summarized and included in a report (Fehr et al., 1996). Suitable locations for the surface marker and monument system were determined as described in the SCP.

A.1.8.2 Studies to provide the information required on present and future value of energy, mineral, land, and ground-water resources (SCP Investigation 8.3.1.9.2)

Background and SCP Plan. The objectives of this investigation were to identify and assess the natural resource potential at the proposed repository site at Yucca Mountain, to collect available data to estimate the future supply, demand, and value of the ground-water resource in southern Nevada, proximal to Yucca Mountain; and to apply the results to determine the likelihood for future exploratory drilling within the boundaries of the perimeter drift. This investigation included two studies developed to accomplish the following.

1. Study 8.3.1.9.2.1 (natural resource assessment of Yucca Mountain, Nye County, Nevada): This study was to (a) conduct a geochemical sampling program to evaluate the potential for precious, base, and strategic metals; energy resources; and industrial mineral resources in the vicinity of Yucca Mountain; (b) examine and qualitatively evaluate the available geophysical data base to determine whether any geophysical anomalies are present that may require additional exploration and possibly constrain any known geochemical anomalies; (c) characterize the local geothermal regime as it might relate to repository performance during the postclosure period and assess the geothermal regime in terms of its energy resource potential for either hydrothermal or conductive reservoir thermal systems; (d) determine the potential for the presence or absence of suitable source rocks, reservoir rocks, and traps and seals at and near the site; (e) determine the potential for occurrence of conventional hydrocarbon resources at and near the site, and provide data for an overall mineral and energy resource assessment; and (f) complete an overall mineral and energy resource assessment that identifies mineral resources with current markets, calculates gross and net values for identified reserves and resources, and evaluates the resource potential of any identified or undiscovered mineral and energy resources.

2. Study 8.3.1.9.2.2 (water resource assessment of Yucca Mountain, Nevada): This study was to assess the current and projected supply and demand situation for ground water in the geohydrologic study area and estimate the value of the ground-water resource.

Changes and Status. The primary objectives of this investigation have not changed since the SCP was issued. The scope has been expanded, however, to include studies formerly included in Investigation 8.3.1.9.3. Given the proposed treatment of human-induced potentially disruptive scenarios (commonly referred to as human intrusion) identified by the National Academy of Sciences, the Project plans to use a stylized human intrusion scenario and compare the long-term performance results with the undisturbed scenario analyses. The use of a stylized scenario precludes the need to precisely identify the probability of having each individual human intrusion event correlated with the attractiveness of the site for potential future drilling.

1. Studies to provide the information required on present and future value of energy and mineral resources (Study Plan 8.3.1.9.2.1) have been or are being implemented using standard industry practices. Results of the assessment of geothermal resources were reported in Flynn et al. (1996), and the results of the assessment of industrial rock and mineral resources were reported in Castor and Lock (1995). A geochemical sampling program was implemented as part of the metallic resources study and preliminary investigations on hydrocarbon resources were begun in 1995. Work on the assessment of hydrocarbon resources at the site resumed in FY 1997, and the final report is expected in the next reporting period. Metallic resources were assessed in a report completed during the second quarter of FY 1997. The natural resources synthesis

report is scheduled for completion during the third quarter of FY 1997. Completion of the synthesis report will conclude all the studies planned in the SCP for the natural resources part of the human interference program. The scope of this study has been expanded to include work formerly included in Study 8.3.1.9.3.1.

2. Studies to provide the information required on present and future value of ground-water resources (Study Plan 8.3.1.9.2.2) have been or are being implemented using standard industry practices. An additional report summarizing the availability, quality, potential uses, and demand for water resources in the area surrounding Yucca Mountain was completed during the second quarter of FY 1997 (Woodward-Clyde Consultants, 1997), but the investigation was less extensive and used more modern methods than discussed in Study Plan 8.3.1.9.2.2. In addition, Nye and Clark counties have developed sophisticated demographic and water-demand forecasts. Therefore, it may be unnecessary for the Project to produce these forecasts. The scope of this study has been expanded to include work formerly included in Study 8.3.1.9.3.2.

A.1.8.3 Studies to provide the information required on potential effects of exploiting natural resources on hydrologic, geochemical, and rock characteristics (SCP Investigation 8.3.1.9.3)

Background and SCP Plans. The objectives of this investigation were to (a) assess the likelihood of inadvertent human interference in the vicinity of Yucca Mountain by evaluating the potential effects of exploration for, or extraction of, natural resources on the hydrologic characteristics of Yucca Mountain, and (b) use the results of these assessments as input for expert judgment to estimate the bounds on the probability of inadvertent human interference with, and intrusion into, the potential repository. This investigation included two studies developed to accomplish the following:

1. Study 8.3.1.9.3.1 (evaluation of data needed to support an assessment of the likelihood of future inadvertent human intrusion at Yucca Mountain as a result of exploration for and/or extraction of natural resources): This study was to (a) determine the maximum drilling density and frequency (drillholes per square kilometer per 10,000 years) that can be reasonably assumed for a repository at Yucca Mountain, and (b) determine the extent to which future ground-water withdrawals will modify the expected ground-water flow paths.

2. Study 8.3.1.9.3.2 (an evaluation of the potential effects of exploration for, or extraction of, natural resources on the hydrologic characteristics of Yucca Mountain): This study was to (a) determine the potential effects of future ground-water withdrawals on the hydrologic system at Yucca Mountain; (b) demonstrate that those initiating events identified in the SCP for the human interference issue are not considered sufficiently credible or significant to necessitate additional investigation; and (c) document this evaluation in a topical report.

Changes and Status. It was determined that no unique data would be generated by this investigation, and the entire scope was transferred to Investigation 8.3.1.9.2.

1. Evaluation of data needed to support an assessment of the likelihood of future inadvertent human intrusion as a result of exploration for and/or extraction of natural resources (Study 8.3.1.9.3.1) was transferred to Study 8.3.1.9.2.1 (natural resource assessment of Yucca Mountain, Nye County, Nevada).

2. The study to evaluate the potential effects of exploration for, or extraction of, natural resources on the hydrologic characteristics of Yucca Mountain (8.3.1.9.3.2) was transferred to Study 8.3.1.9.2.2 (water resource assessment of Yucca Mountain, Nevada). As in the case of potentially disruptive events (i.e., human intrusion) that may penetrate the repository horizon, other anthropogenic effects may be conceived that potentially modify the hydrologic characteristics of the site. Present day conditions will be used to describe the biosphere pathways, and DOE intends to use that same logic when evaluating the potential change in hydrology by anthropogenic processes such as pumping or irrigation.

A.1.9 Meteorology Program (SCP Section 8.3.1.12)

The purpose of the SCP meteorology program was to provide data needed to calculate radiological doses resulting from airborne releases from the repository during the preclosure operational period, to design surface facilities, and to provide hydrometeorologic measurements for hydrologic and climatic studies. The meteorology program was designed to (a) determine regional meteorologic conditions, (b) describe atmospheric and meteorologic phenomena at potential locations of surface facilities, (c) identify population centers relative to wind patterns in the general region of the site, and (d) identify and describe potential extreme weather phenomena and recurrence intervals. The investigations were created to provide an understanding of the meteorology of the area, including both average and extreme climatic phenomena. These data were intended to provide input to the performance and design issues that assess the preclosure radiological safety aspects of the MGDS under normal and accident conditions.

Three of the investigations were directed at various aspects of regional-scale meteorology. These investigations shared common data sources and similar analyses needed to achieve objectives. Thus, investigations were combined into one planning document, the Scientific Investigation Implementation Package for Regional Meteorology, Revision 1 (CRWMS M&O, 1995a), as described in Section 3.8 of this progress report.

The investigations included in the meteorology program are summarized in the following sections.

A.1.9.1 Studies to provide data on regional meteorological conditions (SCP Investigation 8.3.1.12.1)

Background and SCP Plan. The purposes of this investigation were to characterize the regional meteorologic conditions within at least 80 km of Yucca Mountain, extending to Las Vegas, and to coordinate meteorologic monitoring efforts with other Project meteorologic monitoring programs. The objectives of the investigation were to gather, analyze, and report relevant meteorologic data; and to develop a plan that coordinates meteorologic monitoring efforts proposed during site characterization by various Project participants.

Two studies were developed to accomplish data collection and coordination of meteorological monitoring:

1. Study 8.3.1.12.1.1 (characterization of the regional meteorologic conditions): This study was to (a) provide for acquiring and analyzing appropriate meteorologic data and results from relevant studies; and (b) describe regional meteorologic characteristics in a summary report.

2. Study 8.3.1.12.1.2 (plan for synthesis of Yucca Mountain Project meteorologic monitoring): This study was to develop a plan that would coordinate meteorologic monitoring efforts initiated through Characterization Programs 8.3.1.12 (Meteorology), 8.3.1.5 (Climate), 8.3.1.2 (Geohydrology), and 8.3.1.16 (Preclosure hydrology).

Changes and Status. The primary objectives of this investigation have not changed since the SCP was issued. The work in this investigation was combined with work from related regional meteorology characterization investigations 8.3.1.12.3 and 8.3.1.12.4. These other investigations address regional airflow patterns relative to local population centers, and provide meteorologic information needed for the engineering design of surface facilities and for support of radiologic dose calculations. The consolidated work plan was developed as Scientific Investigation Implementation Package for Regional Meteorology.

A.1.9.2 Studies to provide data on atmospheric and meteorological phenomena at potential locations of surface facilities (SCP Investigation 8.3.1.12.2)

Background and SCP Plans. The purpose of this investigation was to provide site-specific meteorologic data to Project investigators working on a variety of site characterization activities. Applications include calculating radiologic doses to workers, including workers in restricted areas, and the general public under routine and accident scenarios. The objective of the investigation was to conduct meteorologic monitoring at Yucca Mountain to provide data that can be used in resolving design and performance issues associated with preclosure radiologic safety. The investigation includes one study that was developed to accomplish the following:

Study 8.3.1.12.2.1 (meteorologic data collection at the Yucca Mountain site): This study was to (a) collect meteorologic data at potential locations of surface facilities and at a sufficient number of additional locations deemed necessary to characterize the wind flow patterns in the vicinity of Yucca Mountain; and (b) process the meteorologic data collected into a format and content that will be useful in assessing radiologic impacts, as required by the design and performance issues.

Changes and Status. The primary objectives of this investigation have not changed since the SCP was issued. The work for this investigation is controlled by Study Plan 8.3.1.12.2.1.

In the activity to collect and process meteorologic data (8.3.1.12.2.1), the network was expanded from five to nine stations during 1992. Modernization changes have been made to ensure that the data content and quality meet the current regulatory monitoring requirements applicable to input data for atmospheric dispersion models. The modernization changes are consistent with the SCP objectives and ensure that the objectives are being met.

The technical staff performing the monitoring and reporting associated with this study assumed field operations and data processing responsibilities for 17 recording precipitation gauge stations previously operated under the USGS in Study 8.3.1.2.1.1 (Section 3.1.1 of this progress report). This additional field work is the responsibility of Study 8.3.1.12.2.1 technical staff.

A.1.9.3 Studies to provide data on the location of population centers relative to wind patterns in the general region of the site (SCP Investigation 8.3.1.12.3)

Background and SCP Plans. The purpose of this investigation was to characterize regional wind flow patterns relative to population centers in the vicinity of Yucca Mountain. This investigation uses data from other regional meteorology and socioeconomic investigations.

Changes and Status. The primary objectives of this investigation have not changed since the SCP was issued. The work in this investigation was combined with work from related regional meteorology characterization investigations 8.3.1.12.1 and 8.3.1.12.4. This work is described under Investigation 8.3.1 12.1.

A.1.9.4 Studies to provide data on potential extreme weather phenomena and their recurrence intervals (SCP Investigation 8.3.1.12.4)

Background and SCP Plan. The purpose of this investigation was to provide meteorologic data required for engineering design of surface facilities. This investigation included a single study developed to accomplish the following:

Study 8.3.1.12.4.1 (characterize the potential extreme weather phenomena and their recurrence intervals): This study was to (a) evaluate the existing historic, meteorologic, and climatologic records, technical publications, and other relevant information to quantify the extreme weather phenomena that may be expected at the Yucca Mountain site and (b) determine recurrence intervals.

Changes and Status. The primary objectives of this investigation have not changed since the SCP was issued. The focus on extreme weather events was expanded to include the typical conditions needed by the design engineers. The work in this investigation was combined with work from related regional meteorology characterization investigations 8.3 1.12.1 and 8.3.1.12.3. This work is described under Investigation 8.3.1.12.1.

A.1.10 Offsite Installations and Operations Program (SCP Section 8.3.1.13)

The purpose of the SCP offsite installations program was to provide data about operations of facilities that could produce radiologic exposures to the public or to site workers as consequences of either normal operations or accidental releases. The investigations included in the offsite installations and operations program are summarized in the following sections:

A.1.10.1 Determination of nearby industrial, transportation, and military installations and operations (nuclear and nonnuclear) (SCP Investigation 8.3.1.13.1)

Background and SCP Plans. The objectives of this investigation were to identify and assess the potential impacts on preclosure performance and design from nearby DOE, industrial, transportation, and military operations. This investigation included three data collection activities developed to accomplish the following:

1. Activity 8.3.1.13.1.1 (identify near-site activities): This activity was to (a) identify and describe all DOE, industrial, commercial, transportation, and military operations within 8 km of the Yucca Mountain site; and (b) evaluate significant operations outside this area that could impact the site.

2. Activity 8.3.1.13.1.2 (characterize nuclear fuel cycle facilities in the area): This activity was to identify all nuclear fuel cycle facilities within 80 km of the Yucca Mountain site or within Nevada areas adjacent to Las Vegas.

3. Activity 8.3.1.13.1.3 (characterize all nuclear facilities not associated with the fuel cycle near the Yucca Mountain site): This activity was to characterize the impacts of all radiologic operations at facilities within 80 km of the Yucca Mountain site that are not part of the nuclear fuel cycle.

Changes and Status. The primary objectives of this investigation have not changed since the SCP was issued. The activities described in the SCP to meet these objectives have been incorporated in the long-range plan for initiation in FY 1997 and completion in FY 1998. The results will be incorporated in the appropriate sections of the Project Integrated Safety Assessment. None of the activities has changed since the SCP was issued.

A.1.10.2 Potential impacts of nearby installations and operations (SCP Investigation 8.3.1.13.2)

Background and SCP Plans. The objective of this investigation was to use the data collected in Investigation 8.3.1.13.1 to assess the impacts that may result from accidents involving any nearby installations and operations. The potential accidents include radiologic and nonradiologic events that may impact site operations. This investigation included four activities developed to accomplish the following:

1. Activity 8.3.1.13.2.1 (evaluate near-site activities): This activity was to (a) review all commercial, DOE, Department of Defense, and transportation operations within 8 km of the site; (b) identify those operations that could act as accident initiators; and (c) quantify the probabilities and magnitudes.

2. Activity 8.3.1.13.2.2 (evaluation of the impact of nuclear fuel cycle operations near the Yucca Mountain site and Las Vegas): This activity was to (a) determine the impact of all nuclear fuel cycle operations within 80 km of the Yucca Mountain site by determining routine yearly releases of radioactive material from all such facilities based on information in safety documentation; and (b) determine the probabilities and magnitudes of potential accidents at the facilities based on past technical reports and safety analysis documentation.

3. Activity 8.3.1.13.2.3 (evaluate the impact of all nuclear facilities not associated with the nuclear fuel cycle near the Yucca Mountain site): This activity was to use data from Activity 8.3.1.13.1.3 to determine airborne concentrations and estimate the probability of such concentrations resulting from operations within 80 km of Yucca Mountain. These estimates provide the basis to estimate potential for exposure of individuals in Las Vegas, Nevada.

4. Activity 8.3.1.13.2.4 (evaluate the impact of ground motion from nuclear testing activities at the Nevada Test Site): This activity was to evaluate the impact of ground motion from nuclear testing activities at the Nevada Test Site. As described in the SCP (DOE, 1988, p. 8.3.1.13-11) this activity was addressed in the resolution of Investigation 8.3.1.17.3 (studies to provide required information on vibratory ground motion that could affect repository design or performance).

Changes and Status. The primary objectives of this investigation have not changed since the SCP was issued. The activities described in the SCP to meet these objectives have been incorporated in the long-range plan for initiation in FY 1997 and completion in FY 1998.

1. The activity to review all transportation operations near the site and assess their potential as accident initiators (8.3.1.13.2.1) has not changed since the SCP was issued

2. The activity to evaluate the impact of nuclear fuel cycle operations within 80 km of the site and in Las Vegas (8.3.1.13.2.2) has not changed since the SCP was issued.

3. The activity to characterize impacts of radiologic operations within 80 km of the site that are not associated with the nuclear fuel cycle (8.3.1.13.2.3) has not changed since the SCP was issued.

4. As noted above, the activity to evaluate the impact of ground motion from nuclear testing is to be addressed in SCP Investigation 8.3.1.17.3.

A.1.11 Surface Characteristics Program (SCP Section 8.3.1.14)

The SCP surface characteristics program was developed to provide data to ensure that potential repository surface facilities, including openings to the underground, protected public health and safety, were technically feasible, and could be constructed at reasonable costs.

The investigations included in the surface characteristics program are summarized in the following sections.

A.1.11.1 Studies to provide topographic characteristics of potential locations of surface facilities (SCP Investigation 8.3.1.14.1)

Background and SCP Plan. The SCP objective for this investigation was to determine the topographic elevation and relief at the potential surface facility locations to provide a basis for evaluating (a) the surface drainage, flood levels, and erosion characteristics in the vicinity of Yucca Mountain; (b) the cut-and-fill requirements for design and engineering of the repository surface facilities, and (c) the stability of natural slopes and cut slopes. Topographic maps were to be used in locating surface facilities, roads, and railways.

The SCP (DOE, 1988, p. 8.3.1.14-18) stated that no studies were needed or planned for Investigation 8.3.1.14.1 (topography) because the requirements for this investigation had been satisfied. The SCP also stated (p. 8.3.1.14-25) that no further studies, tests, or analyses were planned.

Changes and Status. The objective remains the same as that stated in the SCP. Testing was not required.

A.1.11.2 Studies to provide soil and rock properties of potential locations of surface facilities (SCP Investigation 8.3.1.14.2)

Background and SCP Plans. The objectives of this investigation were to (a) conduct an exploration program for characterization of the soil and rock conditions that will influence, or be influenced by, construction of surface facilities; (b) conduct laboratory tests and material property measurements on representative samples of soil and rock; (c) conduct field tests and characterization measurements to determine the in situ physical, mechanical, and dynamic properties of the soil and rock; and (d) apply the results. This investigation included three studies developed to accomplish the following:

1. Study 8.3.1.14.2.1 (exploration program): This study was to (a) review existing site information and conduct a field reconnaissance for the purpose of establishing a preliminary exploration program to include subsurface drilling, test pits, trenching, and geophysical methods; (b) obtain sufficient subsurface data to identify or verify the types, locations, and principal dimensions of all major surface structures composing the proposed project, and (c) fill any gaps in the previous preliminary exploration activity and make additional explorations necessary to define adequately the subsurface conditions.

2. Study 8.3.1.14.2.2 (laboratory tests and material property measurements): This study was to (a) measure the soil or rock weight and volume components using physical property tests; and (b) measure in the laboratory the static and dynamic deformation and strength characteristics of soil and rock samples obtained from the exploratory program.

3. Study 8.3.1.14.2.3 (field tests and characterization measurements): This study was to (a) classify and describe soil and rock conditions in the field and determine their physical properties; (b) measure the deformation and strength characteristics of in situ soil and rock conditions; and (c) use geophysical methods to measure in situ soil and rock properties, profile the alluvium-bedrock contact, locate discontinuities or other structural abnormalities, and determine the depth, thickness, and lateral extent of soil and rock stratigraphic units.

Changes and Status. The objectives have not changed since the SCP was issued. However, much of the data intended to be collected under this investigation has been collected under investigations in other site programs.

Two reports are planned to synthesize site geotechnical data. The first of these, the Site Geotechnical Report (CRWMS M&O, 1996ee), was completed in FY 1996 and included a comprehensive synthesis of geologic and geotechnical investigations to support ESF and Repository subsurface design. The report contains a summary of and implications of geotechnical data including geology, structure, hydrology, laboratory determined rock properties, rock mass quality, and rock mass properties. Minor revisions to this report are planned for completion in FY 1997. A second report, the Surface Facilities Design Report, is planned to present a synthesis of data gathered in the site exploration program to support design of surface facilities. This report is expected to include recommendations for foundation design, minimum footing width, maximum bearing pressure, total settlement estimates, differential settlement estimates, resistance to lateral sliding, passive pressure estimates, and recommendations for site preparation. Neither of these reference documents, which provide compilations of key information supporting design of the repository and surface facilities, was specifically identified in the SCP.

1. In the exploration program study (8.3.1.14.2.1), a report (USBR, 1992) was published that included the results of pavement mapping and core log data from UE-25 NRG#1. This report focused on the north ramp portal area and surface soil characterization for the north portal pad area. In addition, a cross section was developed for the ESF south ramp using surface mapping data.

2. In the laboratory tests and material property measurements (8.3.1.14.2.2), laboratory testing was completed on samples from the north ramp geologic boreholes and trenches and systematic drilling boreholes for intact rock index properties, physical properties, mechanical properties, and thermal properties. Laboratory and field tests were completed to characterize the nonlithified Rainier Mesa Tuff and pre-Rainier Mesa Tuff bedded tuff. Laboratory and field tests were completed to characterize soil parameters for foundation design for selected north portal facilities. These data were submitted to the technical data base.

3. In the field tests and characterization measurements study (8.3.1.14.2.3), a report was completed that presents results of the engineering characterization of the pre-Rainier Mesa and Rainier Mesa tuffs that were encountered by the ESF north ramp (Kessel et al., 1994). This report characterized the extent and estimates of mechanical properties of the nonwelded tuffs found locally west of the Bow Ridge fault. A second report (Brechtel et al., 1995) documents the investigation for the north ramp of the ESF and included geology and rock structure logs for the north ramp geologic boreholes, cross sections with stratigraphic and thermal-mechanical units, rock mechanical properties, rock mass quality and rock mass mechanical properties estimates. A third report (Kicker et al., 1995) included geology and rock structure logs for boreholes USW SD-7, USW SD-9, USW SD-12 and USW UZ-14 and stratigraphic cross section for the ESF main drift, rock mechanical properties, rock mass quality and rock mass mechanical properties estimates.

A.1.12 Thermal and Mechanical Rock Properties Program (SCP Section 8.3.1.15)

The SCP thermal and mechanical rock properties program was developed to provide all site information needed on thermal and mechanical rock properties and on ambient stress and temperature conditions. Data on these properties are needed for a variety of site characterization, process model development, performance assessment, and design activities. The data needed include (a) thermal properties of the host rock for analyses related to waste package design; (b) thermal-mechanical properties of the rock for development of rock properties models and repository design; and (c) in situ stress and temperature conditions for initial and boundary conditions for design calculations, thermal properties of rock for disturbed zone analysis, and bulk properties and radon emanation for radiologic safety analysis.

The investigations included in the thermal and mechanical rock properties program are summarized in the following sections:

A.1.12.1 Studies to provide the required information for spatial distribution of thermal and mechanical properties (SCP Investigation 8.3.1.15.1)

Background and SCP Plans. The objectives of this investigation were to (a) provide laboratory characterization of thermal conductivity and heat capacity and describe the spatial variability of these parameters; (b) provide laboratory characterization of thermal-expansion behavior and describe its spatial variability; (c) provide laboratory characterization of mechanical properties of intact rock and describe spatial variabilities; (d) provide laboratory characterization of mechanical properties of fractures and describe the spatial variabilities; (e) monitor rock-mass deformation around a vertical shaft and measure horizontal in situ stresses; (f) obtain data on in situ thermal and thermomechanical properties for thermo-mechanical units TSw1 and TSw2; (g) obtain in situ measurements of the mechanical properties of the rock mass for thermomechanical unit TSw2; (h) investigate the effects of spatial variability of the rock on drift stability, mining [tunnel] excavation activities, and ground supports; (i) evaluate techniques for underground excavation and ground support, for selecting ground supports to be used in different rock types, and monitor drift stability; (j) quantify the emanation of radon into drifts and observe its dispersion with airflow; and (k) measure parameters needed to design repository ventilation systems. The investigation of thermal and mechanical properties is divided into eight data collection studies, four studies focused on properties of intact rock using laboratory methods, and four studies focused on properties and performance of the rock mass under repository conditions using in situ testing.

1. Study 8.3.1.15.1.1 (laboratory thermal properties). This study was to obtain laboratory data on (a) density and porosity and evaluate the spatial variability of these parameters; (b) volumetric heat capacity and evaluate the spatial variability of this parameter; and (c) thermal conductivity and evaluate the spatial variability of this parameter.

2. Study 8.3.1.15.1.2 (laboratory thermal expansion testing): This study was to obtain laboratory data for thermal-expansion behavior and evaluate the spatial variability of this parameter.

3. Study 8.3.1.15.1.3 (laboratory determination of mechanical properties of intact rock): This study was to obtain laboratory data for the compressive mechanical properties of intact rock and the spatial variability of this parameter for baseline experiment conditions. Evaluate the effects of varying sample size, strain rate, temperature, confining pressure, lithophysal content, saturation state, and anisotropy on compressive mechanical properties, and measure the tensile strength of thermomechanical unit TSw2.

4. Study 8.3.1.15.1.4 (laboratory determination of the mechanical properties of fractures): This study was to (a) obtain data for the mechanical properties of fractures, and the

spatial variability of this parameter for baseline experiment conditions; and (b) evaluate the effects of varying normal stress, displacement rate, temperature, sample size, fracture roughness, and saturation state on the mechanical properties of artificial and natural fractures.

5. Study 8.3.1.15.1.5 (excavation investigations): This study was to (a) monitor rock-mass deformation around a vertical shaft and measure horizontal in situ stresses; (b) demonstrate constructability and stability of underground rooms with cross-sectional dimensions equivalent to those of a repository in both lithophysae-rich and lithophysae-poor material; and (c) obtain data on the deformation response of drifts with cross-sectional dimensions equivalent to those of a repository in welded tuff, evaluate computer code(s), and demonstrate the constructability and stability of repository-sized drifts in lithophysae-rich and lithophysae-poor material.

6. Study 8.3.1.15.1.6 (in situ thermomechanical properties): This study was to (a) estimate the in situ thermomechanical properties of lithophysae-rich tuff (thermomechanical unit TSw1) and to evaluate the thermal and mechanical response of this tuff unit to elevated temperatures; (b) obtain thermal and thermomechanical rock-mass measurements of the effects of thermal inputs on a representative (canister-scale) waste-emplacement borehole in lithophysae-poor tuff (thermomechanical unit TSw2); (c) estimate in situ mechanical and thermomechanical properties of thermomechanical unit TSw2 and test thermomechanical computer models; (d) monitor changes in thermally induced stress in jointed welded tuffs in an accelerated test; (e) evaluate the thermomechanical response of welded tuff around repository openings to expected repository conditions during both construction and operation; (f) develop a data base for evaluating thermal and thermomechanical design analyses and methods applicable for repository considerations; and (g) use site data in predicting drift response and support-rock interactions during construction, operation, retrieval, and postclosure.

7. Study 8.3.1.15.1.7 (in situ mechanical properties): This study was to (a) measure the deformation modulus of the rock mass and evaluate the zone of increased fracturing adjacent to underground openings; and (b) evaluate the mechanical behavior of the rock mass or its components.

8. Study 8.3.1.15.1.8 (in situ design verification): This study was to (a) develop recommendations for mining [excavating] in the repository by monitoring and evaluating mining [excavation] activities in the ESF, and by conducting mining [excavation] investigations; (b) develop recommendations for a ground-support methodology to be used in drifts in the repository, on the basis of evaluations of the ground-support methodology used in the ESF and on experimentation with other ground-support configurations; (c) provide confidence in predictions of usability of the repository underground facilities over the 100-year operational life; (d) contribute to evaluations of the effectiveness of mining [excavating] methods and ground-supports; (e) calibrate and refine criteria for determining stability of the openings; (f) develop techniques for monitoring stability of the repository drifts; and (g) measure the rate of

radon emanation from the repository host rock, and evaluate parameters and variables needed as input to or for testing models to be used for design of the ventilation systems in the repository underground facility.

Changes and Status. The basic objectives of this investigation have not changed since the SCP was issued. The laboratory testing program to determine thermal and mechanical properties of intact rock has been scaled down in terms of the numbers of samples to be tested and the spatial extent of testing. This was primarily a result of the reevaluation and prioritization of project needs for performance assessment and design that evolved over the past two years (DOE, 1994a and 1996a). The spatial variability of rock properties was to be determined from core samples taken from systematic drilling program boreholes (Study Plans 8.3.1.15.1.1 through 8.3.1.15.1.4). The number of boreholes has been reduced (from 12 to 3) resulting in fewer locations sampled because of prioritization of work and resource constraints (DOE 1994a; DOE, 1996a). Samples collected from the ESF will be primarily in the TSw2 (Table 3-2), resulting in some spatial information in that unit, but the statistical basis for sampling, described in the SCP, will not be followed because of schedule and resource constraints. Limited information from boreholes is expected to be sufficient for input to the viability assessment, with more information on rock property variability to be developed before submittal of the license application. Access to the Tsw2 in the ESF provides the opportunity to perform in situ characterization of the repository-horizon rock and also to perform parametric studies.

The in situ testing related to the determination of rock-mass properties and the behavior of the rock mass under repository conditions has changed because of development of the Program Approach (DOE, 1994a) and modifications to the Program Plan (DOE, 1996a). The in situ thermal and mechanical studies (primarily study items 5 through 7 above) and the waste package environment studies were reevaluated to produce a new set of proposed tests that accomplished the same set of objectives in a more streamlined fashion. The results of this reevaluation were documented in the In Situ Thermal Testing Program Strategy (DOE 1995c). The in situ design verification study (study item 8 above) was implemented during construction of the ESF with only minor modifications.

The changes to the studies included in the thermal and mechanical properties investigation are described briefly below:

1. In the laboratory thermal properties study (8.3.1.15.1.1), extensive characterization of density and porosity was deferred because similar measurements were being made elsewhere in the program (see SCP Section 8.3.1.4.3.2). Limited heat capacity measurements in the TSw2 (Table 3-2) were made using the guarded heat flow meter method. Experimental values compare well with theoretical values already submitted to the Reference Information Base (DOE, 1995e). Because it appears that heat capacity can be adequately predicted by theoretical methods, no additional tests are planned. Thermal conductivity data on samples of TSw1, TSw2, PTn, and TCw thermomechanical units (Table 3-2) from boreholes UE-25 NRG#4, UE-25 NRG#5, USW NRG-6, and USW NRG-7 have been completed. Additional tests of the TSw2 unit from samples collected from the Thermal Testing Facility and the Southern Ghost

Dance Fault Alcove (Figure 3-4) are planned to assess spatial variability and anisotropy.

2. In the laboratory thermal expansion testing study (8.3.1.15.1.2), unconfined and confined thermal expansion tests have been conducted on samples from TSw1, TSw2, PTn, and TCw (Table 3-2) from the north ramp geologic and systematic drilling boreholes (Brodsky et al., 1997). In accordance with the SCP, mineralogic characterizations of some specimens were performed so that correlation between the silica components and thermal expansion behavior could be examined (Brodsky et al., 1997). Also, thermal expansion tests at elevated pressures were performed to examine the effects of confining pressure on nonlinear thermal expansion (Martin et al., 1997a). Additional testing (thermal expansion, thermal conductivity, unconfined compression, and elastic modulus measurements), not described in the SCP, will be conducted on TSw2 samples from the Thermal Testing Facility and the Southern Ghost Dance Fault Alcove to assess spatial variability and anisotropy.

3. In the laboratory determination of mechanical properties of intact rock study (8.3.1.15.1.3), extensive testing of basic properties has been performed on core from the north ramp geologic and systematic drilling boreholes (Boyd et al., 1996a; Boyd et al., 1996b; Martin et al., 1994; Martin et al., 1995). Limited creep tests at ambient and elevated temperature have been completed (Martin et al., 1997b). Effects of environmental conditions such as temperature and pressure have also been investigated, primarily in the TSw2 thermomechanical unit. Because of the need to provide data for ESF design, most of the study activities have focused on the TSw2. However, completion of one or more of the remaining systematic drilling boreholes will increase information on spatial variability of features in the TSw2 and other units.

4. In the laboratory determination of mechanical properties of fractures study (8.3.1.15.1.4), fracture specimens from units TCw, TSw1, TSw2, and CHn were tested (Olsson and Brown, 1996). Fracture tests on TSw2 rock were also conducted at elevated temperature (175°C). This work is within the scope of testing described in the SCP.

5. In the excavation investigations study (8.3.1.15.1.5), the access convergence and demonstration breakout tests have been abandoned because of the change from shaft access to the ESF to ramp access (see Dennis, 1991). In addition, some of the information required from these tests will be generated as part of the in situ design verification study (8.3.1.15.1.8). The sequential drift mining test was included in the ESF thermal test as part of the development of the drift for the drift-scale test (see CRWMS M&O, 1996k). Detailed planning for this test was initiated early in FY 1996. The test will be conducted in conjunction with construction of the Thermal Testing Facility. The current plan involves installing multipoint displacement measuring instrumentation from an access drift to near the location where the heated drift test drift will be excavated. This instrumentation will be in place before the heated drift is excavated, and will measure the near field rock response as the drift is

excavated. The instrumentation installed for this test will remain in place and also be used for the drift-scale thermal test to measure rock response to repository emplacement room heating.

6. In the in situ thermomechanical properties study (8.3.1.15.1.6), the project reevaluated the thermal testing and analysis program and proposed a new, more consolidated suite of tests to accomplish the objectives of thermal testing. This strategy was documented in the In Situ Thermal Testing Program Strategy (DOE, 1995c). The strategy was implemented in FY 1996 by incorporating it into this study and initiating the design and fielding of the first ESF thermal test. This test was composed of two parts—a single heater test and a heated drift test. These tests were identified in DOE (1995c) as principal components of the test strategy. The tests in the study have been modified as follows:

- Heater experiment in unit TSw1 (Activity 8.3.1.15.1.6.1). A single heater test in TSw1 was proposed as an alternative test if the ESF construction was delayed (DOE, 1995c). Because of rapid progress in ESF construction, this test has been deferred in favor of testing in the TSw2.

- Canister-scale heater experiment (Activity 8.3.1.15.1.6.2). This test was combined with some elements of other tests into the single heater test. A detailed design of the single heater test was completed and documented in Test Design, Plans and Layout Report for the ESF Thermal Test (CRWMS M&O, 1996k). The test was installed in FY 1996 and started in August 1996.

- Yucca Mountain heated block (Activity 8.3.1.15.1.6.3). The data needs and objectives related to this test have been combined into the Thermal Testing Facility, under Activity 8.3.1.15.1.6.2 and Activity 8.3.1.15.1.6.5.

- Thermal stress measurements (Activity 8.3.1.15.1.6.4). The data needs and objectives related to this test have been combined into the Thermal Testing Facility under Activity 8.3.1.15.1.6.2 and Activity 8.3.1.15.1.6.5.

- Heated room experiment (Activity 8.3.1.15.1.6.5). This test has been combined into the heated drift part of the Thermal Testing Facility. Thermo-mechanical-hydrologic-chemical coupling will be explored in this test. A preliminary test configuration has been developed and documented in Test Design, Plans and Layout Report for the ESF Thermal Test (CRWMS M&O, 1996k). The test consists of a single heated drift 5 m in diameter, with in-drift heat canisters to simulate waste packages. To accelerate the test, "wing" heaters will be emplaced in the ribs of the drift. The heated part of the drift will be approximately 50 m long. The heat from the wing heaters will cause the heated part to simulate a drift within a multidrift heated repository. The location and type of instrumentation to be used in the test has been specified in the test plan. The sequential drift mining test, under Study 8.3.1.15.1.5 will be conducted as part of the construction of the heated drift test

7. In the in situ mechanical properties study (8.3.1.15.1.7), the objectives have been partly incorporated into the ESF thermal tests. A plate loading test will be conducted as part of the heated drift test. This will allow measurement of rock-mass modulus under both ambient and heated conditions. Planning for this test is taking place as part of the consolidated thermal test and is described in Test Design, Plans and Layout Report for the ESF Thermal Test (CRWMS M&O, 1996k). Rock-mass strength experiments have been deferred until after the viability assessment. The need for this information will be reevaluated for licensing. The evaluation criteria, dates of evaluation and work completion are still to be determined.

8. In the in situ design verification study (8.3.1.15.1.8), geotechnical design verification activities are being conducted in the north ramp and main drift of the ESF to provide data that can be used to confirm adequacy of design, construction, and long-term performance from the beginning of ESF construction. The data from these activities will also be used to support repository design, and to validate the ESF design. The evaluation of mining methods has been limited to collection of rock mass quality data and monitoring of selected drill and blast operations to ensure that damage to the rock mass is limited. Comparison of mining [excavation] methods for repository design and evaluation of controlled blasting will not be done because the repository will be constructed by mechanical excavation. Monitoring of ground support systems is proceeding as planned, as is the monitoring of drift stability. Measurements of radon levels and ventilation studies have been deferred due to prioritization of work. A small ventilation study was conducted to evaluate the effect of diesel locomotives in the tunnel.

A.1.12.2 Studies to provide the required information for spatial distribution of ambient stress and thermal conditions (SCP Investigation 8.3.1.15.2)

Background and SCP Plans. The objective of this investigation was to determine the spatial variability of ambient stress and in situ temperature to satisfy performance assessment input requirements for geomechanical and thermomechanical models being used for repository design. In addition, heat flow data was to be used, as necessary, as a check on the internal consistency of models of heat and water flow at Yucca Mountain. This investigation includes two studies developed to accomplish the following.

1. Study 8.3.1.15.2.1 (characterization of the site ambient stress conditions): This study was to (a) characterize the ambient (pre-repository) state of stress of the Yucca Mountain host rock and surrounding units for use as initial conditions for geomechanical models used in the design and performance assessment of the repository underground facilities; (b) conduct anelastic strain-recovery experiments on samples from core holes to determine the spatial variability of horizontal stresses at Yucca Mountain; and (c) conduct overcore-stress experiments in the ESF to determine the in situ state of stress above, within, and below the repository host rock and to

evaluate the extent to which the ambient stress conditions are redistributed adjacent to excavations.

2. Study 8.3.1.15.2.2 (characterization of the site ambient thermal conditions): This study was to (a) characterize the ambient (pre-repository) temperature of the Yucca Mountain host rock and surrounding units for use as initial conditions for thermomechanical models used in the design and performance assessment of the repository underground facilities; (b) measure the spatial variation of temperature with depth in existing surface-based boreholes and provide baseline temperatures within the repository host rock and surrounding units; (c) measure thermal conductivity (near 25°C) of core samples as a check on independent thermal-property determinations; and (d) determine heat flow at Yucca Mountain.

Changes and Status. The objectives of this investigation have not changed significantly since the SCP was issued. However, changes to the scope of work have been made to consolidate related studies (see DOE, 1994a and 1996a). Some of the changes resulted from the change from a shaft-and-main configuration for the ESF and the potential repository described in the SCP to the ramps and drift configuration now baselined. Other changes resulted from DOE's efforts to reevaluate and prioritize the Project's information needs based on scientific criteria that considered the needs to (1) ensure that data needed for site characterization purposes are collected and analyzed, and (2) eliminate data-collection redundancy and overlap. The data-collection needs have been further analyzed and refined as additional knowledge has been gained through years of site characterization activities (DOE, 1994a and 1996a). This process has resulted in the following changes to the investigation.

1. In the study of site ambient stress conditions (8.3.1.15.2.1), much of the work scope was developed to support design and operation of the shaft configuration for the ESF and potential repository. The change in the ESF and potential repository configurations to ramps and drifts eliminated the need for anelastic strain-recovery experiments. Further, the work scope associated with the overcore-stress experiments was transferred to Study 8.3.1.15.1.8 (in situ design verification) (see Section 3.11.8 of this progress report). Studies associated with boreholes USW G-1 and USW G-2 are described in Chapter 1 of the SCP. From 1981 to 1985, hydraulic fracturing stress measurements were conducted at depths of 0.3 to 1.7 km in four wells drilled in Yucca Mountain (Stock et al., 1985; Stock and Healy, 1988). The results of recently completed hydraulic fracturing in situ stress measurements in a 30-m-deep test hole, ESF-AOD-HDFR#1, drilled from the Thermal Testing Facility, have shown that the measured horizontal stresses are only moderately differential and are smaller than the vertical stress. The stress regime $S_v > S_H > S_h$ (where S_v, S_H, and S_h are the vertical, maximum horizontal, and minimum horizontal principal stresses respectively) corresponds to the locally predominant normal faulting. The north-northeastern maximum horizontal stress direction is consistent with the average strike direction of the normal faults. The hydraulic fracturing data generally corroborates the results of ambient stress measurements made prior to preparation of the SCP. Therefore, the pre-SCP data are considered adequate to support the probabilistic seismic hazard

analysis, total system performance assessment, and viability assessment. Additional hydraulic fracturing in situ stress tests will be performed to measure the stress profile along the depth of, and to verify the lateral extent of, the stress regime in the ESF. Planned measurement locations are the Upper Tiva Canyon Alcove (UTCA), Lower Paintbrush (Non-Welded) Contact Alcove (LPCA), Northern Ghost Dance Fault Alcove (NGDFA), Southern Ghost Dance Fault Alcove (SGDFA), and the ESF South Ramp (Figure 3-4). The stress data for each alcove and the South Ramp will provide important data that will constrain the stress regime prevailing throughout the ESF.

2. In the study of site ambient thermal conditions (8 3.1.15.2.2), the work scope has been transferred to the closely related SCP Activity 8.3.1.8.5.2.3 (heat flow at Yucca Mountain and evaluation of regional ambient heat-flow anomalies). In addition, the overall objective of this work was changed to emphasize evaluation of available thermal data. As a result, the need for additional data collection was minimized. In FY 1995, a temperature log was run in borehole USW G-2, which indicated that the temperature profile in the unsaturated zone had remained unchanged since 1984 [see Section 3.6.9 of Progress Report #13 (DOE, 1996f)]. This information, along with temperature data from several boreholes instrumented in the unsaturated zone as part of Study 8.3.1.2.2.3 (see Section 3.1.7 of this progress report), indicated that additional thermal-profile data from surfaced-based boreholes probably are not needed. A large number of thermal-conductivity measurements have been made on core samples from surface-based boreholes and the ESF under Activity 8.3.1.15.1.1.3 (see Section 3.11.1 of this progress report).

The locations at which temperature logs of horizontal boreholes will be run have changed since the SCP was written, primarily because of reconfiguration of the ESF and guidance provided by subsurface observations. The Bow Ridge fault has been tested. More extensive testing of the Ghost Dance fault than that envisioned in the SCP is in progress. Testing of the Drill Hole Wash structure and imbricate fault zone is not currently planned because neither of these fault zones passes directly through the planned emplacement area (Drill Hole Wash structure is at the northern end, and the imbricate fault zone is well to the east). Also, resolving the relative importance of liquid versus gas-phase movement in the fault zones is becoming a testing priority, whereas the SCP emphasized parameter estimation. Testing for liquid-water movement in fault zones, especially the Ghost Dance Fault, has become a testing priority because of isotopic evidence of water percolation in fault zones to the repository horizon (see Sections 3.1.6 and 3.1.8 of this progress report).

A.1.13 Preclosure Hydrology Program (SCP Section 8.3.1.16)

The SCP preclosure hydrology program was intended to provide data to address design and performance issues related to potential for flooding, the availability of water for repository construction and operation, and the subsurface hydrologic conditions that might require engineering measures that are either excessively costly or beyond those reasonably available.

The investigations included in the Preclosure Hydrology Program are summarized in the following sections.

A.1.13.1 Flood recurrence intervals and levels at potential locations of surface facilities (SCP Investigation 8.3.1.16.1)

Background and SCP Plans. The objectives of this investigation were to determine the magnitudes and frequencies of major flood events that can potentially occur during the period of repository operation; identify all potential areas of inundation; and determine the quantities and size characteristics of debris transported by flooding. This investigation included one study developed to accomplish the following:

> Study 8.3.1.16.1.1 (characterization of flood potential of the Yucca Mountain site): This study was to assess the flood and debris flow hazards at and near the potential repository surface facilities locations to allow adequate design of facilities to prevent or reduce hazards to an acceptable level.

Changes and Status. The objectives of the preclosure hydrology program (8.3.1.16) have not changed significantly since the SCP was issued. These objectives have been largely addressed through studies from the Geohydrology Program (8.3.1.2), and through efforts in support of the Technical Basis Report for Surface Characteristics, Preclosure Hydrology, and Erosion (DOE, 1995d). All data necessary to address the DOE and NRC performance requirements specified in regulations have been (a) delivered, reported, or forward-referenced to outputs in the Project Integrated Safety Assessment, (b) fulfilled with surrogate information, or (c) rendered unnecessary based on early stages of the investigation and evaluation of performance impacts.

In the study to characterize the flood potential of the Yucca Mountain site (8.3.1.16.1.1), precipitation and runoff data compiled largely through the above studies and data supplied in a National Weather Service report (NWS, 1977), were used to develop several probable maximum flood studies that were conducted by the U.S. Bureau of Reclamation (Bullard, 1991; Blanton, 1992) and the USGS Survey (Glancy, 1994). The results of a conservative analysis of the potential for flooding were reported in the Technical Basis Report for Surface Characteristics, Preclosure Hydrology, and Erosion (DOE, 1995d). Estimates of water surface elevations associated with the probable maximum flood were shown to pose little problem of repository flooding.

A.1.13.2 Location of adequate water supplies (SCP Investigation 8.3.1.16.2)

Background and SCP Plans. The objectives of this investigation were to (a) locate an adequate water supply for construction, operation, closure, and decommissioning of an MGDS at Yucca Mountain, Nevada, and (b) use the information to assess the suitability of candidate wells for repository water supply through decommissioning of the repository. This investigation included one study develop to accomplish the following:

> Study 8.3.1.16.2.1 (location of adequate water supply for construction, operation, closure, and decommissioning of an MGDS at Yucca Mountain, Nevada): This study was to (a) assess the cost, feasibility, and adequacy of wells UE-25 J#12 and UE-25 J#13 for use as alternative water supply for an MGDS at Yucca Mountain, Nevada; (b) locate a primary water supply for an MGDS at Yucca Mountain, Nevada; (c) locate alternative water supplies for an MGDS at Yucca Mountain, Nevada; and (d) identify and evaluate potential effects of repository-related withdrawals on the local flow system at Yucca Mountain, Nevada.

Changes and Status. The objectives of this investigation have not changed since the SCP was issued. However, the methods used to collect the information were modified to take advantage of information available from other sources.

In the study to locate an adequate water supply for construction, operation, closure, and decommissioning of an MGDS (8.3.1.16.2.1), the process to obtain the water permit for site characterization included holding hearings and collecting depositions regarding issues concerning use of water from wells UE-25 J#12, UE-25 J#13, and USW VH-1. Much data and information regarding water budgets, aquifers, and pumping rates and drawdown were presented by contractors from the USGS Survey, U.S. Park Service, and State of Nevada. A monitoring well (UE-25 JF#3) was installed to monitor any potential impacts to regional water levels by water use from site characterization. Additionally, site and regional water-level monitoring has been a continuous effort, and these data are published annually by the USGS.

A.1.13.3 Ground-water conditions within and above the potential host rock (SCP Investigation 8.3.1.16.3)

Background and SCP Plans. The objectives of this investigation were to (a) determine the amount of water inflow to the repository horizon including seasonal variations in inflow rate; (b) determine the existence of perched water; and (c) define the locations, depths, thicknesses, lateral extents, seasonal variations and degrees of saturation of any perched-water zones identified. Characterization of the hydrologic conditions within and above the repository horizon was to be accomplished by studies being performed in support of Investigation 8.3.1.2.2 (studies to provide a description of the unsaturated zone hydrologic system of the site). Although the bases for addressing the investigations are different (repository design versus long-term performance assessment), the parameters that must be obtained to satisfy both of these investigations are the same. Data on flux, moisture content, and potential influx were to be obtained from the geohydrology program (8.3.1.2). The data collected under the geohydrology program were to be compiled, analyzed, and evaluated under Activity 8.3.1.16.3.1.1, and were to be used to define the moisture conditions at the site that are needed for design. This investigation included one study developed to accomplish the following:

Study 8.3.1.16.3.1 (determination of the preclosure hydrologic conditions of the unsaturated zone at Yucca Mountain, Nevada): This study was to synthesize data from site geohydrology program (8.3.1.2), to determine the preclosure hydrologic characteristics of the unsaturated zone at Yucca Mountain, Nevada.

Changes and Status. The objectives of this investigation have not chanced since the SCP was issued. The data collection efforts were performed under the geohydrology program as described in the SCP. However, the data evaluation efforts were also largely completed under the geohydrology program to avoid having separate and redundant evaluations performed under Investigation 8.3.1.16.3.

The objectives of the study to determine the preclosure hydrologic conditions of the unsaturated zone at Yucca Mountain, Nevada (8.3.1.16.3.1) are being accomplished according to the description in the SCP. The data needed for this investigation are being collected mostly under the geohydrology program, but some data are being compiled, analyzed, and evaluated under this study. Characterization of the hydrologic conditions within and above the repository horizon is being accomplished by studies being performed in support of Investigation 8.3.1.2.2 (studies to provide a description of the unsaturated zone hydrologic system at the site). Data on flux, moisture content, and potential influx are being obtained from the geohydrology program. Information obtained from new and existing boreholes is providing data concerning perched water, zones of saturation, and many other parameters of concern for unsaturated zone characterization.

A.1.14 Preclosure Tectonics Program (SCP Section 8.3.1.17)

The SCP preclosure tectonics program was a comprehensive, multidisciplined program intended to characterize the tectonic events and processes that could impact proposed repository structures, systems, or components considered to be important to safety until permanent closure is achieved. The purpose of the program was to provide characterizations of tectonic processes and events for consideration in the design and operation of certain structures, systems, and components required for exercising the retrieval option. The program described in the SCP was intended to investigate the tectonic characteristics of the site in sufficient scope and detail to provide reasonable assurance that the processes were understood and that the characterization parameters were determined with the confidences needed to support license application requirements. Information was to be provided from a variety of sources and methods including scientific literature, current and historical seismicity data, geologic maps, logs from boreholes and surface trenches, gravity surveys, aeromagnetic and paleomagnetic observations, seismic reflection and refraction profiles and magneto-telluric soundings.

The investigations included in the preclosure tectonics program are summarized in the following sections.

A.1.14.1 Studies to provide required information on volcanic activity that could affect repository design or performance (SCP Investigation 8.3.1.17.1)

Background and SCP Plans. The objectives of this investigation were to identify and evaluate credible volcanic hazards that could affect preclosure repository performance: (a) ash falls from distal silicic volcanic centers in the western Great Basin, and (b) basaltic volcanic eruptions at the site. The potential for silicic ash falls at the site was studied under this investigation, and the potential for basaltic eruptions was studied under the postclosure tectonics program (8.3.1.8). This investigation included one study developed to accomplish the following:

> Study 8.3.1.17.1.1 (potential for ash fall at the site). This study was to (a) compile information on Quaternary silicic volcanism in the western Great Basin, the recurrence of which might produce an ash fall at the site; (b) produce an approximate probability-versus-thickness function for potential ash falls at the site and estimate a particular ash fall thickness that has less than one chance in ten of occurring in 100 years; and (c) estimate the potential particle densities and particle-size distributions of ash falls at the site to support design of ventilation filters.

Changes and Status. The primary objectives of this investigation have not changed. The work described in the SCP was accomplished by compiling and evaluating information on silicic volcanism in the western United States (Perry and Crowe, 1987; DOE, 1996f). No additional work is planned.

A.1.14.2 Provide information on fault displacement that could affect repository design or performance (SCP Investigation 8.3.1.17.2)

Background and SCP Plans. This investigation was intended to provide information that could be used to avoid siting of facilities or waste packages in areas with potential for fault displacements in excess of a few inches. The siting objective for surface faulting was to avoid fault displacement in excess of a few inches beneath the structural foundations of surface facilities considered important to safety. The primary concern regarding faulting in the underground facilities during preclosure was that waste packages might be sheared or become jammed in their waste-emplacement boreholes, making retrieval more difficult and time consuming than it otherwise might be. No single fault with the potential to create such problems was thought to exist, but if such a fault were identified, an attempt would be made to determine its location underground for consideration in the positioning of waste emplacement boreholes. This investigation included one study developed to accomplish the following:

> Study 8.3.1.17.2.1 (faulting potential at the repository): This study was to (a) assess the stability of the site surface with respect to fault displacement at locations proposed for facilities important to safety and demonstrate, with a high degree of confidence, that there is less than a one percent chance of exceeding 5 cm of fault displacement beneath surface facilities important to safety during the preclosure period (approximately 100 years); and (b) assess the potential for displacement on faults that intersect underground facilities and

demonstrate, with a moderate degree of confidence, that there is less than a 10 percent chance of exceeding 7 cm of fault displacement in areas of emplaced waste in 100 years, considering all faults that may intersect these areas.

Changes and Status. The objectives of this investigation have not changed since the SCP was issued. However, the work scope for this investigation and study has been combined with Study 8.3.1.17.3.6 (probabilistic seismic hazards analysis) under Investigation 8.3.1.17.3 (Section A.1.14.3)

A.1.14.3 Provide information on vibratory ground motion that could affect repository design or performance (SCP Investigation 8.3.1.17.3)

Background and SCP Plans. The purposes of this investigation were to develop a seismic-design basis for repository facilities that were important to safety and provide other information that would facilitate the assessment of the adequacy of the seismic-design basis and the identification of credible accidents that might be initiated by seismic events and lead to release of radioactive materials. The seismic-design basis will account for both the potential occurrence of earthquakes on nearby faults and potential future underground nuclear explosions at the Nevada Test Site. The investigation describes the analyses required to develop the seismic design basis for repository facilities important to safety, both surface and underground, and a deterministic methodology proposed for evaluation of seismic hazards. This methodology included 10,000-year cumulative slip earthquake methodology for establishing earthquake magnitudes for use in estimating design ground motions. As originally proposed in the SCP, this did not include evaluation of fault-displacement hazards. This investigation included six studies developed to accomplish the following:

1. Study 8.3.1.17.3.1 (relevant earthquake sources): This study was to (a) identify and characterize those earthquake sources that were relevant to a deterministic seismic hazard analysis of the site including faults with surface geologic expression as well as concealed faults; (b) identify earthquake sources that could generate severe ground motions at the site; and (c) characterize 10,000-year cumulative slip earthquakes for each of the relevant seismogenic sources identified.

2. Study 8.3.1.17.3.2 (underground nuclear explosion sources): This study was to characterize the potential future underground nuclear explosions at the Nevada Test Site that would result in the most severe motions at the repository site.

3. Study 8.3.1.17.3.3 (ground motion from regional earthquakes and underground nuclear explosions): This study was to select or develop ground-motion models that were appropriate for estimating ground motion at the site from regional earthquakes and underground nuclear explosions.

4. Study 8.3.1.17.3.4 (effects of local site geology on surface and subsurface motions): This study was to (a) document systematic effects on surface and subsurface ground

motions resulting from the local site geology based on instrument recordings of ground motion at the site; (b) identify any significant site-wide bias in ground-motion levels as compared with average levels for the southern Great Basin; and (c) develop a calibrated theoretical site-effects model using the wave properties of the local geology for use in extrapolating effects to locations and depths where ground-motion recordings were not available.

5. Study 8.3.1.17.3.5 (ground motion at the site from controlling seismic events): This study was to identify the controlling seismic events (underground nuclear explosions or 10,000-year cumulative slip earthquakes that would generate the most severe ground motions at the site at frequencies of engineering significance) and characterize the resulting controlling ground motions generating suites of strong-motion time histories and corresponding response spectra that were representative in amplitude, frequency content, and duration of site ground motions.

6. Study 8.3.1.17.3.6 (probabilistic seismic hazards analysis): This study was to (a) quantify the probability for experiencing ground motions of varying degrees of severity that might result from earthquakes of varying magnitude and distance from the site and use those results to constrain required technical judgments in the deterministic evaluation of design-basis ground motions, evaluate the adequacy of the deterministic results, and help focus efforts to refine those parameters that were most important for the deterministic calculations, (b) determine average rates for earthquake recurrence as a function of magnitude for the southern Great Basin to a distance of about 100 km from the site then apportion those rates onto active faults and subregional seismic source zones; and (c) estimate the probability of exceeding given ground-motion levels at the site and integrate the contributions to that probability from all identified earthquake sources that could generate potentially damaging ground motion at the site.

Changes and Status. The primary objective of the investigation has not changed since the SCP was issued. However, significant changes in approach and methodology have occurred. These are summarized below.

1. In the study of relevant earthquake sources (8.3.1.17.3.1), the 10,000-year cumulative slip earthquake approach has been abandoned (see Study Plan 8.3.1.17.3.1, R1) because the cumulative slip earthquake approach did not reflect the DOE's updated methodology for seismic hazard assessment. It was determined [Pezzopane, 1993; Progress Report #9, Section 2.2.13.3 (DOE 1994g)] that a probablistic approach was more suitable for evaluating seismic hazards. Therefore, probabilistic seismic hazard analysis is being used for developing the seismic design basis for both ground motion and fault displacement. This methodology is described in two DOE-YMSCO topical reports (DOE, 1994b and 1996c). All work identified in the SCP to compile relevant earthquake sources for use in the probabilistic seismic hazard analysis and to develop attenuation relations for underground nuclear explosions and earthquakes has been completed (Pezzopane, 1996; Pezzopane et al., 1996).

2. In the study of underground nuclear explosion sources (8.3.1.17.3.2), only a preliminary assessment of potential locations and yields of underground nuclear explosions has been completed using available data. There are, however, no further plans to characterize the potential future occurrence of underground nuclear explosions because no additional underground weapons testing is expected in the foreseeable future as a result of a 1996 treaty banning nuclear weapons testing.

3. In the study of ground motion from regional earthquakes and underground nuclear explosions (8.3.1.17.3.3), selection and development of ground-motion models has proceeded largely as described in the SCP. Simulations have been completed with multiple, numerical ground-motion models using a suite of deterministic "scenario earthquakes" and newly developed empirical ground-motion attenuation models for normal-fault earthquakes using a world-wide data set (Abrahamson and Becker, 1996). In addition, a ground-motion attenuation model for underground nuclear explosions using site-specific data collected from surface and subsurface stations at Yucca Mountain has been completed (Abrahamson and Becker, 1996; Walck, 1996).

4. In the study of effects of local site geology on surface and subsurface motions (8.3.1.17.3.4), direct documentation of ground-motion effects has benefitted from recordings made at seismograph stations on bedrock sites on and near Yucca Mountain of the largest after shocks of the M_L = 5.6 Little Skull Mountain earthquake of 1992. Shallow velocity profiles have been used to derive in situ seismic velocities at the potential repository site (Abrahamson and Becker, 1996). As part of the probabilistic seismic hazard analyses being conducted in Study 8.3.1.17.3.6, studies are in progress using resonant-column and dynamic-tensional shear testing to more accurately determine the effects of rock properties on attenuation of ground motion.

5. In the study of ground motion at the site from controlling seismic events (8.3.1.17.3.5), the objectives of this study are expected to be achieved by applying the results of the probabilistic seismic hazard analyses being conducted in Study 8.3.1.17.3.6. As noted in study 8.3.1.17.3.1 in item 1 above, the concept of the 10,000-year cumulative slip earthquake is not being used.

6. In the probabilistic seismic hazards analysis (8.3.1.17.3.6), the study has been expanded to include evaluation of the potential for fault displacement, which originally was to be conducted under Study 8.3.1.17.2.1 (faulting potential at the repository). In addition, the 10,000-year cumulative slip earthquake approach has been abandoned. Instead a probabilistic seismic hazard analysis is being used to develop the seismic design basis for both ground motion and fault displacement. This methodology is described in two topical reports (DOE, 1994b and 1996c). As discussed in those reports, the preferred methodology for seismic hazard analyses includes an elicitation process whereby a panel of experts is assembled to interpret the available seismological, geologic, geophysical, and geotechnical data sets and, through a series of workshops, provide probability estimates for the occurrence of ground motions or

fault displacements of sufficient magnitudes to affect repository design and performance.

A.1.14.4 Preclosure tectonics data collection and analysis (SCP Investigation 8.3.1.17.4)

Background and SCP Plans. The primary purpose of this investigation was to provide the data and analyses required to assess fault displacement that could affect repository design or performance (Investigation 8.3.1.17.2) and assess vibratory ground motion that could affect repository design or performance (Investigation 8.3.1.17.3). The primary focus was the compilation and analysis of information on reported and instrumentally recorded earthquakes that have occurred near Yucca Mountain. The data are needed to develop the technical basis for fault displacement and ground-motion hazards and the preclosure seismic design bases for surface and subsurface facilities. Testing proposed in the SCP included a wide range of activities comparable to site-specific seismic hazard studies for other critical facilities. These included collection of fault-specific paleoseismic data from trenching, monitoring, and analysis of historic and current seismicity; geophysical surveys; downhole and underground measurements of the in situ stress field; geodetic leveling; and tectonic modeling. The limited data collection and analysis that is required by Investigation 8.3.1.17.1 (volcanic activity that could impact the repository) will be performed within that investigation. This investigation included 12 studies developed to accomplish the following:

1. Study 8.3.1.17.4.1 (historic and current seismicity): This study was to (a) compile information on reported and instrumentally recorded earthquakes that characterize the earthquake potential near Yucca Mountain; (b) compile a record of historic seismic events in the southern Great Basin or within 100 km of Yucca Mountain, including type of event, ground-motion intensity for potentially damaging earthquakes, and extent and style of faulting; (c) monitor current seismicity to provide empirical information on the current frequency of earthquakes in the southern Great Basin, characteristics of faulting, how seismic wave amplitudes scale with magnitude and attenuate with distance in the region, and how ground motions vary with depth and with surface geology in the site area; and (d) evaluate the potential for human activities to significantly perturb the natural seismic hazard at the site by inducing seismicity at or near the site.

2. Study 8.3.1.17.4.2 (location and recency of faulting near prospective surface facilities): This study was to (a) identify appropriate trench locations in Midway Valley at proposed locations for repository surface facilities that are important to safety through detailed geologic mapping and remote sensing studies; and (b) conduct exploratory trenching in Midway Valley to investigate possible occurrences of late-Quaternary surface-fault rupture in the vicinity of planned surface facility locations important to safety and to identify sites without evidence of significant late-Quaternary faulting.

3. Study 8.3.1.17.4.3 (Quaternary faulting within 100 km of Yucca Mountain, including the Walker Lane): This study was to (a) identify Quaternary faults within 100 km of

Yucca Mountain and characterize those faults capable of future earthquakes that could impact design or affect performance of the waste facility; (b) conduct and evaluate deep geophysical surveys in an east-west transect crossing the Furnace Creek fault zone, Yucca Mountain, and the Walker Lane to help identify and locate potentially significant seismic source zones including possible through-going extensions of the Walker Lane and the Furnace Creek fault zone and the relation of these features to detachment faults and to Quaternary faults; evaluate the postulated incipient rift zone in Crater Flat; (c) compare results of seismic-reflection surveys with results of magneto-telluric surveys; (d) characterize the conductivity structure of the crust in the Yucca Mountain region; provide data for analysis to determine if buried magma bodies are present in the vicinity of Yucca Mountain; (e) characterize the Quaternary and Holocene fault and fracture pattern within 100 km of the site and relate that pattern to wrench fault systems, including the Walker Lane, the Death Valley-Furnace Creek fault zone, and the Mine Mountain-Pahranagat shear zone; (f) determine whether the Beatty scarp originated through tectonic or fluvial processes, the nature of movement along the scarp (if tectonic), and the age of the scarp; (g) ascertain the amount of post middle Miocene horizontal rotation of bedrock alongside wrench faults and of bedrock suspected to be part of the upper plate above subsurface wrench faults; (h) evaluate the Cedar Mountain earthquake of 1932 and its relevance to wrench tectonics of the Walker Lane and to potential sources of ground shaking and rupture within 100 km of the site; (i) evaluate the potential for ground shaking associated with future movement along the Bare Mountain fault zone, estimate the age of the most recent faulting and the recurrence intervals of faulting on the Bare Mountain frontal fault, and determine the nature and age of faulting within the fault complex east of the frontal zone; (j) evaluate structural domains and characterize the Yucca Mountain region with respect to regional patterns of faults and fractures; (k) classify the area into subareas (domains) containing relatively homogeneous fault and lineament populations suggestive of Quaternary faulting; (l) map the areal extent of desert varnish coatings; and (m) identify areas of suspected hydrothermal alteration.

4. Study 8.3.1.17.4.4 (Quaternary faulting proximal to the site within northeast-trending fault zones): This study was to (a) evaluate the potential for ground motion resulting from future movement on Quaternary left-lateral strike-slip faults within northeast-trending fault zones east and south of the site-area; and (b) determine the location, spatial orientation, length, width, Quaternary recurrence rate, and the location, amount, and nature of Quaternary movement of the Rock Valley, Mine Mountain, Stagecoach Road, and Cane Spring fault systems.

5. Study 8.3.1.17.4.5 (detachment faults at or proximal to Yucca Mountain): This study was to (a) supply information pertaining to the distribution, displacement rate, and age of detachment faults proximal to Yucca Mountain to determine whether they represent a significant earthquake source and whether they conceal a significant earthquake source at depth; (b) evaluate the significance of the Miocene-Paleozoic contact in the Calico Hills area to detachment faulting and to determine whether the contact of Miocene volcanic rocks on Paleozoic strata is tectonic or depositional; (c) evaluate

postulated detachment faults in the Beatty-Bare Mountain area and determine if they have been active in the Quaternary; (d) evaluate the potential relationship of breccia within and south of Crater Flat to detachment faulting; (e) evaluate postulated detachment faults in the Specter Range and Camp Desert Rock areas and determine whether the basal contact of the Horse Spring Formation is depositional or tectonic and if movement has occurred in the Quaternary; and (f) evaluate the age of detachment faults using radiometric ages.

6. Study 8.3.1.17.4.6 (Quaternary faulting within the site area): This study was to (a) identify and characterize Quaternary faults that intersect or project toward the surface facility, the repository, or the controlled area and determine the potential for future earthquakes that could impact design or affect performance of the waste facility; (b) synthesize data pertaining to the location, spatial orientation, length, width, Quaternary recurrence rate, and the location, amount, and nature of Quaternary movement of faults within the site area; (c) identify hitherto unrecognized Quaternary faults; and (d) evaluate age and recurrence of movement on suspected and known Quaternary faults including the Paintbrush Canyon, Solitario Canyon, Windy Wash, Ghost Dance, and Bow Ridge faults.

7. Study 8.3.1.17.4.7 (subsurface geometry and concealed extensions of Quaternary faults at Yucca Mountain): This study was to evaluate the subsurface geometry and concealed extensions of Quaternary faults at Yucca Mountain using the following methods: intermediate seismic refraction and reflection, detailed gravity surveys, detailed aeromagnetic surveys, ground magnetic surveys, surface geoelectric, gamma-ray measurements, thermal infrared, and shallow seismic-reflection (mini-sosie) methods.

8. Study 8.3.1.17.4.8 (stress field within and proximal to the site area): This study was to (a) provide data on the ambient stress field at the site and its immediate vicinity that will aid in evaluating future movement on faults, stability of potential pathways for radionuclide travel controlled by or related to fracture aperture, stability of mined excavations, response of the rock mass to thermal loading, and applicability of tectonic models; (b) measure vertical and lateral variations of in situ stress at the site including the vicinity of the steep hydrologic gradient and the postulated detachment fault and in subjacent Paleozoic rocks below Yucca Mountain; (c) evaluate and test shallow borehole hydrofrac and triaxial strain recovery methods for determination of in situ stress, (d) evaluate published and unpublished data on paleostress orientation at and proximal to the site and assess the relevance of these data to Quaternary tectonics; (e) evaluate theoretical stress distributions associated with potential tectonic settings of Yucca Mountain including wrench-fault, normal fault, and detachment-fault tectonic models; (f) evaluate the degree to which in situ stress data constrain applicability of these tectonic models to neotectonics of the site; and (g) evaluate the potential relation between fracture aperture and in situ stress.

9. Study 8.3.1.17.4.9 (tectonic geomorphology of the Yucca Mountain region): This study was to (a) conduct studies of tectonic geomorphology in the Yucca Mountain region to document the magnitude of Quaternary uplift and subsidence and to evaluate regional variation in the nature and intensity of Quaternary faulting; (b) evaluate the age and areal distribution of surfaces that appear to have been tectonically stable at and near Yucca Mountain through studies of desert varnish; (c) evaluate extent of areas of Quaternary uplift and subsidence at and near Yucca Mountain through evaluation of fluvial fans in the Amargosa Desert, Crater Flat, Fortymile Wash, Rock Valley, and Ash Meadows; and (d) evaluate variations in the nature and intensity of Quaternary faulting within 100 km of Yucca Mountain through morphometric and morphologic analysis.

10. Study 8.3.1.17.4.10 (geodetic leveling): This study was to (a) conduct geodetic releveling of base stations and benchmarks to evaluate possible historic and contemporary vertical displacements across potentially significant Quaternary faults within 100 km of Yucca Mountain and to characterize the historic rate of uplift and subsidence; and (b) survey selected base stations near Yucca Mountain using global positioning satellite.

11. Study 8.3.1.17.4.11 (characterization of regional lateral crustal movement): This study was to evaluate rates and orientations of historic and current lateral crustal movement in the Basin and Range province and the Yucca Mountain region using analyses of existing data on seismicity, historic fault offset, and creep.

12. Study 8.3.1.17.4.12 (tectonic models and synthesis): This study was to (a) conduct tectonic modeling and synthesis to evaluate all data relevant to tectonics at Yucca Mountain; (b) develop a model or range of models that establishes the causal relation between application of tectonic forces and formation of structures (wrench, detachment, normal, and left-lateral strike-slip faulting, oroclinal bending, etc.) observed at Yucca Mountain and vicinity; (c) link observed rates of formation of those structures with regional rates of crustal strain; (d) forecast changes in tectonic setting and the manner in which those changes will affect both the regional crustal strain rate and tectonic stability in the Yucca Mountain region; (e) estimate the effect of those changes on rate and nature of crustal strain at Yucca Mountain and vicinity; (f) estimate the future rate of tectonic processes at Yucca Mountain and evaluate the applicability of this information to geologic hazards at the site; and (g) evaluate tectonic disruption sequences involving faulting, folding, uplift and subsidence, and volcanism that are potentially significant to design or performance of the repository.

Changes and Status. The objectives of this investigation have not changed since the SCP was issued. Sufficient data have been collected in Investigation 8.3.1.17.4 to form an adequate technical basis for proceeding with the seismic hazard analysis. The seismic hazard characterization program has focused on characterizing Quaternary faults at and near Yucca Mountain through trench excavation, mapping, and analysis in order to constrain the Quaternary history of faulting and earthquakes. Multiple trenches have been excavated across each of the known or suspected Quaternary faults in the site area and on the most active Quaternary faults in the region. Trench interpretations, slip-rate and recurrence analyses, and fault-displacement and length analyses are nearly complete. A catalog of historic earthquakes has been prepared. Information from monitoring the Little Skull Mountain earthquake in 1992 and continuing aftershocks has greatly increased understanding of the characteristics of moderate-magnitude earthquakes. In situ stress and geodetic-leveling data have been compiled and analyzed. Alternate tectonic models constrained by available geologic mapping and geophysical surveys have been formulated. Although the overall objectives of the SCP have been met, some changes in scope and strategy have occurred since the SCP was issued. These changes are summarized below.

1. In the study of historic and current seismicity (8.3.1.17.4.1), the compilation of historic seismic events was expanded to include those events that occurred within a 300-km radius at the site rather than the originally designated 100-km radius. This modification in scope was in response to discussions with the NRC. In the monitoring of current seismicity, the southern Great Basin seismic network has been upgraded to provide more precise information for the Yucca Mountain area. Whereas the original seismic network consisted of 49 analog seismograph stations within a 150-km radius of Yucca Mountain, the upgraded network will consist of 27 digital stations within a 50-km radius, 23 of which have been installed (see Section 3.13.9 of this progress report). The upgraded southern Great Basin seismic network is significantly more sensitive than the original network and can detect earthquakes with magnitudes as low as -1.0. This enhanced sensitivity has enabled detection of ESF excavation-induced seismicity. In addition, the upgraded network has 9 strong-motion stations at Yucca Mountain, whereas the SCP expected about 6. Finally, continuous monitoring of two seismometers installed in borehole UE-25 UZ#16 is being conducted. These seismometers, which consist of vertical-component geophones installed for vertical seismic profiling, are especially sensitive to ESF excavation by blasting and to induced seismicity caused by overall ESF excavation.

2. In the study of location and recency of faulting near prospective surface facilities (8.3.1.17.4.2), all SCP objectives have been achieved without significant change in scope. Faults demonstrating Quaternary activity were identified, but none of these are located in the immediate vicinity of prospective surface facilities or the potential repository. No further work is planned for this study.

3. In the study of Quaternary faulting within 100 km of Yucca Mountain (8.3.1.17.4.3), some of the principal objectives were not met for various reasons, including (a) the work was performed in another study and (b) the expected results would not justify the resources needed to obtain the information based on previous results. The Project has embarked on an expert elicitation to evaluate the probability and effects of possible seismic and tectonic events. This elicitation will use a wide range of data and experience to appropriately bound the reasonable range in initiating events and intensities. These bounds will be incorporated in analyses of both preclosure and

postclosure performance assessment. Significant changes in scope from that outlined in the SCP are as follows:

- Seismic reflection surveys were limited to a 37-km-long traverse extending eastward from the east flank of Bare Mountain across Crater Flat to the east side of Yucca Mountain (see Progress Report #15, Section 3.3.3, Activity 8.3.1.4.2.1.2, DOE, 1997c). No surveys were conducted across the Furnace Creek fault zone because of concerns about probable poor data quality for deep reflectors and the high cost of the reflection surveys. The report of the Seismic Methods Peer Review Panel (Burns et al., 1991) recommended that a "test line" be run across Crater Flat and Yucca Mountain. According to the peer review report, the quality of the data collected in this line would form the basis for decisions regarding further intermediate and deep reflection profiling. DOE's conclusion from the regional seismic line collected in 1994 was that data quality in the Tertiary section was adequate to estimate the location and character of the Paleozoic-Tertiary contact and concluded that the contact was unlikely to be a detachment fault. However, data for the deeper reflectors were of poor quality and suggested that poor data quality would likely result from seismic-reflection profiling in other areas. This conclusion about likely quality of the data led to the decision not to undertake seismic profiling for characterizing regional seismic sources. However, geologic field studies were conducted along the Death Valley-Furnace Creek fault zone to characterize the style of faulting and to determine the history and magnitude of fault displacements along this most active of fault systems in the Yucca Mountain region. Data resulting from these studies are considered adequate for characterizing the paleoseismic history along this fault system and for meeting the objectives of the probabilistic seismic hazard analysis. The data are being fully evaluated for these purposes by the expert panel involved in the probabilistic seismic hazard analysis to determine the maximum-magnitude earthquake and recurrence rate for calculating the hazard potential of the fault system.

- No new magneto-telluric surveys were made to supplement earlier surveys across parts of the Yucca Mountain area. Although magneto-telluric data can be expected to provide certain constraints on crustal structure and composition, final interpretations of the data require integration with coincident data from deep seismic profiles, teleseismic data, heat-flow and Curie isotherm determinations, and gravity measurements. A cost-benefit analysis resulted in a management decision that the personnel requirements and cost of additional magneto-telluric surveys were too high when compared with the expected results in terms of providing quantitative data that would significantly augment other geologic and geophysical data sets being used to interpret the Yucca Mountain structure

- The Cedar Mountain earthquake and its potential as a source for producing future ground shaking at the Yucca Mountain site are being evaluated in Study 8.3.1.17.3.6 (probabilistic seismic hazards analysis) as part of the effort involved in probabilistic seismic hazards analysis

- Structural domains and regional patterns of faults and fractures are being evaluated as part of Study 8.3.1.17.4.12. The Yucca Mountain area has been classified into subareas containing relatively homogeneous fault and lineament populations.

- Desert-varnish coatings are not being mapped as part of Study 8.3.1.17.4.3, but the general distribution is being provided through the mapping of surficial deposits as part of Activity 8.3.1.5.1.4.2 (see Section 3.4.4 of this progress report). Desert-varnish coatings in the immediate vicinity of Yucca Mountain also were described in Whitney and Harrington (1993).

- Hydrothermal alteration has not been a subject of study in 8.3.1.17.4.3. Altered rocks in the Calico Hills area were mapped as part of Study 8.3.1.17.4.5, and alteration zones are also being described based on outcrop observations and core examinations being made in Study 8.3.1.4.2.1 (see Section 3.3.3 of this progress report).

4. In the study of Quaternary faulting proximal to the site within northeast-trending fault zones (8.3.1.17.4.4), all SCP objectives have been met, including characterization of the Stagecoach Road fault, which was studied as part of Study 8.3.1.17.4.6. No further work is planned for this study.

5. In the study of detachment faults at or proximal to Yucca Mountain (8.3.1.17.4.5), all SCP objectives have been achieved without significant changes in scope. Importantly, the Paleozoic-Tertiary contact appears to be an unconformity rather than an active detachment surface (see Section 3.13.13 of this progress report). No further work is planned for this study.

6. In the study of Quaternary faulting within the site area (8.3.1.17.4.6), all SCP objectives are being met, with the Stagecoach Road fault added to the number of individual faults that were trenched and mapped in detail.

7. In the study of subsurface geometry and concealed extensions of Quaternary faults at Yucca Mountain (8.3.1.17.4.7), the SCP objectives are being achieved in other site characterization studies as discussed in Section 3.13.15 of this progress report. Geophysical surveys are being performed in Study 8.3.1.4.2.1 (see Section 3.3.3 of this progress report), and the data are being used to interpret fault geometries at depth. The resulting interpretations are being applied in the probabilistic analyses of seismic hazards at the potential repository site (Study 8.3.1.17.3.6, Section 3.13.8 of this progress report).

8. In the study of the stress field within and proximal to the site area (8.3.1.17.4.8), a study plan was prepared but has not been finalized. The planned work primarily involves measurements of the vertical and lateral variations of in situ stress in new boreholes that would have to be drilled in the immediate vicinity of the potential repository site. The drilling of these boreholes, however, is not part of the long-range

plan. Several of the principal objectives of the study are being met in other studies, most notably in Study 8.3.1.17.4.12, the scope of which investigation includes evaluating (a) data on paleostress orientation at and proximal to the site and the relevance of these data to Quaternary tectonics, and (b) theoretical stress distributions with potential tectonic settings of the site. Crustal-stress orientations also are considered in probabilistic seismic hazard analyses (Study 8.3.1.17.3.6). Note that a large number of publications describe crustal stresses in the southwestern United States, including some close to Yucca Mountain (e.g., Stock et al., 1985).

9. In the study of tectonic geomorphology of the Yucca Mountain region (8.3.1.17.4.9), the SCP objectives are being met in other studies as discussed in Section 3.13.17 of this progress report. Quaternary deposits are being mapped in Study 8.3.1.5.1.4 (see Section 3.4.4 of this progress report), with particular emphasis given to alluvial fan deposits in Fortymile Wash and their significance for interpreting the Quaternary history of the area. Data on the nature and intensity of Quaternary faulting within 100 km of Yucca Mountain are being collected in Studies 8.3.1.17.4.3 and 8.3.1.17.4.6, including the geomorphic expression of features marking fault alignments and scarps. The relevance of using desert-varnish coatings for evaluating slope stability in the immediate site area during the Quaternary was discussed in Whitney and Harrington (1993). No further work is planned for this study.

10. In the geodetic-leveling study (8.3.1.17.4.10), all SCP objectives are being met. In addition to monitoring contemporary vertical displacements across Quaternary faults, lateral crustal strain is being measured by a regional network of Global Positioning System stations and by methods involving very long baseline interferometry. This study of the lateral crustal strain was transferred from Study 8.3.1.17.4.11. Most of the study has been completed, but additional resurveys of level lines and Global Positioning System recordings along established traverses will be made contingent upon availability of funding. However, the value of additional resurveys is considered minimal based on the results of earlier surveys that detected no changes in elevation that could be attributed to fault movements at or near Yucca Mountain (Keefer et al., 1996). The only exceptions to this are elevation changes that occurred in response to the 1992 Little Skull Mountain earthquake, the effects of which are well documented.

11. In the characterization of regional lateral crustal movement (8.3.1.17.4.11), the SCP objectives are being achieved primarily in Study 8.3.1.17.4.10, and the data are being applied extensively in Study 8.3.1.17.4.12.

12. In the tectonic models and synthesis study (8.3.1.17.4.12), all SCP objectives are being met, with the exception of the evaluation of tectonic disruption sequences. This objective is being addressed in further work being planned in Study 8.3.1.8.2.1 (see Section 3.6.3 of this progress report).

A.1.15 Altered Zone Characterization

Altered zone characterization was not included in the SCP; rather it was developed after the SCP was issued and initiated to provide data on the area surrounding the immediate repository emplacement area The altered zone characterization effort consists of a single study that includes four activities. Unlike previous sections, this section presents a summary at the study level rather than the investigation level; individual activities, however, are not summarized as numbered items.

The altered zone is generally considered to be the volume of rock that surrounds the near-field environment (emplacement area) and is defined as that part of the natural system that is likely to experience fundamental changes to hydrologic, mineralogic, or chemical conditions because of reactions caused by heating of the repository block from radioactive decay of emplaced nuclear waste. The altered zone is distinguished from the near-field environment on the basis of processes that are expected to dominate In the altered zone, hydrologic processes are expected to be dominated by increased water availability and increased saturation. The increased moisture content is expected to be produced by vapor condensation at the margins of the near-field environment. Temperatures in the altered zone are expected to be elevated several tens of degrees centigrade relative to ambient conditions. Geochemical processes are expected to be dominated by fluid-rock interactions and reactive transport. The altered zone is expected to be less dynamic than the near-field environment in that the residence times for water are expected to be longer and the dryout zone is not expected to feature zones of condensation at the margins of the near-field environment. The fluid-rock interactions are expected to result in significant coupling between hydrologic and geochemical processes, such that fluid pathways and geochemical conditions will evolve in a synergistic way.

Generally, the altered zone will be considered to be the regions surrounding the emplacement areas that maintain temperatures sufficiently low to allow liquid water to exist in pores and fractures This distinction has the advantage of focusing attention on the dominant processes that may affect performance in different regions of the repository [e.g., evaporation of water and mineral dehydration in the near-field environment (generally surrounded by a region dominated by water-rock interactions) and the kinetics of dissolution and precipitation in the altered zone]

Work reported in the Preliminary Near-Field Environment Report (Wilder, 1993) focused on the environmental conditions that directly impact the waste package container materials and the waste form Those same processes or interactions were recognized as potential causes of changes in fundamental properties that could extend for considerable distances into the rock mass or natural system Therefore, a zone termed the altered zone was defined and a study was developed to characterize this region wherein fundamental changes to hydrologic, mineralogic, or chemical conditions may take place within the natural system, but where these conditions do not interact directly with the waste packages (rather interact with the near-field environment) and where the changes are more significant than in the far-field environment where ambient conditions tend to prevail Study Plan 8.3.1.20.1.1, "Characterization of the Altered Zone," was developed to document this work.

A.1.15.1 Altered zone characterization (SCP Study 8.3.1.20.1.1)

Background and Plans. The objectives of this study were (a) to evaluate the impact of chemical, mineralogic, and mechanical changes on hydrologic properties and determine the kinetics of the change processes; (b) compare computer codes and evaluate their suitabilities for application to altered zone evaluations; (c) determine parameter values, limits, or ranges needed to define the waste package (near-field) environment; and (d) determine, using simulations, the expected response of the altered zone over time. Four activities, described in the lettered items, were included in this study.

Changes and Status. Study Plan 8.3.1.20.1.1 has been reviewed and revised, and no significant changes resulted. The revised study plan has been submitted to DOE for approval

A.2 REPOSITORY PROGRAM (SCP SECTION 8.3.2)

A.2.1 Introduction

As envisioned in the SCP, the repository was to consist of thin-wall waste packages that would be emplaced in boreholes drilled in the floors or walls of emplacement drifts. However, since the SCP was written, this repository design concept has changed substantially, in part because of DOE goals for earlier waste acceptance. Current plans are to emplace large, robust waste packages in drifts. The emplacement of waste packages in drifts is expected to have significant performance and cost advantages over borehole emplacement. First, drift emplacement would allow the packages to radiate heat to a larger area and thus would help control maximum temperatures. Second, a severe seismic event with shear displacements in the repository horizon would be less likely to damage drift-emplaced waste containers. Third, drift emplacement would simplify emplacement operations by eliminating the need to drill boreholes and emplace waste packages in them. Finally, boreholes appear to have a greater tendency to accumulate ground water and to confine the products of degradation.

The repository design concept in the SCP would have interfaced with the excavations planned for the ESF. However, since the SCP was written, both the repository and ESF concepts have changed. The current repository design is integrated with the drift-based approach under which the ESF was actually constructed. Access to the proposed repository is expected to be via a more gently sloped ramp than was envisioned in the SCP. This concept is consistent with the change to large waste packages and would allow use of the ESF north ramp already completed.

Another change that has occurred is that the design is no longer planned to be documented in a license application design report. Instead, the information that it would have contained will be an integral part of the license application documentation.

Although repository design has substantially changed from that described in the SCP, most of the approaches and types of technical information identified in the SCP to support the design are still consistent with the current Program approach.

The status of the repository design activities discussed in the SCP is discussed in more detail in the following sections.

A.2.2 Summary of Changes in the Repository Program

This section discusses in order each section contained in Section 8.3.2 of the SCP—the section that outlined the repository program. First, appropriate background is provided and SCP plans are given. Then the changes that have occurred since the SCP was written are discussed and the current Project status outlined. In this discussion, references to sections, tables, and figures are to the SCP unless otherwise stated.

Overview of repository program (SCP Section 8.3.2.1)

Background and SCP Plans. This SCP section served as the introduction for the description of the repository program and introduced the four repository design issues to be discussed. In addition, the section provided details on the interrelationships of the issues, the manner in which duplication of effort would be avoided, and the approach to ensuring issue resolutions were appropriately integrated. The second major component of this section was a description of the major phases of the repository design from the completed conceptual design (described in Section 6 of the SCP) through final procurement and construction design.

Changes and Status. The issues discussed in this section (and throughout the SCP) are, overall, still applicable, and the program is working toward closing them. However, the designations of the issues and subissues used in the SCP are not generally being used. In other words, although "Configuration of underground facilities" is still a subject being addressed by the Program, it is not commonly referred to as "Issue 1.11." The phases of design described in this section are still generally applicable. The current design to support the 1998 viability assessment, though not discussed in the SCP, fits within the period close to the end of advanced conceptual design and the beginning of license application design. There will be no license application design report; instead the information that it would contain will be an integral part of the license application documentation. The terms "Title I" and "Title II" have been dropped from Project use because of the overlapping of meanings between them and the work scopes of the design phases. The names of the design phases are now used to define work scopes. For example, drawings and specifications released for bidding are now referred to as bid documents, regardless of how many are released at one time. Partial releases are no longer referred to as bid packages. Another change is the use of a Management and Operating Contractor to develop the design, as opposed to a "Systems Engineering Development and Management" contractor

Verification or measurement of host-rock environment (Section 8.3.2.1.1)

Background and SCP Plans. This section introduced and discussed the development of models for the understanding of the site host-rock conditions for three distinct phases: before excavation, after excavation but before waste emplacement; and after waste emplacement. The section introduced three following subsections, each covering one of the above phases.

Changes and Status Understanding of the site host ro is still an important part of the repository program The program is still focused on developing an understanding of the reaction of the host rock to both excavation and waste emplacement.

Pre-waste-emplacement environment (SCP Section 8.3.2.1.1.1)

Background and SCP Plans. This section described 15 activities required to characterize the site in its undisturbed, initial condition. Listed are 5 additional site data requirements needed for seismic evaluations The various site programs through which the data would be acquired were noted

Changes and Status. All items are still applicable to repository design. Data acquisition in these areas continues. The development of the ESF has provided, and continues to provide, much of the information listed.

Post-subsurface-excavation environment (SCP Section 8.3.2.1.1.2)

Background and SCP Plans. This section described a suite of information to be gathered for design of the subsurface openings. The information required was primarily geared toward response of the host rock to the development and continued existence of the subsurface openings. Six different activities were listed and described.

Changes and Status. These data are currently being acquired in various ESF testing and monitoring programs. All data needs are still current with the exception of "borehole scale stress and deformation." The change from borehole emplacement to in-drift emplacement was first described in Section 4.1.17 of Progress Report #11 (DOE, 1995b). Because emplacement boreholes are no longer planned, the data needs associated with them are no longer needed.

Post-waste-emplacement environment (SCP Section 8.3.2.1.1.3)

Background and SCP Plans. This section discussed information needed to allow understanding of the conditions that will exist after heat-producing waste is placed in the repository. Six tasks were listed and described as required to understand the waste heat effects.

Changes and Status. All information described is still applicable and is being collected as part of the ESF single-heater and heated-drift tests. As discussed above for 8.3.2.1.1.2 information related to borehole emplacement is no longer needed.

Coupled interaction tests (SCP Section 8.3.2.1.2)

Background and SCP Plans. This section described the approach planned to address the coupled thermal, hydrologic, mechanical, chemical, and radiological phenomena that must be considered for design, construction, and performance analyses for the repository. The section included a table that summarizes 40 combinations of coupled processes to be investigated in given SCP studies or activities.

Changes and Status. The Project's general approach to investigating coupled site processes is consistent with that presented in this section. The Project is investigating the processes as described in Table 8.3.2.1-1, although some of the specific tests in the table have been canceled. Specifically, there has been no "well testing with conservative (8.3.1.2.3.1.6) or reactive (8.3.1.2.3.1.8) tracers throughout the site." The "heater experiment in unit TSw1" (8.3.1.15.1.6.1), "canister-scale heater experiment" (8.3.1.15.1.6.2), and "heated room experiment" (8.3.1.15.1.6.5) have not been conducted, but have been replaced by a single-heater test and drift-scale test in the ESF. These changes have occurred because the Project has pursued a more focused suite of tests than those described in the SCP. In addition, the single-heater and drift-scale tests are expected to accomplish most of the objectives of the tests described in the SCP in a more timely and cost-effective manner.

Design improvement activities and tests (SCP Section 8.3.2.1.3)

Background and SCP Plans. This section described the planned approach to optimizing design. The section stated that the Project was not seeking an optimum design solution, but instead was seeking a design that has been optimized to the point of providing an acceptable solution emphasizing certain characteristics. These characteristics included licenseability and simplicity. The section also provided a table of planned design tradeoff analyses.

Changes and Status. The approach taken to design optimization to date is consistent with the approach described in this section. The tradeoff analyses in Table 8.3.2.1-2 are part of the present program, although some of the results are not consistent with the titles of the tradeoff studies. For example, in-drift emplacement is now planned, and because of the change in emplacement mode and move to larger waste package designs, waste packages are not planned to be transported by hoists. In addition to the tradeoff analyses shown in this table, the program has performed or will perform many other such analyses. In-drift emplacement was prompted by a design concept change to large-capacity waste packages. (The reasons for the shift to large, robust waste packages are discussed in the introduction, Section A.4 (waste package program) of this appendix.

Emplacement of waste packages in drifts instead of boreholes is expected to have significant advantages. Overall repository excavation costs are expected to be lower because boreholes are not necessary. Drift emplacement would allow the packages to radiate heat to a larger area and thus would help control maximum temperatures. Borehole emplacement of the larger waste package would result in violation of both the peak rock temperature goal (200°C) and the fuel cladding temperature goal (350°C). A severe seismic event with shear displacements in the repository horizon would be less likely to damage drift-emplaced waste containers than borehole-emplaced containers because drift emplacement provides extra clearance between the containers and the drift wall. Drift emplacement would simplify emplacement operations and would maintain flexibility of thermal loading because packages could be spaced as needed along the drift. Finally, boreholes appear to have a greater tendency to accumulate ground water and to confine the products of degradation. This tendency raises concerns about corrosion and criticality. Given that the borehole emplacement approach is no longer being considered, there are no activities associated with horizontal versus vertical emplacement borehole orientation nor with borehole spacing and length. Waste packages are to be transported via rail down the gently sloping (-2.15 percent) north ramp into the repository. Thus, there are no activities associated with hoisting of waste packages.

Repository modeling (SCP Section 8.3.2.1.4)

Background and SCP Plans. This section introduced the four following sections on various numerical modeling applications. Sections follow on geomechanical, seismic, ventilation, and safety analyses.

Changes and Status. This introductory material contains no specific information, so status is not relevant. The following discussions of Subsections 8.3.2.1.4.1 through 8.3.2.1.4.4 provide status on topics for this SCP section.

Geomechanical analyses (SCP Section 8.3.2.1.4.1)

Background and SCP Plans. This section described the understanding of geomechanical response current at the time the SCP was written. Listed were three types of analytical tools planned for providing perspectives on this response. The section then described the understanding of rock mass thermal response and three types of analytical tools planned for development to provide perspectives on this response. Next, the understanding of the combined contribution of excavation and thermal effects to rock mass response was described, and two methods planned for use in predicting thermomechanical response were mentioned. Types and scales of analyses planned to be considered were also discussed.

Changes and Status. Current understanding of the processes is consistent with that provided in the SCP. The analytical tools and analyses described are being used or are planned for use.

Seismic analyses (SCP Section 8.3.2.1.4.2)

Background and SCP Plans. This section listed five phenomena planned for consideration in seismic analyses.

Changes and Status. The Program is considering the phenomena described in this section in seismic analyses performed to date or planned.

Ventilation analyses (SCP Section 8.3.2.1.4.3)

Background and SCP Plans. This section provided a general description of the planned ventilation analyses and specifically stated that codes for ventilation analyses will be qualified for thermal effects. Two types of planned analyses were also discussed.

Changes and Status. The program is performing the types of ventilation analyses discussed in the section. The code being used for ventilation network analyses without thermal effects has been qualified. The original code used for ventilation analyses that include thermal effects was qualified, but recent updates to that code have not yet been qualified. The most recent code upgrade will be qualified before it is used for quality affecting work.

Safety analyses (SCP Section 8.3.2.1.4.4)

Background and SCP Plans. This section provided a brief statement that safety analyses would be conducted in addressing repository design criteria for radiological and nonradiological health and safety. The section stated that codes used for this purpose would be ones that have been proven through extensive past use in the nuclear industry.

Changes and Status. The program is performing analyses consistent with tho: . called for in this section. Codes used for this purpose are proven, nuclear industry codes.

Issue resolution strategy for Issue 1.11: Have the characteristics and configurations of the repository and repository engineered barriers been adequately established to (a) show compliance with the postclosure design criteria of 10 CFR 60.133 and (b) provide information for the resolution of the performance issues? (SCP Section 8.3.2.2)

Background and SCP Plans. This section presented the strategy planned to address 10 CFR 60.133 and to resolve performance issues. Figure 8.3.2.2-1a provided a detailed flowchart of this approach. The regulatory basis as described in this section included both 10 CFR 60.133 requirements and 10 CFR Part 960 guidelines (Subpart C Sections 4-2-3 and 4-2-5). The section described four functions that the postclosure waste disposal system must satisfy: (1) select repository orientation, layout, etc., to contribute to c: .tainment and isolation; (2) limit water uses and chemical changes during construction; (3) limit excavation-induced changes in rock mass permeability; and (4) design thermal loading taking into account performance objectives and thermomechani esponse of host rock. The section then identifies specific processes contributing to each fun Tables 8.3.2.2-1 through 8.3.2.2-4 provided specific performance measures, goals, and confidence levels for addressing these functions, and accompanying text amplifies the tables. Specific design basis statements were made, such as "The present design basis is that the underground excavations will be backfilled before repository closure."

Changes and Status. The current strategy for addressing this issue is generally consistent with the strategy presented in this section of the SCP. The four major functions described in the section are still valid and are being addressed in the current program. The types of performance measures described in the tables are generally being used in the current program. Those measures associated with borehole emplacement have been modified or deleted as appropriate to reflect the current emplacement concept. Because of the limited amount of blasting planned to be performed (none in the emplacement drifts), the performance measure for permeability change has been deleted. The confidence levels from the tables are being used to establish the need for additional testing and results. Many of the goals have changed as knowledge of the mountain has improved and as the emplacement mode has shifted from boreholes to horizontal in-drift emplacement. The major difference in the present design basis from that provided in the SCP section is that in-drift emplacement of waste packages has replaced borehole emplacement. Emplacement drift backfill is not currently part of the repository design basis. To date, performance assessment results indicate that although backfill could enhance repository ability to perform postclosure isolation functions, emplacement drift backfill is not needed to meet those performance objectives. All other excavations are planned to be backfilled before closure.

Information Need 1.11.1: Site characterization information needed for design (SCP Section 8.3.2.2.1)

Background and SCP Plans. This section described site characterization information believed at the time the SCP was written to be necessary to support design. The section describes three products intended to satisfy the information need: (1) a data requirements list, (2) a reference thermal/mechanical stratigraphy, and (3) development of reference thermomechanical rock properties. The stratigraphy was to be based on a three-dimensional stratigraphy contained in an interactive graphics information system. Table 8.3.2.2-5 listed performance parameters, goals, needed versus current confidence, and expected values. The section also described the Interactive Graphics Information System, required for the usable area and flexibility evaluation, and listed data required for use in the Interactive Graphics Information System. In addition, products and approaches intended to be used to organize information to meet the information need were briefly discussed.

Changes and Status. The three major products described in this section are being developed by the program through the following documents:

- The data requirements list is contained in the Repository Design Data Needs report (CRWMS M&O, 1995b).
- The stratigraphy is being built using the Lynx geoscience modeling system and is described in two reports: Definition of the Potential Repository Block (CRWMS M&O, 1995d) and Definition of Repository Block Limits (CRWMS M&O, 1994b).
- Thermomechanical rock properties are contained in the Geographic Nodal Information Study and Evaluation System (GENISES), a data base containing site and engineering data, and in the Reference Information Base (DOE, 1995e).

The Interactive Graphics Information System is in place to support stratigraphy development. Thermomechanical rock properties are being entered in the Reference Information Base as called for in the section. The performance measures, goals, and needed confidence levels are included in the present program. The program is consistent with the products described in the section text. As discussed earlier, because waste emplacement in boreholes is no longer planned, the emplacement borehole-related information needs are no longer relevant.

Design Activity 1.11.1.1: Compile a comprehensive list of all the information required from site characterization to resolve this issue (SCP Section 8.3.2.2.1.1)

Background and SCP Plans. This design activity involved compiling in one place all information needed to resolve the issue, including applicable statistical requirements such as acceptable error and level of uncertainty.

Changes and Status. The Repository Design Data Needs report (CRWMS M&O, 1995b) summarizes the site data needed for surface and subsurface repository design. The report states what data are needed, when they are needed, and the degree of completeness to which they are needed for each design phase. The last aspect includes applicable statistical requirements consistent with the SCP. The three levels of completeness used in the report are substantially complete, bounded, and conservative. Data needs listed in SCP Table 8.3.2.2-5 were considered during the development of the report, and those considered still valid (which includes most of the data needs) were incorporated into it.

Design Activity 1.11.1.2: Determine adequacy of existing site data (SCP Section 8.3.2.2.1.2)

Background and SCP Plans. This design activity involved determining adequacy of site data and determining where additional data are needed, using statistical methods. The results of these determinations would be used to recommend further data be acquired or trade-off studies be performed.

Changes and Status. The Repository Design Data Needs report (CRWMS M&O, 1995b) analyzes the adequacy of site data and, using that analysis, recommends additional data needs. The level of data completeness is estimated for each data need required for the various stages of repository design. The term "completeness" is used as a measure of the adequacy and sufficiency of data needed for the existing Program Plan schedule and scope. This is a subjective approach intended as a general planning guide. More quantitative ratings that measure data confidence by specifying statistical probabilistic limits have not been used because such a level of detail is more appropriate for the development of test programs. However, the following descriptors for completeness also consider data variability, which can be regarded as a qualitative measure of confidence:

- Substantially Complete: Data at this level are substantially complete and additional analysis or collection is not likely to significantly change the results or conclusions. Data variability (a combination of measurement uncertainty and inherent randomness), e.g., spatial distribution, is reasonably defined.

- Bounded: Realistic bounding values, with upper and lower extremes identified, have been established for data at this level. Data variability is moderately defined.

- Conservative: Data are sufficient to estimate credible extreme or worst case values, conditions, or assumptions. Data variability is approximately defined.

Design Activity 1.11.1.3: Document reference three-dimensional thermal/mechanical stratigraphy of Yucca Mountain (SCP Section 8.3.2.2.1.3)

Background and SCP Plans. This design activity stated that topical reports would be produced that will describe the three dimensional stratigraphy of Yucca Mountain, relying on the Interactive Graphics Information System and recorded in the Reference Information Base.

Changes and Status. Work on this activity reflects the intent of the design activity. Work focuses on two areas: (1) definition of the thermal/mechanical units and (2) development of a three-dimensional computer model. Reports have been and are being developed as called for in the design activity, including Definition of the Potential Repository Block (CRWMS M&O, 1995d) and Definition of Repository Block Limits (CRWMS M&O, 1994b). The computer model LYNX is updated as new information is received. Data are being entered in the Reference

Information Base (DOE, 1995e) as planned in the design activity to support development of a three-dimensional stratigraphy model. The model output, a three-dimensional profile of Yucca Mountain, is also planned to be entered in the Reference Information Base. Topical reports are not currently planned on this subject. Instead, this information will be contained in design analyses.

The LYNX modeling activity is integrated closely with the three-dimensional geologic framework and Integrated Site Modeling activity described in the discussion of SCP Section 8.3.1.4.2.3 in this Appendix. Relevant horizons and faults from the Integrated Site Modeling activity are used in the LYNX-based model to support design.

Though related, the two modeling activities have different content and purpose. The Integrated Site Modeling activity is constructed to be comprehensive to feed all hydrologic, properties, and transport models including performance assessment, while the design model provides geometric information in a focused geographic area. The Integrated Site Modeling activity covers 65 square miles, encompassing the entire conceptual controlled area boundary, while the design model is focused on the repository block. The Integrated Site Modeling activity contains 36 lithostratigraphic horizons from the surface to the top of the Paleozoic, while the design model extends only to the Calico Hills formation and uses a different grouping of the rock units.

Design Activity 1.11.1.4: Preparation of reference properties for the reference information base (SCP Section 8.3.2.2.1.4)

Background and SCP Plans. This design activity called for the development of topical reports that would give properties and describe how they were determined from field and laboratory measurements. The reports were to be compared with the issue requirements to ensure adequate data is available. Work to be performed in support of this design activity included rock characteristics, initial conditions of stress and temperature, geology (stratigraphy and structure), and design data.

Changes and Status. The Project has, through the 1996 draft revised Program Plan, systematically identified information needed to support licensing. The SCP Issue to which this design activity pertains is a part of the information base thought to be needed when the SCP was written. Now, in light of enhanced understanding of the site, the information currently expected to be needed is sometimes different from that described in the SCP. Therefore, the Project has not attempted to verify that the Reference Information Base contains all the information specified in the SCP. Instead, reliance is placed on completion of activities in the Program Plan to ensure the Reference Information Base contains sufficient information to support licensing.

Application of results (SCP Section 8.3.2.2.1.5)

Background and SCP Plans. This design activity reiterated the three products resulting from the information need described in SCP Section 8.3.2.2.1. This section stated that the required site data list would guide site characterization testing. The reference stratigraphy had been entered in the Reference Information Base to support design and performance analysis. The reference rock properties would also be incorporated in the Reference Information Base for the same purpose.

Changes and Status. The current program is using the information as called for in the SCP section. Documentation of information is as described previously.

Information Need 1.11.2: Characteristics of waste package needed for design of the underground facility (SCP Section 8.3.2.2.2)

Background and SCP Plans. This information need identified waste package information needed in the Reference Information Base to support design of the repository. The section described four specific waste package characteristics needed to resolve the issue (thermal decay, package size, package temperature constraints, and waste inventory). An integrated list of waste package input items was to be provided, and the completeness of the list would be checked by reviewing the processes and goals associated with the issue and by identifying interactions and predicted response of the site to the design. Three methods of determining waste package temperature information were described. Use of ORIGEN2 code or a like code was specified.

Changes and Status. Work is in progress to address all four waste package characteristics specified in this information need. Rather than compiling an integrated list of waste package input items, individual items are requested as needed and provided when available, typically by way of controlled documents. This informal approach improves responsiveness and integration between disciplines. The completeness of the design for the underground facility will in itself provide evidence that complete inputs have been provided. The current values being used in design are listed in the Controlled Design Assumptions Document (CRWMS M&O, 1996c). ORIGEN2 and other codes are being used as indicated in the information need. The rationale for the information need as stated in the SCP is still applicable. Some of the waste package characteristics are enumerated in the Engineered Barrier Design Requirements Document (DOE, 1995i) but quantified elsewhere. Information on thermal decay of commercial spent nuclear fuel and defense high-level waste is found in the LWR Radiological PC Data Base (CRWMS M&O, 1993b) and High Level Waste PC Data Base (CRWMS M&O, 1993c), respectively; information on size, temperature constraints, and waste inventory is found in the Controlled Design Assumptions Document. The documents listed as providing design information are obsolete. A more up-to-date description is given in the MGDS Advanced Conceptual Design Report (CRWMS M&O, 1996b). The specific information needed is generally still as listed in the SCP, but the following changes have occurred. Thermal power output is now considered to be a function of age, burnup, enrichment, and reactor type for commercial spent nuclear fuel. This information is contained in the LWR Radiological PC Data Base. Tolerances on the various quantities are not being addressed at present but may be addressed in the future. In current design efforts, waste package internal temperatures are emphasized more than surface temperatures because internal temperatures are considered more restrictive.

References are made in the SCP section to emplacement boreholes; for reasons described below in the discussion for 8.3.2.2.3.3, emplacement boreholes will not be used (CRWMS M&O, 1996b).

Design Activity 1.11.2.1: Compile waste package information needed for repository design (SCP Section 8.3.2.2.2.1)

Background and SCP Plans. This design activity involved determining what waste package information was needed for underground facility design, obtaining the data, and documenting it in the Repository Design Requirements Document.

Changes and Status. This design activity was addressed consistent with the intent of the SCP. Waste package information needed to support repository design was documented in the Controlled Design Assumptions Document (CRWMS M&O, 1996c). Current values are compiled and published in the Controlled Design Assumptions Document, LWR Radiological PC Data Base (CRWMS M&O, 1993b), and High Level Waste PC Data Base (CRWMS M&O, 1993c). Values are updated as necessary to reflect design changes. The information will be included in the appropriate design requirements documents after resolution of the document hierarchy, which includes elimination of the repository design requirements document. (See the discussion of Information Need 4.4.4 (SCP Section 8.3.2.5.4) in this appendix.

Application of results (SCP Section 8.3.2.2.2.2)

Background and SCP Plans. This section stated that waste package information resulting from addressing information need 1.11.2 would be used in designing the underground facility.

Changes and Status. The Project is meeting the intent of this SCP section. Waste package information is being used on an ongoing basis in support of repository design. As discussed previously, the borehole emplacement concept is no longer being pursued, and waste package information related to this concept is not required.

Information Need 1.11.3: Design concepts for orientation, geometry, layout, and depth of the underground facility that contribute to waste containment and isolation including flexibility to accommodate site-specific conditions (SCP Section 8.3.2.2.3)

Background and SCP Plans. This section described approaches planned to obtain data for determining orientation, geometry, layout, and depth of the repository. Table 8.3.2.2-6 listed five products planned to be used to satisfy the information need. Table 8.3.2.2-7 described information expected to be required to complete the five products with the required level of confidence. Finally, the section described how each product would be developed.

Changes and Status. The Project has addressed or is addressing all five products discussed in this SCP section. One significant difference, discussed further with respect to Design Activity 1.11.3.3, is that the Project is no longer considering borehole emplacement, because it is not feasible with the planned large waste packages currently for use. Also, altnough the change to in-drift emplacement was not the direct result of a performance evaluation, substantial waste package and repository performance benefits are expected to result from the change. All Table 8.3.2.2-7 input items are being obtained, with the exception that those related to borehole emplacement have been modified to apply to in-drift emplacement. The SCP descriptions of how each product will be developed are current except for the decision on vertical or horizontal borehole emplacement orientation, which is no longer irrelevant.

Design Activity 1.11.3.1: Area Needed determination (SCP Section 8.3.2.2.3.1)

Background and SCP Plans. This design activity was to determine the area required for the underground facility.

Changes and Status. This design activity is being addressed in a manner consistent with that described. Area expected to be needed does not differ substantially from that expected at the time the SCP was written, although the proposed layout has changed substantially because of changes in the emplacement concept and from other considerations. The emplacement area required has decreased somewhat because the planned repository thermal loading has increased; emplacement area required is inversely proportional to the thermal loading. Total area required includes thermal buffers, accesses, and underground support and operations areas (CRWMS M&O, 1996b).

Design Activity 1.11.3.2: Usable area and flexibility evaluation (SCP Section 8.3.2.2.3.2)

Background and SCP Plans. This design activity involved analyzing the structure and stratigraphy of Yucca Mountain to identify usable areas and to ensure adequate area was characterized, to produce drift layout arrangements, to ensure drift arrangements fit geology and structure, and to identify site geologic data requirements.

Changes and Status. This activity is proceeding as described. A three-dimensional computer model is being used to develop the boundaries of potential repository development (CRWMS M&O, 1995b). The boundaries being developed generally are in agreement with the primary area identified in the SCP (Mansure and Ortiz, 1984). Reconfiguration of the repository and use of a higher thermal load than planned in the SCP would allow all 70 000 MTU of waste to be placed west of the Ghost Dance fault. This would provide more flexibility in emplacement by allowing the potential usable area east of the Ghost Dance fault to be reserved for contingencies. The results of these activities, however, are not planned to appear in topical reports or be placed in the Reference Information Base as discussed in the SCP. Instead, these results will appear in design analyses, technical documents, and drawings.

Design Activity 1.11.3.3: Vertical and horizontal emplacement orientation decision (SCP Section 8.3.2.2.3.3)

Background and SCP Plans. This design activity was to provide the performance evaluation necessary to document the choice of vertical or horizontal emplacement.

Changes and Status. This design activity is not being addressed as described. The SCP contemplated placing relatively small waste packages in vertical or horizontal boreholes, which would then be capped and sealed from the emplacement drifts. One waste package was planned for vertical boreholes, and multiple waste packages were planned for horizontal boreholes. The Project has subsequently substantially increased the size of waste packages for reasons discussed in the introduction to Section A.3 (Waste Package Program) of this appendix. The increased size of the waste packages made placing them in boreholes impractical. The present emplacement scenario would have waste packages placed directly on pedestal supports in the center of emplacement drifts. The decision not to use borehole emplacement was not the direct result of a performance evaluation. Rather, it resulted from the change to large waste packages coincident with the multi-purpose canister concept. The Project decided to go to the multi-purpose canister concept on the basis of the cost efficiency and better long-term performance of producing and emplacing a smaller number of very robust, large capacity packages. Although the current Program approach does not emphasize multi-purpose canisters, significant performance advantages are expected to result from the planned in-drift emplacement of large, robust waste packages as compared with the borehole emplacement concept described in the SCP.

Design Activity 1.11.3.4: Drainage and moisture control plan (SCP Section 8.3.2.2.3.4)

Background and SCP Plans. This design activity provided postclosure design requirements for the layout of the underground facility that would result in limiting the amount of water in contact with waste packages to provide a favorable containment and isolation environment.

Changes and Status. This design activity is being addressed in a manner consistent with that described. Current design follows the SCP concepts. The repository on the whole would be sloped such that any water entering the repository would drain to a low point at the north end of the repository. The emplacement drifts would be sloped so water would drain from them to the access drifts. In addition, there would be a small "step" at the intersection of the emplacement drifts and the access drifts, that would make the invert of the emplacement drifts slightly higher than the invert of the access drifts. A high thermal load would keep temperature above boiling for an extended time period and thus would keep liquid-phase water from contacting the waste packages.

Design Activity 1.11.3.5: Criteria for contingency plan (SCP Section 8.3.2.2.3.5)

Background and SCP Plans. This design activity provided criteria for a contingency plan to address postclosure performance issues, such as fault standoff and thermal load adjustments.

Changes and Status. This design activity is being addressed in a manner consistent with that described. Flexibility is available to adjust for different thermal loads, to deal with unexpected loss of emplacement area, and to adapt to changed conditions. The current repository design (reconfigured from that shown in the SCP) and the planned use of a higher thermal load than in the SCP would allow all 70 000 MTU of waste to be placed west of the Ghost Dance fault (upper emplacement block). This concept would provide more flexibility in emplacement by allowing the potential usable area east of the Ghost Dance fault (lower emplacement block), which is approximately 20 percent of the upper emplacement block area, to be reserved for contingencies. In addition, the area north of Drill Hole Wash is being investigated for possible inclusion into the upper repository block.

Application of results (SCP Section 8.3.2.2.3.6)

Background and SCP Plans. This activity committed to using data from the resolution of information need 1.11.2 to support repository design.

Changes and Status. This activity is being addressed in a manner consistent with that provided in the SCP section.

Information Need 1.11.4: Design constraints to limit water usage and potential chemical changes (SCP Section 8.3.2.2.4)

Background and SCP Plans. This information need described methods and approaches for developing design constraints to limit water usage and potential chemical changes in the underground facility. Two products were identified as needed to address the information need: material inventory criteria and water usage criteria. Table 8.3.2.2-9 provided a list of parameters and information items needed to develop the products. The section also stated that two sets of criteria were necessary; the first was with regard to modification of the postclosure geochemical environment of the waste package as a result of preclosure activities, and the second was the degree of saturation of the host rock as a result of preclosure activities. Finally, some details were provided on how the material inventory criteria and water management criteria were to be developed.

Changes and Status. The program has developed material inventory criteria and water management criteria for the ESF. A similar process will be used to develop such criteria for the repository. The parameters and information called for in Table 8.3.2.2-9 are being addressed. The current approach is generally consistent with the discussion provided in the section for obtaining the products. The exceptions are that drilling of emplacement boreholes and types of materials in emplacement boreholes do not apply because of a change in the emplacement concept, and the current thermal loading is expected to keep the waste packages dry for a period significantly greater than 300 years.

Design Activity 1.11.4.1: Chemical changes resulting from the use of construction materials (SCP Section 8.3.2.2.4.1)

Background and SCP Plans. This design activity involved quantifying chemical changes such as changes in pH that result from using a given quantity of construction materials, using the approach described in the information need.

Changes and Status. Chemical changes as a result of introduction of construction materials have been quantified using the approach described in the information need. The potential long-term effects of using cementitous materials (concrete and grout), organic compounds and additives, and steel members are being studied. Methods of altering the pH of Portland™ cement are also being studied.

Design Activity 1.11.4.2: Material inventory criteria (SCP Section 8.3.2.2.4.2)

Background and SCP Plans. This design activity involved establishing limits on the inventory of materials that will be used in construction and operation of the underground facility and limits on the amounts of such materials to be left in the postclosure repository. The design activity called for using the approach discussed in the information need in this effort.

Changes and Status. The program is addressing this design activity in a manner consistent with the approach described in the information need. All tracers, fluids, and materials being used underground in the ESF must first be approved by the DOE. Limits on inventories of various construction materials are applied, as stated in the design activity. Criteria have been written specifically for materials used in the ESF, and these are expected to apply to the repository as well. Specific criteria for the repository will be developed as a result of performance assessment and design studies currently under way.

Design Activity 1.11.4.3: Water management criteria (SCP Section 8.3.2.2.4.3)

Background and SCP Plans. This design activity established limits on the amount of water to be used for underground facility construction and operation, indicating amounts and locations for individual operations and using the approach and obtaining the data described in the information need.

Changes and Status. The problem of water management criteria for repository construction has not been addressed because repository design is not sufficiently mature. On the basis of the current advanced conceptual design, however, some changes in emphasis to section 8.3.2.2.4 relative to water management criteria are expected. The SCP identified the use of water for drilling of emplacement boreholes as a primary concern. The current design for in-drift emplacement eliminates this specific issue. Nevertheless, the use of water for construction of repository access and emplacement drifts will need to be evaluated to establish the effects of added water on potential repository performance. Appropriate limits on water use based on this evaluation will be required so that any adverse effects of added water on potential repository performance are controlled to an acceptable level. Similar work providing criteria for the control of water use during site characterization construction and testing activities has been ongoing since FY 1992. This work, reported in Section 6.21 of the progress report, does not have an SCP reference (although it is responsive to NRC concerns in the Site Characterization Analysis (NRC, 1989) regarding site impacts during site characterization).

Application of results (SCP Section 8.3.2.2.4.4)

Background and SCP Plans. This section stated that information obtained for information need 1.11.3 would be used as input to advanced conceptual design and license application design reports and in the reference postclosure design. The section stated that the results of this information need would be (a) criteria placed on the preclosure design process and (b) inputs to performance assessment.

Changes and Status. Information obtained for this information need has been used as input to advanced conceptual design. It also will be used in the future as input to license application design, but not to a license application design report as planned in the SCP. There will not be a license application design report because the information that it would contain will be an integral part of the license application documentation. This information is also being used in performance assessment as appropriate.

Information Need 1.11.5: Design constraints to limit excavation-induced changes in rock mass permeability (SCP Section 8.3.2.2.5)

Background and SCP Plans. This information need provided approaches planned to be used to develop design constraints to limit changes in the rock mass permeability. Processes for limiting magnitude and extent of blast-induced permeability, limiting potential for subsidence by limiting extraction ratio and drift sizes, and backfilling drifts at decommissioning were identified along with their associated performance measures and tentative goals. The information need was planned to be satisfied through completion of two products: excavation methods criteria and a long-term subsidence control strategy. The section also provided the technical basis for addressing the information need and the parameters and input items expected to be obtained. Data and other information needed to satisfy the issue were cited in Table 8.3.2.2-11. Appropriate criteria were to be developed for guiding the repository design using information from waste package characteristics and ground-water travel time. The two products that were to be developed to satisfy this issue are described here in some detail: (1) Product 1.11.5-1 - Excavation Methods Criteria discussed the expectation that drifts would be constructed using drill and blast methods, including issues of worker safety and health and currently available technology; and (2) Product 1.11.5-2 - Long-Term Subsidence Control Strategy discussed the need for usability of access to the repository throughout the operational period, which requires prevention of subsidence during this period. Also discussed is the need to ensure that significant postclosure surface subsidence does not lead to the creation of preferred pathways for water migration. The section also discussed the expectation that drift and pillar stability analyses would be performed to estimate the extent and magnitude of loosening of the rockmass above a backfilled drift are stated.

Changes and Status. The program is, in general, addressing this information need as discussed in the SCP section. Excavation methods for the entire repository, with particular emphasis on the emplacement drifts, are being evaluated. The initial studies on excavation method have been documented in reports. The excavation system will be further analyzed during FY 1997, and preliminary drawings will be prepared. Preliminary requirements have been developed, and equipment and excavation sequence and concepts have been evaluated with the particular goal of reducing excavation-induced changes in rock mass permeability. The current analyses differ from the SCP material in Table 8.3.2.2-10 and Product 1.11.5-1 in that all blasting has been eliminated in the emplacement area and from virtually all nonemplacement areas by using tunnel boring machines and roadheader type mechanical excavation equipment. Mechanical excavation should lead to less impact on the rock mass permeability by eliminating blast damage potential. Current plans differ from the excavation criteria in Table 8.3.2.2-11 because the current horizontal in-drift emplacement mode is different from the borehole emplacement, and, therefore, no work is being performed on borehole design. Long-term subsidence control strategy is being addressed as planned in SCP product 1.11.5-2 listed in Tables 8.3.2.2-10 and -11. Drift and pillar stability analyses are being performed using the best available data and appropriate thermal load range. Efforts are being made to minimize the drift sizes while meeting the operational criteria. The extraction ratio is being maintained within the limit used in the SCP-Conceptual Design Report (SNL, 1987) for vertical borehole emplacement. The analyses are being performed to evaluate the preclosure access requirement mentioned for this product, as well as to gauge the extent of disturbance by determining the long-term rock mass displacement.

A very preliminary evaluation was performed to evaluate the long-term subsidence potential. The difference from the parameters and input items listed in Table 8.3.2.2-11 is that backfilling of the emplacement drifts is currently being considered as an option to be maintained instead of being considered mandatory. Drift and pillar stability analyses are being performed without the backfill as a stabilizing factor. The design is being developed using the logic of developing requirements and criteria and performing conceptual and preliminary design to meet the preliminary requirements and develop new requirements. The process is similar to the one discussed in the SCP section.

Design Activity 1.11.5.1: Excavation methods criteria (SCP Section 8.3.2.2.5.1)

Background and SCP Plans. This design activity identified constraints to be placed on excavation methods because of postclosure performance considerations, using the approach identified in the information need. Table 8.3.2.2-11 presented the excavation parameters and input required to satisfy this information need for this activity.

Changes and Status. The program is addressing this design activity in a manner generally consistent with that described in the information need. However, no work is being performed on borehole design (indicated in Table 8.3.2.2-11, under the column of "Parameters and input items") because of the change made from borehole to in-drift emplacement. Furthermore, the SCP-Conceptual Design Report assumed that most or all the repository would be excavated by drill-and-blast methods because mechanical methods had not yet been proved feasible in the welded tuffs. This assumption was a function of the repository layout at that time. The repository layout has since been revised so that less than one percent of the repository is now expected to be excavated by drill-and-blast. Almost all of the repository, including all emplacement drifts, will be excavated by mechanical means, approximately 90 percent of which will be by tunnel boring machine and the remainder by machines such as a roadheader. Using a tunnel boring machine is generally considered to produce the least possible disturbance to the surrounding rock mass (smallest possible extent of the damaged zone). Tunnel boring machine feasibility has been demonstrated by the excavation of over 6000 m in the ESF.

Design Activity 1.11.5.2: Long-term subsidence control strategy (SCP Section 8.3.2.2.5.2)

Background and SCP Plans. This design activity was intended to develop a position regarding the potential for postclosure subsidence (and its impact on containment and isolation) and to determine whether current goals are adequate to limit potential for subsidence. The design activity would be addressed using the approach described in the information need. Table 8.3.2.2-11 provide the parameters and input required to satisfy this information need.

Changes and Status. The program has addressed this design activity in a manner generally consistent with the approach described in the information need. Conceptual studies have been performed and preliminary analyses are being performed in the area of work described in the SCP as product 1.11.5-2. The potential for subsidence has been addressed as follows. The current repository layout consists of a series of long parallel emplacement drifts separated by long parallel pillars. The possibility of ground subsidence is essentially eliminated by requiring the pillars to be large enough that they would not fail under the estimated stress regime. Empirical evidence (Peng, 1992) indicates that pillars will not collapse and surface subsidence will not occur if the excavation extraction ratio in the emplacement areas is less than 0.50. The current design criteria requires the excavation extraction ratio to be less 0.30; the current layout has an excavation extraction ratio of about 0.22, which further increases overall stability. The difference between the current approach and the parameters and input listed in Table 8.3.2.2-11 is that the SCP-Conceptual Design Report assumed that all emplacement drifts would be backfilled within 500 mm of the crown. The current design does not use backfill as a basis for design, although it also does not preclude backfilling. The analyses for long-term stability are being performed without assuming backfill in the emplacement drifts. If added in the future, backfill would only decrease the potential for subsidence.

Application of results (SCP Section 8.3.2.2.5.3)

Background and SCP Plans. This activity stated that the products and information developed under information need 1.11.5 could be used as input to reference postclosure design and as criteria for design of the preclosure repository.

Changes and Status. Information obtained for this information need is being provided to preclosure and postclosure design as indicated in this SCP section. The conceptual design was used as input to the total system performance assessment, and the current preliminary design will provide input to the total system performance assessment to support the viability assessment. The products 1.11.5-1 and 1.11.5-2 being developed under this information need provide input to the preclosure repository design in the areas of drift and pillar sizes, drift configuration and orientation, and ground support needs.

Information Need 1.11.6: Repository thermal loading and predicted thermal and thermomechanical response of the host rock (SCP Section 8.3.2.2.6)

Background and SCP Plans. This information need presented the approach to obtaining design thermal loading, taking into account performance objectives and thermomechanical response of the host rock. The information need was intended to be satisfied through five products: allowable areal power density, borehole spacing strategy, sensitivity studies, strategy for containment enhancement, and reference calculations. The information need would be resolved through analyses and information items listed in Tables 8.3.2.2-13 and 8.3.2.2-14. The section discussed the approaches planned to support development of the products and described the three scales of analyses expected to be performed to resolve the information need: container-scale, drift-scale, and far-field.

Changes and Status. The Project generally is following the approach described in the SCP section to address the information need. The five products are being obtained, but with some changes. Product 1.11.6-1 - Areal Power Density, expresses repository thermal load in terms of areal power density which has units of kW/acre. Thermal load is currently being expressed in terms of MTHM acre because this quantity is fixed (i.e., not age dependent) for a given waste package. For a given fuel acceptance scenario, the MTHM acre has an equivalent initial kW/acre. The Project is considering basing the spacing of waste packages on an equivalent energy density to smooth temperature variations resulting from spacings using kW/acre or MTHM acre. Two waste packages having the same MTHM could have significantly different initial heat outputs (kW), and two waste packages having the same initial heat output could have significantly different total heat output. Equivalent energy density considers the total heat output from a waste package over some period of time, such as 1000 years, and then spaces the waste packages based on total heat output.

Product 1.11.6-2 - Borehole Spacing is not relevant because the emplacement concept has changed from boreholes to horizontal-in-drift. However, the equivalent of borehole spacing for in-drift emplacement is waste package and drift spacing, which are being addressed.

Product 1.11.6-4 - Strategy for Containment Enhancement mentions the goal of keeping the waste packages dry by maintaining the temperature above boiling for 300 years. Under the current higher thermal loading being assumed by the project, most of the repository will be above boiling for substantially longer than 300 years.

Information items described in the tables in this section are being obtained except for thermomechanical properties of overburden. These data are not being obtained because there is little thermal effect in the overburden and, therefore, the data are not needed.

The three scales of analyses described in the information need are consistent with the approach to such analyses currently being pursued, except that the container-scale analyses do not consider borehole liners or the effects of borehole collapse. However, the equivalent of these, namely drift support systems and drift stability, are included in the drift-scale analyses.

Design Activity 1.11.6.1: Thermal loading for underground facility (SCP Section 8.3.2.2.6.1)

Background and SCP Plans. This design activity established allowable thermal loading as a function of waste age and burnup. The section stated that the effort should start with far-field calculations and should also consider near-field constraints. The approach was to be consistent with that presented in the information need.

Changes and Status. The approach to developing a design thermal loading is generally consistent with the approach described in the information need, except for a change of units (see previous discussion for the information need). Thermal loading in the SCP was expressed as the areal power density in units of kW/acre. Currently, thermal loading is expressed in MTHM/acre, which for a given fuel acceptance scenario corresponds to an average kW/acre. Current design is focusing on thermal loads of 80 to 100 MTHM/acre, which is higher than the thermal load associated with the SCP repository layout. The change from borehole to in-drift waste package emplacement required several thermal constraints to be modified or deleted. More emphasis is currently being placed on postclosure performance than was evident in the SCP. For example, the SCP had a not-to-exceed borehole wall temperature goal of 275°C, which was deleted in the Controlled Design Assumptions Document (CRWMS M&O, 1996c) as recommended by the thermal goal reevaluation report (CRWMS M&O, 1993d) because of the decision to not use borehole emplacement. In addition, the SCP had a goal to keep the majority of the borehole walls above boiling for more than 300 years. This goal was changed in the thermal goal reevaluation report to a goal to maximize the time the waste package stays above boiling consistent with the thermal strategy. There was also a goal in the SCP that boreholes should not load containers beyond the limits imposed under Issue 1.10. This goal, which would set limits on the load that a waste package could experience, does not appear in current Program requirements documents because of the change from borehole emplacement. Current studies are evaluating limitations on thermal loads necessary to prevent violation of thermal goals (CRWMS M&O, 1996o)

Design Activity 1.11.6.2: Borehole spacing strategy (SCP Section 8.3.2.2.6.2)

Background and SCP Plans. This design activity was intended to establish strategy for choosing borehole spacings as a function of waste thermal output such that all near-field constraints will be satisfied. The activity was intended to be addressed using an approach consistent with that described in the information need.

Changes and Status. With the change from borehole to in-drift emplacement, the focus of this activity shifted to a waste package and emplacement drift spacing strategy. Otherwise, the goal of this activity remains the same: develop waste package spacings such that near-field thermal goals are not violated and postclosure performance objectives are achieved (CRWMS M&O, 1996b).

Design Activity 1.11.6.3: Sensitivity studies (SCP Section 8.3.2.2.6.3)

Background and SCP Plans. This design activity was intended to determine predicted repository thermal and thermomechanical response to variations in model input data. The information would be used to evaluate adequacy of data gathered and to ensure goals have been met with proper confidence. The approach intended was described in the information need.

Changes and Status. The goal of this activity remains unchanged. Recent work has dealt with determining the sensitivity of repository thermal and thermal/mechanical response to the various parameters, including thermal loading, waste package spacing, emplacement drift diameter, age of fuel before emplacement, and backfill in emplacement drifts.

Design Activity 1.11.6.4: Strategy for containment enhancement (SCP Section 8.3.2.2.6.4)

Background and SCP Plans. This design activity was intended to document how design of the underground facility has taken into account containment and keeping the containers dry for 300 years. The approach intended was described in the information need.

Changes and Status. The goal of this activity and the approach to addressing it remain unchanged. Ongoing studies in support of the currently planned high thermal loading are concentrating on the means of maintaining the temperature of as many waste packages as possible above boiling for as long as possible (considerably longer than the 300 years mentioned in the SCP). Studies have concluded that increasing the waste loading at the edges of the underground facility, as suggested in product 1.11.6-4, would have an insignificant effect on repository performance.

Design Activity 1.11.6.5: Reference calculations (SCP Section 8.3.2.2.6.5)

Background and SCP Plans. This design activity provided a consistent set of calculations with proper quality assurance of thermal and thermomechanical response of host rock that can be used to support performance assessment. The approach intended was described in the information need.

Changes and Status. The goal of this activity and the approach to addressing it remain unchanged. Current work under this activity is concentrating on thermal modeling of the TSw2 thermal/mechanical unit for combined excavation, thermal, and seismic loads.

Application of results (SCP Section 8.3.2.2.6.6)

Background and SCP Plans. This section stated that information obtained for this information need would be input to advanced conceptual design and license application design reports, documented in the reference postclosure design, and used as criteria for repository design.

Changes and Status. Information obtained for this information need was provided to the design organization for advanced conceptual design. The information also will be used to support the license application design and be documented in the reference postclosure design. There will be no license application design report because the information it would contain will be an integral part of the license application documentation.

Information Need 1.11.7: Reference postclosure repository design (SCP Section 8.3.2.2.7)

Background and SCP Plans. This information need was to be satisfied by developing of two products: (1) a reference postclosure design that would help form the basis of performance assessment and (2) documentation in the advanced conceptual design and license application design reports of compliance of the postclosure design with 10 CFR 60.133. The information need listed five information items that must be documented as part of the reference postclosure design: (1) location, size, shape, and drainage pattern of underground openings, (2) anticipated postclosure state of openings, (3) location, function, and design of seals, (4) criteria for dismantling underground structures and facilities, and (5) documentation of surface monuments, if any.

Changes and Status. As part of ongoing design work, the Project is documenting the reference postclosure design that will be used in performance assessment. The design is being documented in reports, analyses, and drawings and identified in the configuration management system data base. There will be no license application design report used for documentating postclosure design because the information it would contain will be an integral part of the license application documentation. The five information items described in the information need are being addressed, except that the postclosure state of the openings now refers to the emplacement drifts instead of the emplacement boreholes. Also, current plans are to backfill emplacement drifts only if there is a demonstrated performance need and not just because access is no longer needed.

Design Activity 1.11.7.1: Reference postclosure repository design (SCP Section 8.3.2.2.7.1)

Background and SCP Plans. This design activity established what information would constitute the reference postclosure design and documented the information in the advanced conceptual design and license application design reports.

Changes and Status. The goal of this activity remains unchanged. A list of information needed for performance assessment has been prepared. The design was documented in the MGDS Advanced Conceptual Design Report (CRWMS M&O, 1996b) and will also be documented for license application design. However, as explained previously in the discussion of the information need, design will not be documented in a license application design report.

Design Activity 1.11.7.2: Documentation of compliance (SCP Section 8.3.2.2.7.2)

Background and SCP Plans. The objective of this design activity was to document the determination of whether the postclosure design complied with the design goals of this issue in the advanced conceptual design and license application design reports.

Changes and Status. The goal of this activity remains unchanged. Preliminary documentation of compliance has been prepared for the design to date, as discussed in the MGDS Advanced Conceptual Design Report. The determination of whether the postclosure design is expected to comply with the design goals for this issue will be documented for license application design. However, as explained previously in the discussion of the information need, compliance will not be documented in a license application design report.

Application of results (SCP Section 8.3.2.2.7.3)

Background and SCP Plans. This section stated that the reference design produced to satisfy this information need would be placed in the Reference Information Base (DOE, 1995e) for use as input to performance assessment.

Changes and Status. The reference design is being documented, but not in the Reference Information Base. Instead, the design is being documented in reports, analyses, and drawings. Information being documented as a result of these activities is being used to support assessments of repository and waste package performance as specified in this SCP section.

Schedule for configuration of underground facilities (SCP Section 8.3.2.2.8)

Background and SCP Plans. This section provided a schedule for addressing Design Activities 1.11.1.1 through and 1.11.7.2.

Changes and Status. The schedule for obtaining information for key activities has been revised as described in the semiannual progress reports. This method of documenting changes is consistent with the text in the SCP section. The Project has not, however, undertaken to ensure the schedule revisions for all the specific items in Table 8.3.2.2.-15 are included in the progress reports. The schedules presented in the 1988 SCP were based on the DOE's June 1987 Mission Plan Amendment (DOE, 1987a and 1987b), which assumed the license application for the repository would be submitted to the NRC in 1995. In 1989, the Secretary of Energy assessed the progress and needs of the site characterization program, and a new schedule was adopted that delayed license application submittal to 2001. The program plan supporting the 2001 submittal, which was issued in December 1994 (DOE, 1994a), contains a schedule for accomplishing major Program activities, but it does not explicitly revise the schedule for all SCP activities and studies. Scheduled completion dates for SCP activities may be further revised in the future as a result of new developments in the site characterization program, changes in Program priorities, or changes in funding profiles. These changes will be discussed, as appropriate, in future progress reports; the Project, however, does not plan to necessarily address how and why each SCP schedule item has changed

Issue resolution strategy for Issue 2.7: Have the characteristics and configurations of the repository been adequately established to (a) show compliance with the preclosure design criteria of 10 CFR 60.130 through 60.133 and (b) provide information for the resolution of the performance issues? (SCP Section 8.3.2.3)

Background and SCP Plans. This section stated that the issue is concerned with the features of the repository that relate to radiological safety. Figure 8.3.2.3-1 showed the relationship of this issue to other issues and to the site characterization program. The section described the proposed licensing strategy for resolving the issue, including a logic diagram. The section also identified functional requirements and discussed performance allocation. Table 8.3.2.3-2 listed subfunctions in support of the functional goals, along with processes, performance measures, tentative goals, and confidence levels needed for each subfunction. Table 8.3.2.3-3 listed various parameters required for resolution of the issue. The text describes the approach to testing to ensure all goals are met including verifying that the as low as reasonably achievable principle had been met. Finally, the section describes how the information needs to address the issue would be approached and how they related to each other.

Changes and Status. The issue resolution strategy for this issue being pursued by the Project is consistent with that presented in this section (including the licensing strategy section). Performance allocation is being addressed by the functional analysis process currently under way. The logic diagram in Figure 8.3.2.3-2a is consistent with the current Program. Subfunctions in Table 8.3.2.3-2 and parameters in Table 8.3.2.3-3 are being addressed in requirements documents and subsequently in design. Table 8.3.2.3-3 and the text referred to 30 CFR Chapter I, Subchapters D, E, and N. The source for the statement is 10 CFR 60.131(9). Since that part of 10 CFR Part 60 was written, 30 CFR Chapter I has been reorganized and Subchapters D and E were eliminated as headings. The parts of 30 CFR that were in Subchapters D and E are now parts 18-29, 31-33, and 35-36 of Subchapter B.

The current approach to testing is consistent with the approach discussed in the SCP section. The current approach to addressing the information needs is consistent with the approach described in this section, except that, as noted previously, the design configuration information and results will not be placed into, or obtained from, the Reference Information Base.

Environmental data specified in Table 8.3.2.3-3 is being collected as follows. The eight meteorological parameters (wind speed, wind direction, atmospheric stability, mixing layer depth, average ambient temperature, atmospheric moisture, precipitation, and barometric pressure) are being monitored two ways. Except for mixing layer depth, the parameters are being monitored locally (within about 20 km) using a nine-station network in the vicinity of Yucca Mountain. This activity is discussed further in Section A.1.9.2 of this appendix. All the parameters are included in the Scientific Investigation Implementation Package for Regional Meteorology (CRWMS M&O, 1995a), whose scope includes the 80-km radius of Yucca Mountain described in the SCP. To date, recreational use of water bodies has not been examined but may be considered as part of the development of the repository license application. The Project is monitoring surface water runoff but so far has not emphasized a goal for surface water runoff to surface water bodies. This work is discussed further in Sections A.1.9.1, A.1.9.3, and A.1.9.4 of this appendix.

Information Need 2.7.1: Determination that the design criteria in 10 CFR 60.131 through 60.133 and any appropriate additional design objectives pertaining to radiological protection have been met (SCP Section 8.3.2.3.1)

Background and SCP Plans. This information need stated that three site parameters were required: (1) concentrations of naturally occurring radon and its daughters in repository airstreams, (2) use of shielding properties of host rock, and (3) quantification of transport of radioactive materials to workers and the public. A list of site data required was provided and the logic process for addressing the information need was described.

Changes and Status. The parameters and data listed in the information need are being obtained. The current logic process to meeting the information need is consistent with that discussed in the SCP section.

Design Activity 2.7.1.1: Design evaluation for compliance with radiological safety design criteria and performance goals (SCP Section 8.3.2.3.1.1)

Background and SCP Plans. This design activity evaluated the repository design against radiological safety design criteria and performance goals. Parameters to be used were those listed in the information need. The activity was intended to consist of a complete radiological safety design analysis and performance goal assessment of the reference repository design, operating plan, and supporting analyses at each phase of design.

Changes and Status. As stated in the previous discussion for the information need, the parameters listed therein are being addressed subject to changes noted in the discussion of the issue resolution strategy for Issue 2.7. A performance assessment and preliminary MGDS hazards analysis were performed for and documented in the MGDS Advanced Conceptual Design Report (CRWMS M&O, 1996b). Safety analyses and additional performance assessments will occur in conjunction with design work to support the viability assessment and the license application.

The SCP outlined a comprehensive design for radiological controls, many of which have only been considered conceptually for the repository. Specifically, these include (a) monitors and controls that limit the dispersion of radioactive contamination in and from the repository, (b) radiation alarms for airborne radiation, (c) alarms for explosion and fire detection, and (d) instrumentation and control systems for other safety-related repository features. These instrumentation requirements have been considered. No impediments are forecast for eventual design and implementation based upon currently expected repository conditions. Analyses to determine the radiological environmental conditions related to such designs are expected during FY 1997, from which detailed design may proceed during subsequent fiscal year efforts.

Structures, systems, and components important to safety are currently being evaluated as part of the ongoing Q-List activity. Compilation of the revised list is expected at the end of FY 1997 to reflect major repository design changes. The as low as reasonably achievable principle is being implemented in the design process.

Additionally, the NRC drivers for radiation protection controls are undergoing changes that are expected to be reflected in changes to 10 CFR Part 60. The changes expected include revisions that effectively would alter the radiation design limits for both worker and public exposure rates during both Class I and Class II accidents and events. Any such changes that occur will potentially drive changes in the program as envisioned in the SCP.

Application of results (SCP Section 8.3.2.3.1.2)

Background and SCP Plans. This section stated that information for this information need would be used in preclosure design and technical feasibility studies to demonstrate compliance with radiological safety design criteria and performance goals.

Changes and Status. Information obtained for this information need is being used in a manner consistent with that specified in this SCP section.

Information Needs 2.7.2 and 2.7.3: (1) Determination that the design criteria in 10 CFR 60.131 through 60.133 and any appropriate additional design objectives pertaining to the design and protection of structures, systems, and components important to safety have been met, and (2) Determination that the design criteria in 10 CFR 60.131 through 60.133 and any appropriate additional design objectives pertaining to criticality control have been met (SCP Section 8.3.2.3.2)

Background and SCP Plans. This information need listed site parameters required to address the need and provided a basic logic for addressing it.

Changes and Status. The Project is addressing this information need in a manner consistent with this section. The site parameters listed in the information need are being addressed.

Application of results (SCP Section 8.3.2.3.2.1)

Background and SCP Plans. This section stated that information obtained for this information need would be used directly to demonstrate compliance with radiological safety design criteria and performance goals.

Changes and Status. The Project is addressing this information need in a manner consistent with this section of the SCP.

Schedule for repository design criteria for radiological design (SCP Section 8.3.2.3.3)

Background and SCP Plans. This section of the SCP provided a schedule for addressing Design Activity 2.7.1.1.

Changes and Status. The schedule for obtaining information for key activities has been revised as described in the semiannual progress reports. This method of documenting changes is consistent with the text in the SCP section. The Project has not, however, undertaken to ensure the schedule revisions for all the specific items in Table 8.3.2.3-4 are included in the progress reports. The schedules presented in the 1988 SCP were based on the DOE's June 1987 Mission Plan Amendment (DOE, 1987a and 1987b), which assumed the license application for the repository would be submitted to the NRC in 1995. In 1989, the Secretary of Energy assessed the progress and needs of the site characterization program, and a new schedule was adopted that delayed license application submittal to 2001. The program plan (DOE, 1994a) supporting the 2001 submittal, which was issued in December 1994, contains a schedule for accomplishing major Program activities, but it does not explicitly revise the schedule for all SCP activities and studies. Scheduled completion dates for SCP activities may be further revised in the future as a result of new developments in the site characterization program, changes in Program priorities, or changes in funding profiles. These changes will be discussed, as appropriate, in future progress reports; the Project, however, does not plan to necessarily address how and why each SCP schedule item has changed.

Issue resolution strategy for Issue 4.2: Are the repository design and operating procedures developed to ensure nonradiological health and safety of workers adequately established for the resolution of the performance issues? (SCP Section 8.3.2.4)

Background and SCP Plans. This section stated that the issue is concerned with the features of the repository that relate to mining (nonradiological) worker safety. Designs and procedures for the repository were to address at least 12 factors listed in the section. The section also discussed major factors affecting worker safety and included certain assumptions regarding whether several potential events or accidents should be of concern. A five-step approach to resolving the issue was presented in the text and graphically depicted in Figure 8.3.2.4-1. The text also listed "system subelements" that do and do not require site data. Tables 8.3.2.4-1 through 8.3.2.4-9 provided specific functions, processes performed, performance measures, goals, and needed confidence for achieving the goals.

Changes and Status. The issue resolution strategy for this issue being pursued is consistent with that presented in this section and the logic diagram in Figure 8.3.2.4-1. The 12 factors listed in the section are being addressed. The system subelement for borehole emplacement has been deleted. The functions and performance measures in Tables 8.3.2.4-1 through 8.3.2.4-9 are being addressed, but some of the tentative goals have been modified or deleted to be consistent with the change in the basic repository emplacement concept and other design changes. These goals deal with limiting rock damage caused by blasting (little or no blasting will now occur), rockfall criteria (being addressed by a robust full-circle type lining), air cooling power (now incorporated by specifying other ventilation parameters), and duration of drift stability (now about 150 years, including a retrieval operation period, instead of 100 years). The current approach to addressing the information needs is consistent with the approach described in this section.

Information Need 4.2.1: Site and performance assessment information needed for design (SCP Section 8.3.2.4.3)

Background and SCP Plans. This information need required that information needed to implement design and operating procedures be identified. The proposed two-part approach to doing this involved (1) addressing the issue of developing and documenting the procedures and (2) identifying information needed to implement those procedures. The section then discussed how each part would be addressed. Next, specific parameters for the information need were identified. Finally, the logic for obtaining the information was briefly discussed.

Changes and Status. The current program is using the two-part approach described in the information need, including the parameters and logic process that were planned.

Design activity to verify access and drift usability (SCP Section 8.3.2.4.1.1)

Background and SCP Plans This design activity described seven demonstrations and tests planned in the ESF to demonstrate that design and operating procedures were adequate for repository design.

Changes and Status. This design activity is being conducted essentially as described. The only significant difference is that the emphasis in the SCP on blasting studies has not occurred because of repository redesign, which will result in less than one percent of the repository being excavated by drill-and-blast. (See the previous discussion for Design 8.3.2.2.5.1)

Activity 1.11.5.1: Design activity to verify air quality and ventilation (SCP Section 8.3.2.4.1.2)

Background and SCP Plans. This design activity provided an approach to designing the repository ventilation system using four specific parameters.

Changes and Status. This design activity is being conducted as described in the SCP.

Application of results (SCP Section 8.3.2.4.1.3)

Background and SCP Plans. This section stated that information obtained for the associated information need would provide the data base required to assess the adequacy of design and operating procedures for worker nonradiological health and safety.

Changes and Status The information being obtained is being used as described.

Schedule for non-radiological health and safety (Issue 4.2) (SCP Section 8.3.2.4.2)

Background and SCP Plans. This section of the SCP provided a schedule for addressing Design Activities 4.2.1.1 and 4.2.1.2.

Changes and Status. The schedule for obtaining information for key activities has been revised as described in the semiannual progress reports. This method of documenting changes is consistent with the text in the SCP section. The Project has not, however, undertaken to ensure the schedule revisions for all the specific items in Table 8.3.2.4-10 are included in the progress reports. The schedules presented in the 1988 SCP were based on the DOE's June 1987 Mission Plan Amendment (DOE, 1987a and 1987b), which assumed the license application for the repository would be submitted to the NRC in 1995. In 1989 the Secretary of Energy assessed the progress and needs of the site characterization program, and a new schedule was adopted that delayed license application submittal to 2001. The program plan (DOE, 1994a) supporting the 2001 submittal, which was issued in December 1994, contains a schedule for accomplishing major Program activities, but it does not explicitly revise the schedule for all SCP activities and studies. Scheduled completion dates for SCP activities may be further revised as a result of new developments in the site characterization program, changes in Program priorities, or changes in funding profiles. These changes will be discussed, as appropriate, in future progress reports; the Project, however, does not plan to necessarily address how and why each SCP schedule item has changed.

Issue resolution strategy for Issue 4.4: Are the technologies of repository construction, operation, closure, and decommissioning adequately established for the resolution of the performance issues? (SCP Section 8.3.2.5)

Background and SCP Plans. This section stated that the issue was concerned with determining whether the repository can be designed, constructed, operated, and closed using reasonably available and proven technology. A five-step approach to resolving the issue was presented in the text and graphically depicted in Figure 8.3.2.5-1. Tables 8.3.2.5-1 through 8.3.2.5-12 provided specific functions, processes performed, performance measures, goals, and needed confidence for achieving the goals for 12 system elements. Finally, the section provided a list of five criteria planned to support the assessment that the technology is reasonably available.

Changes and Status. The issue resolution strategy for this issue being pursued and the logic diagram in Figure 8.3.2.5-1 is consistent with the current Program. The SCP text states that system elements not requiring site-specific data are not discussed further in the SCP, but will be addressed in a repository design plan. There will be no repository design plan. Instead, these elements will be addressed in design analyses and system design description documents (see the following discussion below for Information Need 4.4.4). The performance measures and parameters in Tables 8.3.2.5-1 through 8.3.2.5-12 are being addressed as part of ongoing design and site characterization except for those in Tables 8.3.2.5-5 and 8.3.2.5-10 that deal with borehole emplacement, which is no longer part of the repository design. Some of the tentative goals and expected values have been modified or deleted to be consistent with the change in the basic repository emplacement concept and other design changes. These goals deal with limiting rock damage caused by blasting (little or no blasting will now occur), rockfall criteria (being addressed by a robust full-circle type lining), air cooling power (now incorporated by specifying other ventilation parameters), and duration of drift stability (now about 150 years, including a retrieval operation period, instead of 100 years). The five criteria planned in the SCP for use in supporting the assessment are consistent with the current program approach.

Information Need 4.4.1: Site and performance assessment information needed for design (SCP Section 8.3.2.5.1)

Background and SCP Plans. This information need summarized the site-related parameters identified as being required by the remaining information needs under Issue 4.4. The section provides four observations in support of the technical basis for the information need and refers to the parameters in Tables 8.3.2.5-1 through 8.3.2.5-12 for use in addressing the information need. The section then provides a justification for selecting these parameters.

Changes and Status. The four observations in the information need are still considered valid. Exceptions stated in the preceding discussion for Issue 4.4 to the parameters in Tables 8.3.2.5-1 through 8.3.2.5-12 apply. The current program is consistent with the logic presented in the information need.

Application of results (SCP Section 8.3.2.5.1.1)

Background and SCP Plans. This section stated that the information obtained to address the associated information need would be used to address Issue 4.4 by providing information needed in Information Needs 4.4.2 through 4.4.10 to update the Reference Information Base (DOE, 1995e) for use in license application design and to provide guidance for site data gathering.

Changes and Status. The information obtained for Information Need 4.4.2 through 4.4.10 is being used as described, except that very little, if any, of the information obtained will be placed in the Reference Information Base. Instead, the information will be presented in design analyses and system design description documents.

Information Need 4.4.2: Characteristics and quantities of waste and waste packages needed for design (SCP Section 8.3.2.5.2)

Background and SCP Plans. This information need was to serve as interface between waste package design and repository design. It would be considered satisfied when waste package-repository interface requirements were finalized and passed on to design requirements documents. The section provided four waste-related parameters needed to support the information need and a nine-point logic process to support the selection of the parameters.

Changes and Status. The current approach is generally consistent with the parameters and logic process described in the information need. The exceptions are those items specifically related to (a) borehole emplacement (a design concept not currently under consideration); (b) the period of retrievability (increased from 50 to 100 years); and (c) the waste quantities (will not appear in the generic requirements document). The generic requirements document has been deleted from the document hierarchy. (See the following discussion on Information Need 4.4.) The waste quantities will be stated in the Controlled Design Assumptions Document (CRWMS M&O, 1996c) and in individual system design description documents.

Application of results (SCP Section 8.3.2.5.2.1)

Background and SCP Plans. This section provided a cross reference for how information from the associated information need would be used in other issues and information needs.

Changes and Status. The current program approach uses the information obtained in this information need as specified in the SCP section.

Information Need 4.4.3: Plan for repository operations during construction, operation, closure, and decommissioning (SCP Section 8.3.2.5.3)

Background and SCP Plans. This information need was to produce a plan for repository operations. The section described how design information was to be used to develop the operations plan and listed parameters planned as input to the plan. Finally, the section provided a logic process for developing the plan.

Changes and Status. The approach to developing the operations plan currently being pursued is consistent with that described, including use of the specified parameters and logic process. The repository operations plan will not be further described in a repository design plan because there is no such plan; instead, the operations plan will be described in a concept of operations document.

Design Activity 4.4.3.1: Operations plan to accompany the advanced conceptual design (SCP Section 8.3.2.5.3.1)

Background and SCP Plans. This design activity was to produce an operations plan to accompany advanced conceptual design that focused mainly on waste handling operations, including retrieval.

Changes and Status. A concept of operations (operations plan) was included in the MGDS Advanced Conceptual Design Report (CRWMS M&O, 1996b). As planned by the SCP, this plan focused on waste handling operations, including retrieval.

Design Activity 4.4.3.2: Operations plan to accompany the license application design (SCP Section 8.3.2.5.3.2)

Background and SCP Plans. This design activity was to produce an operations plan to accompany the license application design. The plan would contain the results of design decisions made during advanced conceptual design and would contain operations only for the selected emplacement option. Sufficient detail would be included to support radiological and nonradiological safety analyses.

Changes and Status. The concept of operations for viability assessment is being developed. A preliminary version has been published (CRWMS M&O, 1996s). This work will lead to a concept of operations for license application. The Project currently plans to develop the concept of operations in a manner consistent with that described in the information need.

Application of results (SCP Section 8.3.2.5.3.3)

Background and SCP Plans. This section described how the operations plan would be used

Changes and Status. The Project plans to use the operations plan in a manner consistent with that described.

Information Need 4.4.4: Repository design requirements for construction, operation, closure and decommissioning (SCP Section 8.3.2.5.4)

Background and SCP Plans. This information need would be satisfied by the publication and control of the repository design requirements for each phase of repository design. The information need called for clearly documenting and maintaining in the repository design requirements, the controlled assumptions and baseline design configuration. Requirements planned to be considered in generation of the repository design requirements were listed and a graphic requirements document hierarchy was given in Figure 8.3.2.5-2. A logic process was described for meeting the information need, including a description of how changes to the repository design requirements would be made. Table 8.3.2.5-14 provided an organization of repository design requirements documents.

Changes and Status. The current approach to documenting design requirements, organizing the design requirements documents, and controlling changes to the documents has changed from the approach provided in the information need. This change is because (a) the NRC commented that the flow down and traceability of requirements were cumbersome and (b) the DOE determined that requirements were written at too low a level of detail. The current approach addresses these concerns. The work required by this information need will be accomplished, but the requirements will not appear in the documents envisioned in the SCP. The generic requirements document discussed in the SCP has been superseded. The current requirements document hierarchy consists of the CRWMS Requirements Document (DOE, 1995j) (highest level), followed by an MGDS Requirements Document (DOE, 1996b) (next highest level), followed by two equal level documents, the Repository Design Requirements Document (DOE, 1994f) and the Engineered Barrier Design Requirements Document (DOE, 1995i). The revised requirements document hierarchy involves revising the first two documents to provide requirements generally written at a higher level than they are now. Requirements from the Repository Design Requirements Document and the Engineered Barrier Design Requirements Document will be incorporated at a higher level in the MGDS Requirements Document. When Revision 3 of the MGDS Requirements Document is approved, the two lower-level documents will be removed from Level 2 Change Control Board control. Below the0 OCRWM document hierarchy, system description documents, organized by systems, structures, and components, will be used to implement applicable requirements and criteria.

Design Activity 4.4.4.1: Repository design requirements for license application design (SCP Section 8.3.2.5.4.1)

Background and SCP Plans. This design activity developed the repository design requirements for use in license application design. The section described plans for updating the Repository Design Requirements Document (DOE, 1994f) before the initiation of license application design; the update would contain substantially more detail on waste handling operations, a single emplacement orientation, and the results of numerous design decisions made during advanced conceptual design.

Changes and Status. The update to the repository design requirements described in the design activity will be made in a manner generally consistent with that described. This update will actually occur in the MGDS Requirements Document (DOE, 1996b) and the system description documents mentioned in the discussion of Information Need 4.4.4.

Application of results (SCP Section 8.3.2.5.4.2)

Background and SCP Plans. The section stated that the principal users of information obtained for the associated information need would be designers responsible for developing reference designs for the repository and its seals. The section also provided a cross-reference to issues and information needs that would use the information.

Changes and Status. The Repository Design Requirements Document was originally planned to answer the issues and information needs identified when the SCP was written. However, these issues and information needs will now be addressed by the system description documents mentioned in the discussion of Information Need 4.4.4.

Information Need 4.4.5: Reference preclosure rep itory esign (SCP Section 8.3.2.5.5)

Background and SCP Plans. This information need was intended to result in development of a reference postclosure design. The section stated that the SCP-Conceptual Design Report (SNL, 1987) was the reference design when the SCP was written and described how the advanced conceptual design and license application design could build on this design. The section also discussed planned development of design reports, topical reports, tradeoff studies, etc. In the logic section, the information need listed 10 supporting activities requiring site data and 7 that do not require site data.

Changes and Status. The current approach to developing and documenting the reference postclosure design is consistent with that described in the information need, except that the design is not being documented in the Reference Information Base (DOE, 1995e). Instead, the design is being documented in various documents in the project baseline. The list of supporting activities mentioned in the SCP is being accomplished.

Application of results (SCP Section 8.3.2.5.5.1)

Background and SCP Plans. This section stated how the reference designs will be used and provided a cross reference to other information needs that would use the information.

Changes and Status. The current approach to developing and using the reference design is consistent with that provided in the SCP section.

Information Need 4.4.6: Development and demonstration of required equipment (SCP Section 8.3.2.5.6)

Background and SCP Plans. This information need was the focal point for the equipment development program. Four principal products were planned: a list of equipment, designs for unique equipment, the equipment itself, and demonstrations to establish capabilities of the equipment. The section described briefly how these products would be used. Specific site parameters needed were listed. The logic process listed a six-step approach to the development and demonstration of equipment. Six system-elements considered potential candidates for equipment demonstration were listed. Described were the development and demonstration of a prototype emplacement borehole boring machine and site data to support that demonstration.

Changes and Status. The four products in this information need are being developed, and they are being used as described in the information need. The site parameters listed are being addressed. The logic process provided in the information need is consistent with the current approach, with two exceptions. First, proof-of-principle tests for some potential types of emplacement equipment will be performed if determined necessary after the license application instead of before it. This change is not considered a problem because, with the change in emplacement concept, potential repository emplacement equipment is much simpler than equipment that would have been needed to support borehole emplacement. Proof-of-principle tests for some other equipment types and operations (e.g., bridge cranes and welding of waste packages) may occur before license application submittal. The second exception is that the development process and proof-of-principle tests will be documented in design analyses and the system description documents mentioned in the discussion of Information Need 4.4.4, instead of in a repository design plan and topical reports. The boring machine discussion no longer applies because the machine described is for excavating emplacement boreholes, which are not needed for horizontal-in-drift waste package emplacement. Accordingly, the tests planned to be conducted in the ESF for this equipment will not be performed. Similarly, different emplacement and retrieval equipment is now being considered to support in-drift emplacement. For normal conditions, retrieval equipment is assumed to be the same as emplacement equipment. The Project has successfully demonstrated use of a tunnel boring machine in the ESF at Yucca Mountain. Use of a roadheader in the ESF has met with limited success in the welded tuff at the repository level. The Project intends to let potential commercial manufacturers demonstrate the probable success of larger, more powerful roadheaders.

Application of results (SCP Section 8.3.2.5.6.1)

Background and SCP Plans. This section described how the equipment designs and performance would be used, including a cross reference to other information needs and issues.

Changes and Status. The Project plans to use equipment design and performance information in a manner consistent with that provided in the SCP section but modified by the equipment changes mentioned in the discussion of Information Need 4.4.6.

Information Need 4.4.7: Design analyses, including those addressing impacts of surface conditions, rock characteristics, hydrology, and tectonic activity (SCP Section 8.3.2.5.7)

Background and SCP Plans. This information need was the principal place where rock mechanics analyses, hydrologic analyses, and ventilation calculations were discussed. Table 8.3.2.5-15 listed products and studies to support this information need. Also listed were site parameters needed to perform the required analyses. Underground system elements that require structural analyses were discussed in detail, including discussions of understandings of the phenomena. Table 8.3.2.5-16 listed planned analyses. The information need stated that sensitivity analyses would be performed and discussed codes planned for use in analyses.

Changes and Status. The products, studies, and analyses planned in the SCP to address this information need are generally being developed. There have been, however, some significant changes resulting from changing from borehole emplacement to in-drift emplacement, which means in-drift emplacement equipment will be developed instead of borehole emplacement equipment. For the same reason, there will be no studies of emplacement borehole stability, borehole hydrology, and borehole liner compatibility, but similar studies will be conducted for in-drift emplacement. Other changes include a Project policy establishing a longer period of retrievability. The goal for retrieval is that all waste should be retrievable for 100 years after the beginning of emplacement (DOE, 1994a). This change was made because the Project has pursued a more focused approach that will include fewer studies than previously planned. The longer retrievability period will allow a longer period of performance confirmation and therefore increased confidence that the more limited scope of site characterization has provided adequate understanding of predicted site and repository performance. There has also been a change in ground support and lining strategy. The current concept in emplacement drifts is to install one robust ground support/liner system that is suitable for all ground classifications. This approach was chosen to simplify ground support design and reduce costs. This system would be installed immediately behind the tunnel boring machine. In all other excavations, temporary ground support compatible with the ground classification would be installed immediately behind the tunnel boring machine and a permanent liner would be installed later. Also, results of reference calculations will not be placed in the Reference Information Base (DOE, 1995e) for reasons mentioned in the discussion for Information Need 4.4.5. Sensitivity analyses are being used in manner consistent with the discussion in the information need; however, they are being performed for in-drift emplacement rather than for borehole emplacement. The codes currently being used or planned for use are consistent with the discussion of codes in the information need.

Application of results (SCP Section 8.3.2.5.7.1)

Background and SCP Plans. This section described how the information obtained for the associated information need would be used, including a cross-reference to other analysis areas.

Changes and Status. The Project plans to use information and analyses described in the associated information need in a manner consistent with that provided in the SCP section, with the exception of changes described in the preceding discussion for Information Need 4.4.7.

Information Need 4.4.8: Identification of technologies for surface facility construction, operation, closure, and decommissioning (SCP Section 8.3.2.5.8)

Background and SCP Plans. This information need evaluated the effectiveness of site elements that affect design, construction, and operations of the repository facilities during the preclosure period. Four criteria would be used for this purpose. The section described the product of the information need and listed site parameters required to be addressed to support the information need. Finally, the logic process intended to be used was described; the discussion included then-current understandings of the important processes and phenomena affecting the information need

Changes and Status. The Project is using the four evaluation criteria provided in the information need to address the information need. The identified site parameters are being addressed. The logic process described in the information need and the understandings contained in the discussion are current. However, results will be documented in design analyses and system description documents instead of in the repository design plan and in topical reports. Also, there will not be a separate license application design report because the information that it would contain will be an integral part of the license application documentation.

Application of results (SCP Section 8.3.2.5.8.1)

Background and SCP Plans. This section described how the information obtained for the associated information need would be used, including a cross reference to other analysis areas.

Changes and Status. The Project plans to use information and analyses described in the associated information need in a manner consistent with that provided in the SCP section.

Information Need 4.4.9: Identification of technologies for underground facility construction, operation, closure, and decommissioning (SCP Section 8.3.2.5.9)

Background and SCP Plans. This information need constituted the assessment that all aspects of the underground facility could be constructed, operated, closed, and decommissioned using reasonably available technology. The assessment was to be included in a summary chapter of the documents that define the reference postclosure repository designs. A list of parameters needed, organized by system elements, was provided. The information need also described the logic process for addressing the information need, organized by system element.

Changes and Status. The approach to addressing the information need is generally consistent with that described. The list of parameters and the understandings and plans in the logic process are also generally valid. As stated in the previous discussion on Information Need 4.4.6, equipment demonstrations will occur after the license application is developed, not before as planned in the SCP. There will be no equipment development for borehole emplacement, but there will be comparable work for in-drift emplacement. The SCP conclusion that no additional work is needed to develop a rock handling system is still valid, even though the excavation will no longer be predominantly by blasting. Rock handling methods for excavation by tunnel boring machine were adequately demonstrated in the ESF. Documentation of the results will be in design analyses and the system description documents mentioned in the discussion for Information Need 4.4.4 instead of in topical reports as planned in the SCP. Also, there will not be a separate license application design report because the information that it would contain will be an integral part of the license application documentation.

Application of results (SCP Section 8.3.2.5.9.1)

Background and SCP Plans. This section described how the information obtained for the associated information need would be used, including a cross reference to other analysis areas.

Changes and Status. The Project plans to use information and analyses described in the associated information need in a manner consistent with that provided in the SCP section.

Information Need 4.4.10: Determination that the seals for shafts, drifts, and boreholes can be placed with reasonably available technology (SCP Section 8.3.2.5.10)

Background and SCP Plans. This information need would determine if reasonably available technology was available for emplacing shaft, drift, and borehole seals. A series of evaluations was planned. Summaries of the results would be provided in major design reports, and topical reports would be developed. Parameters needed to satisfy the information need were listed, and the logic process for obtaining the information discussed.

Changes and Status. The approach currently being taken to addressing this information need is consistent with that described in the information need, including the parameters and the logic process described. The only difference is the results will be documented in design analyses and the system description documents mentioned in the previ discussion for Information Need 4.4.4 instead of in topical reports as planned in the SCP. Al o, there will not be a separate license application design report because the information that it would contain will be an integral part of the license application documentation.

Application of Results (SCP Section 8.3.2.5.10.1)

Background and SCP Plans. This section described how the information obtained for the associated information need would be used.

Changes and Status. The Project plans to use information and analyses described in the associated information need in a manner consistent with that provided in the SCP section.

Schedule for preclosure design and technical feasibility (SCP Section 8.3.2.5.11)

Background and SCP Plans. This section of the SCP provided a schedule for addressing Information Needs 4.4.1 through 4.4.10. Table 8.3.2.5-18 described major events and provided planned completion dates.

Changes and Status. The schedule for obtaining information for key activities has been revised as described in the semiannual progress reports. This method of documenting changes is consistent with the text in the SCP section. The Project has not, however, undertaken to ensure the schedule revisions for all the specific items in Table 8.3.2.5-18 are included in the progress reports. The schedules presented in the 1988 SCP were based on the DOE's June 1987 Mission Plan Amendment (DOE, 1987a and 1987b), which assumed the license application for the repository would be submitted to the NRC in 1995. In 1989, the Secretary of Energy assessed the progress and needs of the site characterization program, and a new schedule was adopted that delayed license application submittal to 2001. The program plan (DOE, 1994a) supporting the 2001 submittal, which was issued in December 1994, contains a schedule for accomplishing major Program activities, but it does not explicitiv revise the schedule for all SCP activities and studies. Scheduled completion dates for SCP activities may be further revised as a result of new developments in the site characterization program, changes in Program priorities, or changes in funding profiles. These changes will be discussed, as appropriate, in future progress reports; the Project, however, does not plan to necessarily address how and why each SCP schedule item has changed.

A.3 SEAL PROGRAM (SCP SECTION 8.3.3)

A.3.1 Introduction

When the SCP (DOE, 1988) was written, seals for boreholes, shafts, ramps, and emplacement drifts were considered to be of potentially great importance to repository performance. Accordingly, an entire SCP section (8.3.3) was devoted to seals.

The Project's current approach to investigating seal issues is generally consistent with the approach presented in the SCP. However, current understanding of site processes and performance indicates that seal performance is not as significant an issue for overall repository performance as was believed when the SCP was written. Two factors have contributed to the Project decision to deemphasize seals: (1) the increase in thermal loading since the SCP was written, which lessens the potential for water to enter the drifts, and (2) preliminary results from total system performance assessments, which indicated acceptable performance was possible without accounting for the benefits from seals. Therefore, seal design and issue investigation have received a relatively low priority to date.

For the advanced conceptual design, the Project summarized previous seal work and established a seal design consisting of shafts, ramps, and boreholes, as well as backfill of all underground openings except emplacement drifts.

The studies and analyses described in the SCP will generally be performed to more definitively determine the need for and appropriateness of seals in various repository applications. Plans for specific investigations are described in the material that follows.

A.3.2 Summary of Changes in Seal Program

This section discusses in order each section contained in Section 8.3.3 of the SCP—the section that outlined the seal program. First, appropriate background is provided and SCP plans are given. Then the changes that have occurred since the SCP was written are discussed and the current Project status outlined. In this discussion, references to sections, tables, and figures are to the SCP unless otherwise stated.

Seal program (SCP Section 8.3.3)

Background and SCP Plans. This section described the activities necessary to develop seal designs and demonstrate seal performance. A one-page discussion that described what was contained in following sections.

Changes and Status. A separate status on this introductory section is not needed.

Overview of the seal program (SCP Section 8.3.3.1)

Background and SCP Plans. This section provided a general discussion of the seal program planned, including the planned timing for seal testing, development, and installation. The section described planned seal testing activities, and Figure 8.3.3.1-1 provided planned sequencing of seal activities.

Changes and Status. The presently planned approach to seal testing and installation is consistent with the approach described, including activity sequencing and planned testing. Testing during site characterization activities, however, is currently in abeyance until a better determination of the need for seals is made.

Seal environment (SCP Section 8.3.3.1.1)

Background and SCP Plans. This section described the aspects of the site environment important to seal performance. Listed was example information needed for design and evaluation of seals.

Changes and Status. The current understanding of the site environment as applicable to seal performance is consistent with that presented in this section. Plans list to obtain the information shown in the section as being needed.

Seal components (SCP Section 8.3.3.1.2)

Background and SCP Plans. This section contained a detailed discussion of seal components and described important properties for prospective seal materials. The section stated that cementitious and clay materials have a high probability of creating acceptable seals and discussed supportive test results.

Changes and Status. The current understanding of seal components is consistent with that described in the SCP section.

Seal designs (SCP Section 8.3.3.1.3)

Background and SCP Plans. This section cross referenced other SCP sections and the SCP-Conceptual Design Report (SNL, 1987) for seal designs current when the SCP was written. The section states that the advanced conceptual design and the license application design would be the next two phases in seal design. Planned studies and evaluations to support seal design are discussed.

Changes and Status. For the advanced conceptual design, the Project summarized previous seal work and established seal design to consist of seals in shafts, ramps, and boreholes, as well as backfill of all underground openings except emplacement drifts. The studies and analyses described in the SCP section will be performed in order to more definitively determine the need for and appropriateness of seals in various repository applications.

Seal modeling (SCP Section 8.3.3.1.4)

Background and SCP Plans. This section briefly described the planned use of models and codes to support performance evaluations of seals.

Changes and Status. The planned approach to modeling seal performance is consistent with that provided in the SCP section.

Issue resolution strategy for Issue 1.12: Have the characteristics and configurations of the shaft and borehole seals been adequately established to (a) show compliance with the postclosure design criteria of 10 CFR 60.134 and (b) provide information for the resolution of the performance issues? (SCP Section 8.3.3.2)

Background and SCP Plans. This section described how all seals for the repository would be addressed, provided the approach to resolving the issue, and demonstrated the approach graphically in Figure 8.3.3.2-1. Figure 8.3.3.2-2 showed the potential sealing subsystem, seal locations, and seal components. Table 8.3.3.2-1 showed functions, processes, material properties, performance measures, tentative design goals, and needed confidence. Table 8.3.3.2-2 described general design constraints to be passed to Issue 1.11. Table 8.3.3.2-3 described site parameters, goals, confidence, etc., to support resolution of Issue 1.12. Table 8.3.3.2-4 listed miscellaneous information needed to resolve Issue 1.12. Table 8.3.3.2-5 showed design basis performance goals for the sealing subsystem.

Changes and Status. The current approach to addressing the seal issue is consistent with that provided in this SCP section. The parameters to be addressed in the tables are being addressed. The tentative design goals listed are being reevaluated for compatibility with the latest repository configuration and operations concepts. The performance goals described in the SCP are not being addressed because of the relatively low priority placed on seal performance and the expectation that regulations pertinent to seals are likely to change. When the regulations are established and an approach for seal performance assessment is developed for use in total system performance assessment, appropriate goals will be developed for seal performance.

Information Need 1.12.1: Site, waste package, and underground facility information needed for design of seals and their emplacement methods (SCP Section 8.3.3.2.1)

Background and SCP Plans. This information need was intended to obtain site, waste package, and underground facility data needed for seal design. The section discussed the parameters listed in this discussion of Issue 1.1.2 (SCP Section 8.3.3.2) in some detail, including understandings current at the time the SCP was written. Finally, the logic process applicable to addressing the information need was described.

Changes and Status. The current approach to obtaining information to support seal design is consistent with that described, including parameters to be addressed and the logic process planned for use.

Application of results (SCP Section 8.3.3.2.1.1)

Background and SCP Plans. This section stated how the data obtained for the associated information need would be used.

Changes and Status. The Project plans to use the information obtained for this information need as described in the SCP section.

Information Need 1.12.2: Materials and characteristics of seals for shafts, drifts, and boreholes (SCP Section 8.3.3.2.2)

Background and SCP Plans. This information need described how seal materials would be developed, described what general types of information would be needed, and stated that parameters needed were covered in the discussion of Issue 1.12 (SCP Section 8.3.3.2). Testing plans were described in the information need. Table 8.3.3.2-6 listed potentially important seal component properties and why information on them was needed. This investigation was intended to collect information to confirm the geochemistry of the ground waters and rock units at the repository horizon. This information would be used to confirm the predicted effects on seal materials, especially those associated with elevated temperatures, caused by the emplacement of waste in the repository. This information was needed to ensure that the design for seals was compatible with the geochemical conditions under ambient and elevated temperature conditions. Laboratory t[illegible] determine material properties, establishing of hydraulic conductivity of various seals [illegible]ls and consolidation testing of crushed tuff, and in situ testing to evaluate seals under realistic conditions would be conducted to address Information Need 1.12.2.

Changes and Status. The approach to determining seal materials characteristics is consistent with that provided in the information need, including information needed and plans for testing. The objective has not changed since the SCP was issued, but the data needed to resolve this information need have not yet been obtained. The initial effort to establish the technical basis for developing seal designs for the sealing program, using on preliminary site geohydrologic data, has been documented (Fernandez et al., 1987). The specific objectives of this comprehensive study were to develop performance goals, to assess the need for seals, to develop design requirements, and to recommend potential sealing materials for the sealing system. A second report (Fernandez et al., 1993) discussed the field testing program and technical rationale for consideration in adopting a sealing strategy for site characterization boreholes and underground access ways. The report also discussed objectives and plans for a seal testing program consistent with the results of the evaluation of design, performance assessment, and regulatory requirements. From these studies, any additional tests necessary to meet performance objectives will be determined. Numerous tests have been conducted to derive a degradation model for cementitious materials emplaced in a tuffaceous environment. Some of these tests included hydrothermal experiments on samples of high-silica concrete and grout, numerical analysis to simulate the products of the laboratory experiments, and analysis to determine volumetric changes accompanying the reaction of cements and UE-25 J#13 water. During FY 1997 systems engineering studies are planned to evaluate design, performance assessment, and regulatory requirements (including State and Federal) for sealing boreholes, shafts, and ramps. Systems engineering studies will also evaluate specific requirements for an abandonment plan for the surface-based drilling program, summarize and report these requirements, and evaluate the need for additional laboratory seal material properties and performance tests and in situ seals tests. In addition, objectives and plans for a seal testing program will be developed consistent with the results of the evaluation of design, performance assessment, and regulatory requirements. From these studies, any additional tests necessary to meet performance objectives will be identified.

Study 1.12.2.1: Seal material properties development (SCP Section 8.3.3.2.2.1)

Background and SCP Plans. The SCP contained no discussion under this heading.

Changes and Status. Not applicable.

Activity 1.12.2.1.1: Detailed property determination of cementitious-based and earthen materials (SCP Section 8.3.3.2.2.1.1)

Background and SCP Plans. This activity was to initiate laboratory testing to determine material properties for seal components. General testing plans were described.

Changes and Status. This activity is contained in Study Plan 8.3.3.2.2.1, "Seal Materials Properties Development." That document is in agreement with the work expected as described in the SCP.

Activity 1.12.2.1.2: Hydraulic conductivity and consolidation testing of crushed tuff (SCP Section 8.3.3.2.2.1.2)

Background and SCP Plans. This activity established the hydraulic conductivity and consolidation behavior of crushed tuff to support development of criteria for shaft and drift backfill. General test plans were described.

Changes and Status. This activity is contained in Study Plan 8.3.3.2.2.1, "Seal Materials Properties Development." That document is in agreement with the work expected as described in the SCP.

Design Activity 1.12.2.2: A degradation model for cementitious materials emplaced in tuffaceous environment (SCP Section 8.3.3.2.2.2)

Background and SCP Plans. This activity was to develop a degradation model to provide insight into how material properties of seal components, especially permeability and strength, could alter after being in contact with tuff. General test plans were described.

Changes and Status. Future work in this area will depend upon future systems studies to determine the needs and functions of seals.

Study 1.12.2.3: In situ testing of seal components (SCP Section 8.3.3.2.2.3)

Background and SCP Plans. This study was to initiate in situ testing to evaluate seal component behavior. The process was presented for determining the need for in situ testing (the last two steps of which were incomplete when the SCP was written). The section referred to the discussion on Issue 1.12 (SCP Section 8.3.3.2) for properties needed and provided a discussion of site properties needed for addressing Issue 1.12. Discussed were the adequacy of data needed, emplacement concerns, and details of possible tests and studies.

Changes and Status. The contents of Study Plan 8.3.3.2.2.3, "In Situ Testing of Seal Components" are generally in agreement with the work expected as described in the information need. This work is currently unfunded, and future work scopes will depend upon future systems studies to determine the needs and functions of seals.

Application of results (SCP Section 8.3.3.2.2.4)

Background and SCP Plans. This section stated how information obtained for the associated information need would be used.

Changes and Status. The approach is consistent with the SCP section.

Information Need 1.12.3: Placement method for seals for shafts, drifts, and boreholes (SCP Section 8.3.3.2.3)

Background and SCP Plans. This information need would develop the placement method for seals for drifts, shafts, and boreholes. Listed are specific parameters of interest and the logic process expected to be needed to address the information need.

Changes and Status. The present approach is consistent with the approach presented in the information need, including parameters needed and the logic approach.

Application of results (SCP Section 8.3.3.2.3.1)

Background and SCP Plans. This SCP section stated how information obtained for the associated information need would be used.

Changes and Status. The approach is consistent with the SCP section.

Information Need 1.12.4: Reference design of seals for shafts, drifts, and boreholes (SCP Section 8.3.3.2.4)

Background and SCP Plans. This information need would provide the reference design for seals. Parameters needed are those described in Information Need 1.12.1 The information need also provided the logic process planned for the seal design effort.

Changes and Status. The current approach to seal design is consistent with the approach provided in the information need.

Design Activity 1.12.4.1: Development of the advanced conceptual design (ACD) for sealing (SCP Section 8.3.3.2.4.1)

Background and SCP Plans. This SCP section contains no text.

Changes and Status. Status is not required.

Design Subactivity 1.12.4.1.1: Define subsystem design requirements (SCP Section 8.3.3.2.4.1.1)

Background and SCP Plans. The objective of this subactivity was to develop design requirements for seal components. The activity included seven tasks planned to support this effort.

Changes and Status. To date, little design work has been funded and performed on repository seals. A preliminary seal design was presented in the MGDS Advanced Conceptual Design Report (CRWMS M&O, 1996b). That design was adapted from the one shown in the SCP Conceptual Design Report (SNL, 1987) by considering changes made to the layout since then. Because advanced conceptual design is complete, all work under this design activity is now closed. Uncompleted work will be performed to support the viability assessment and later as part of license application design.

Design Subactivity 1.12.4.1.2: Perform trade-off studies to support advanced conceptual design development (SCP Section 8.3.3.2.4.1.2)

Background and SCP Plans. This subactivity provided technical justification for selection of seal design options. The section explained the intended focus of advanced conceptual design work in this area, including seven planned trade-off studies.

Changes and Status. Seal trade-off studies per se were not performed as part of advanced conceptual design because of their relatively low priority. Two factors have contributed to a Project decision to reduce emphasis and overall funding for seals-related work: (1) the increase in thermal loading since the SCP was written, which lessens the potential for water to enter the drifts, and (2) preliminary results from total system performance assessments that indicated acceptable performance was possible without accounting for the benefits from seals. Some aspects of the Engineered Barrier System Performance Requirements Systems Study (CRWMS M&O, 1996bb) are also applicable to this issue. Because advanced conceptual design is complete, all work under this design activity is now closed. Additional trade-off studies will be performed as determined necessary to support the viability assessment and later as part of license application design.

Design Subactivity 1.12.4.1.3: Develop advanced conceptual design for seals (SCP Section 8.3.3.2.4.1.3)

Background and SCP Plans. This subactivity provided design details that could be used to support license application design and performance assessment activities. The section stated that the advanced conceptual design would summarize the results of trade-off studies and described some specific information to be included.

Changes and Status. The MGDS Advanced Conceptual Design Report presented the seal design, but it did not summarize all the information described in the subactivity because little or no design work has been done on seals since the SCP-Conceptual Design Report was written. The advanced conceptual design for seals was adapted from the design in the SCP-Conceptual Design Report by considering changes made to the repository layout since then. Because advanced conceptual design is complete, all work under this design activity is now closed. Additional seals design will be performed to support the viability assessment and later as part of license application design.

Design Activity 1.12.4.2: Development of the license application design for sealing (SCP Section 8.3.3.2.4.2)

Background and SCP Plans. This SCP section contained no technical text.

Changes and Status. No status is required.

Design Subactivity 1.12.4.2.1: Define subsystem design requirements (SCP Section 8.3.3.2.4.2.1)

Background and SCP Plans. This subactivity refined design requirements for sealing components to support license application design.

Changes and Status. Work not performed under seals advanced conceptual design will be performed as part of the viability assessment and later as part of license application design. The exact scope of future work will depend upon future systems studies to determine the needs and functions of seals. The systems studies are expected to encompass the work scope described in the SCP, and determine how seals relate to the selected repository thermal strategy. Exact timing of the studies will depend on available funding.

Design Subactivity 1.12.4.2.2: Perform trade-off studies to support license application design development (SCP Section 8.3.3.2.4.2.2)

Background and SCP Plans. This subactivity provided technical justification for the selection of final seal designs. Several planned trade-off studies were listed.

Changes and Status. Trade-off studies, as expected in the SCP, will be performed as part of the viability assessment and later as part of license application design.

Design Subactivity 1.12.4.2.3: Develop license application design for seals (SCP Section 8.3.3.2.4.2.3)

Background and SCP Plans. This subactivity provided the license application design for seals. Described were four activities to support this task.

Changes and Status. Seal design will be developed as part of the viability assessment and later as part of license application design. The approach to be taken is expected to be consistent with that described in the subactivity.

Application of results (SCP Section 8.3.3.2.4.3)

Background and SCP Plans. This section described how information obtained to address the associated information need will be used.

Changes and Status. The Program plans to use seal information obtained to support this information need in a manner consistent with that provided in the SCP section.

Schedule for seal characteristics (Issue 1.12) (SCP Section 8.3.3.2.5)

Background and SCP Plans. This section of the SCP provided a schedule for addressing studies and design activities related to sealing. Table 8.3.3.2-10 described major events and provided planned completion dates.

Changes and Status. The schedule for obtaining information for key activities has been revised as described in the semiannual progress reports. This method of documenting changes is consistent with the text in the SCP section. The Project has not, however, undertaken to ensure the schedule revisions for all the specific items in Table 8.3.3.2-10 are included in the progress reports. The schedules presented in the 1988 SCP were based on the DOE's June 1987 Mission Plan Amendment (DOE, 1987a and 1987b), which assumed the license application for the repository would be submitted to the NRC in 1995. In 1989, the Secretary of Energy assessed the progress and needs of the site characterization program, and a new schedule was adopted that delayed license application submittal to 2001. The program plan (DOE, 1994a) supporting the 2001 submittal, which was issued in December 1994, contains a schedule for accomplishment of major Program activities, but it does not explicitly revise the schedule for all SCP activities and studies. Scheduled completion dates for SCP activities may be further revised as a result of new developments in the site characterization program, changes in Program priorities, or changes in funding profiles. These changes will be discussed, as appropriate, in future progress reports; the Project, however, does not plan to necessarily address how and why each SCP schedule item has changed.

A.4 WASTE PACKAGE PROGRAM (SCP SECTION 8.3.4)

A.4.1 Introduction

The Project's waste package design has changed substantially from the design concepts described in the SCP (DOE, 1988). Most changes to the design that have occurred have been caused by the change from a thin-wall, borehole-emplaced waste package to a thick-wall, in-drift-emplaced waste package. This change was driven in part by DOE goals for earlier waste acceptance. In addition, the robust waste packages currently planned are believed to have many performance and cost advantages over the packages envisioned in the SCP. Large, robust waste packages would allow fewer waste packages to be built and emplaced, would require a smaller total number of welds, would have thicker walls to attenuate radiation, and would have greater mechanical strength than would the containers envisioned in the SCP. The robust, multibarrier packages would provide significantly longer containment than would the original thin-wall concept.

Emplacing waste packages in drifts is also expected to have significant performance and cost advantages over borehole emplacement. Drift emplacement would allow the packages to radiate heat to a larger area and thus would help control maximum temperatures. A severe seismic event with shear displacements in the repository horizon would be less likely to damage drift-emplaced waste containers. Drift emplacement would simplify emplacement operations and would maintain flexibility of thermal loading because waste packages could be spaced as needed along the drift. Boreholes appear to have a greater tendency to accumulate ground water and to confine the products of degradation.

Although the waste package design concept has changed substantially, the approaches embodied in the issue resolution strategies described in the SCP have not changed significantly. A more detailed discussion of how and why the waste package and emplacement concepts have changed can be found in the discussion of 8.3.4 that follows.

The Project's approach to investigating the near-field environment is also generally consistent with the approach described in the SCP, but the studies and activities described in the SCP have been reorganized. Although the currently planned work scope is similar to that planned in the SCP, one study was split into two studies, and numerous activities under the various studies have been canceled and superseded by new studies. These changes were made during the progress of site characterization for several reasons. In some instances, the changes reflected improved understanding of what information is needed to support performance assessment. In other instances, changes were made for convenience in organizing the work. The near-field discussions in this section provide a cross reference between the SCP studies and activities and the current studies and activities.

The following sections explain how the Project plans to implement the SCP with regard to designing the waste package and obtaining an understanding of the near-field environment to support performance assessment and ensure the environment does not compromise the ability of the waste package to perform its design functions.

A.4.2 Summary of Changes in the Waste Package Program

This section discusses in order each section contained in Section 8.3.4 of the SCP—the section that outlined the waste package program. First, appropriate background is provided and SCP plans are given. Then the changes that have occurred since the SCP was written are discussed and the current Project status outlined. In this discussion, references to sections, tables, and figures are to the SCP unless otherwise stated.

Waste package program (SCP Section 8.3.4)

Background and SCP Plans. This section described the general strategy for waste package development and demonstration of postclosure compliance. The strategy was shown graphically in Figure 8.3.4-1.

Changes and Status. The strategy remains largely intact, and performance is still allocated to the waste package and other components of the engineered barrier segment. The following changes have occurred. The waste package program is now governed by the revised draft Program Plan (DOE, 1996a). Assumptions about water quality made in the SCP have been modified because of advances in understanding of the environment; the current assumptions are that introduced materials and thermal effects can result in large changes in near-field water chemistry (Wilder, 1996). Container materials have been chosen for use in the viability assessment design (CRWMS M&O, 1996y), but testing will continue on a variety of corrosion resistant and corrosion allowance metals, as well as alternative container materials. Performance is still allocated not only to the containment barriers but also to the waste form and "engineered environment." "Engineered environment" means the components of the engineered barrier segment other than the waste package. Performance allocation to spent nuclear fuel cladding is being considered.

Throughout this section and its subsections, there are references to small, thin-walled, single-barrier waste packages that will be emplaced in vertical boreholes. The current approach is to use large, thick-walled, multibarrier waste packages that will be emplaced in drifts (CRWMS M&O, 1996b). This change will not be repeated in the discussions of lower-level SCP sections that follow unless there are ramifications for other aspects of the discussion.

Using large, thick-walled, multibarrier waste packages emplaced in drifts has many advantages over the packages envisioned in the SCP. Large packages would have a smaller surface area to volume ratio, so more costly materials and/or thicker layers could be used in the containment barriers without as great an effect on overall repository cost. With large waste package capacities, the number of packages would be reduced, so there would be fewer closure welds to be made and inspected. Thick container walls would absorb radiation, making the packages easier to handle by reducing measures required for radiation protection and reducing the effects of radiolysis on the near-field environment. Thick walls would also provide greater mechanical strength in the event of a handling accident. Multiple barriers reflect the defense-in-depth concept and allow the designer to choose different and complementary materials that provide longer containment over a wide range of conditions.

Emplacing waste packages in drifts is also expected to have significant advantages. Overall repository excavation costs are expected to be lower because boreholes are not necessary. Drift emplacement would allow the packages to radiate heat to a larger area, and thus would help control maximum temperatures. A severe seismic event with shear displacements in the repository horizon would be less likely to damage drift-emplaced waste containers than borehole-emplaced containers because drift emplacement provides extra clearance between the containers and the drift wall. Drift emplacement would simplify emplacement operations and would maintain flexibility of thermal loading, because packages could be spaced as needed along the drift. Finally there would be fewer concerns about corrosion and criticality. Compared with drifts, boreholes appear to have a greater tendency to accumulate ground water and to confine the products of degradation.

Overview (SCP Section 8.3.4.1)

Background and SCP Plans. This section described three issues related to waste package development. Relationships between design- and performance-related issues used in performance allocation were discussed and presented graphically in Figure 8.3.4.1-1.

Changes and Status. The issues described in the SCP section remain central to current efforts. In spite of design changes, current plans are to have minimal ventilation under normal operating conditions and no backfill in emplacement drifts, so the waste package environment would not depend strongly on whether the repository is operational or closed. This assumption is consistent with that presented in the SCP section. Backfill, however, is still under consideration as an option Interaction of Issues 1.10, 2.6, and 4.3 with other issues is still as described in Figure 8.3.4.1-1. Issue 1.10 is still the only waste package design issue that involves the acquisition of site characterization data.

Waste package environment (SCP Section 8.3.4.1.1)

Background and SCP Plans. This section described in general terms the environment into which the waste package would be placed and the expected effect of the waste package on that environment. The section summarized the understandings of the environment current at the time the SCP was written.

Changes and Status. When the SCP was written, limited collapse of boreholes around the waste packages was expected and thus limited stresses from rockfall, although an oxidizing environment was clearly expected. Emplacement drifts are now expected to collapse eventually, and substantial loading by rock impact is possible. Questions have been raised about the assumption that the vadose water will be similar to UE-25 J#13 water, but water from the repository horizon is still not available. Thermal goals are still in effect (CRWMS M&O, 1996c), but the goals have been modified to reflect changed designs. Attempts are being made to use heat to reduce the aggressiveness of the environment.

Waste package components (SCP Section 8.3.4.1.2)

Background and SCP Plans. This section described considerations of waste package designs and discussed in very general terms the waste expected to be emplaced.

Changes and Status. The waste packages envisioned by the authors of the SCP were smaller and generally simpler than those of current designs. The general thrust of waste package design has changed because of ongoing efforts to provide long containment at a reasonable cost. Major changes as a result of these efforts were the planned use of a thick-walled, more robust waste container, and larger waste packages that could accommodate more waste. Current designs also add a second containment barrier, a basket and basket guides in disposal containers for spent nuclear fuel, and a canister guide in disposal containers for waste glass. DOE-owned spent fuel has been added to the Project baseline, and a waste package that would contain both waste glass and DOE-owned spent fuel is being designed. Various additional components may be needed to accommodate DOE-owned spent fuel. Rod consolidation at the repository is no longer in the baseline (CRWMS M&O, 1996c). Aggressive conditions are now accommodated by using thick-walled, multibarrier containers that include a highly corrosion-resistant barrier. Alternative materials are also still under consideration. Also see the previous discussion of the waste package program (SCP Section 8.3.4).

Waste package designs (SCP Section 8.3.4.1.3)

Background and SCP Plans. This section briefly described the general approach planned to be taken in designing the waste package, including understandings current at the time the SCP was written and objectives for the design work. The section emphasized efforts in designing for mechanical loads and containment.

Changes and Status. Current work continues to address the concerns noted in the SCP section, but emphasis on thermal design, long-term criticality control, and shielding has been substantially increased. In the current design approach, requirements have been placed on the handling loads that the waste packages must sustain (CRWMS M&O, 1996c), but the packages are so strong that there is little effect on design. Requirements for containment by the waste package under accident conditions have been quantified (CRWMS M&O, 1996c). Current goals for containment are more stringent (CRWMS M&O, 1996c) than those described in the SCP, in that containment is to be provided for 1000 years. This change was made because of Program emphasis on very long containment.

Waste package modeling (SCP Section 8.3.4.1.4)

Background and SCP Plans. This section briefly described the planned approach to waste package modeling in support of design and performance assessment.

Changes and Status. Waste package modeling has changed to the extent required by changes in design; notably, analyses of borehole failure have been replaced by analyses of rockfall. (See the previous discussion of the waste package program (SCP Section 8.3.4).)

Processes included in postclosure modeling are essentially unchanged from those described in the SCP. Some processes, such as radionuclide transport within the waste package, will be modeled at a higher (bounding) level of abstraction than was planned in the SCP because of the complexity of flow in a flooded, partially degraded waste package.

Issue resolution strategy for Issue 1.10: Have the characteristics and configurations of the waste packages been adequately established to (a) show compliance with the postclosure design criteria of 10 CFR 60.135 and (b) provide information to support resolution of the performance issues? (SCP Section 8.3.4.2)

Background and SCP Plans. This section provided the overall strategy for dealing with two aspects of waste package postclosure behavior. The first is related to waste package properties and interactions with the environment; the second is testing and analysis to support performance assessment. The section presented the proposed approach to addressing these issues, both in text and graphically in Figure 8.3.4.2-1. Figure 8.3.4.2-2 demonstrated the proposed approach to modeling. Table 8.3.4.2-1 presented model hierarchy and model inputs for the issue, including needed confidence. Table 8.3.4.2-2 presented performance measures tentative goals, and needed confidence for addressing the issue. Table 8.3.4.2-3 presented performance parameters and goals for the issue. Table 8.3.4.2-4 provided a list of input parameters for characterization models for the issue. The section also discusses a design envelope for the waste package that included eight considerations. Design goals were discussed for each consideration. A list of limits to alteration of water chemistry was also provided.

Changes and Status. Although the general approach described in this section is still applicable, numerous details of its application have changed. The structure of the model hierarchy for Issue 1.10 is generally still valid, but "Borehole Stability" (Figure 8.3.4.2-2) has been replaced by "Drift Stability" because of changes in design emplacement mode. In addition, synergistic effects (such as galvanic protection of one containment barrier by another) are now thought to have substantial effects on performance, but these effects were not evident from the model hierarchy. Effects of waste package degradation on criticality control were also missing from the hierarchy. Model inputs for Issue 1.10 in Table 8.3.4.2-2 are largely unchanged. Changes in design have required substantial changes i performance measures, parameters, and goals. Design basis loads for rock fall in Table 8.3.4.2-2 have not yet been determined. Tectonic processes are of little importance for drift emplacement, and the separate goal in Table 8.3.4.2-2 for containers breached by tectonic processes is no longer in effect. Waste package materials have been selected for use in the viability assessment design (CRWMS M&O, 1996y). Requirements have been set for the mechanical strength of the waste package (CRWMS M&O, 1996c). Goals for loads on waste packages (shown in Table 8.3.4.2-3) are no longer in effect because drift emplacement provides little control over such loads.

No longer in effect is the goal that the vadose water should remain similar to that in the undisturbed environment because emplaced materials and thermal effects are thought to cause significant changes in water chemistry, regardless of the thermal load. The quantity of water that contacts the waste packages may be large for a few packages, contrary to the SCP assumption. The current list of input parameters for models of containment and release is still being developed based on testing data. Constraints on drift stability are now driven mostly by retrievability considerations. Current waste package design constraints are more closely related to providing long containment to control release of radionuclides than the SCP predicted. This approach has been taken because, when waste forms are isolated from the atmospheric environment of an unsaturated repository for an extended period of time, fission product decay histories result in lower releases of radioactivity when the waste packages are eventually penetrated. (See the previous discussion of waste package environment (SCP Section 8.3.4.1.1.) Lateral inhomogeneity may occur at such a fine scale that separation of the site into regions as suggested in the SCP section may be impractical; for example, one waste package may have a large water flux while its neighbors have small fluxes. Percolation rate and flow paths are still thought to be vital to performance. Recent investigators have given a variety of percolation rates; quantitative predictions in the SCP for water flux are for an obsolete design; ground-water focusing (rather than diversion as discussed in the SCP) is postulated to occur because of the disturbance of the host rock during excavation. Design goals in the SCP section for water flux control are no longer in effect because of the difficulty of predicting and controlling fluxes over long times, but fluxes are expected to be small. SCP design goals for drainage of emplacement boreholes are no longer in effect because of changes in design emplacement mode. SCP design goals for rock-induced load on the waste package are no longer in effect because the emplacement mode has changed, but efforts are ongoing to specify design basis rock falls applicable to the in-drift mode currently under consideration. Design goals for thermal loading have been modified; the emphasis is now on using decay heat to keep containers dry as long as possible rather than for an arbitrary period of 300 years as specified in the SCP because of Project emphasis on very long containment. The SCP goal of characterizing the inventory of primary radionuclides to within ±20 percent is no longer in effect because the goal is considered inappropriately stringent. Related goals of using decay heat to provide a benign environment and of controlling criticality will have a similar effect.

Selection criteria are being used in place of SCP design goals for container materials (CRWMS M&O, 1996y). Several candidate materials have been considered for each waste package component, and the performance of these materials has been compared. Use of selection criteria is expected to provide an equivalent design benefit as would be obtained through use of design goals. The design goal for uniform oxidation and corrosion of container materials is no longer in effect because it is not applicable to a multibarrier design that incorporates a corrosion-resistant barrier. The SCP design goal for fabrication is still in effect; corrosion tests will include welded samples. SCP design goals for handling that limit impact loads and scratch depth are considered excessively stringent for the current, thick-walled waste container design, so it may be appropriate to relax the limits on the distance of fall or depth of scratch that can be tolerated. SCP design goals for the borehole liner are no longer applicable because current designs do not include this component. Limits to alteration of water chemistry are no longer in effect. Current designs use a full concrete lining for emplacement drifts, which could easily produce changes in pH that exceed the prescribed limit. However, these changes are expected to promote long containment because high values of pH (to a point) tend to result in low corrosion rates for carbon steel

Information Need 1.10.1: Design information needed to comply with postclosure criteria from 10 CFR 60.135(a) for consideration of the interactions between the waste package and its environment (SCP Section 8.3.4.2.1)

Background and SCP Plans. This information need was intended to show that relevant environmental factors would be considered in waste package desig[illegible]. The section provided a list of parameters to be addressed and briefly stated the logic planned to be used.

Changes and Status. The current Program approach is consistent with that described in the information need, including the list of parameters and the logic. The list of factors from 10 CFR 60.135(a)(2) is incomplete, but the missing parameters may be addressed in the future.

Design Activity 1.10.1.1: Consideration of 10 CFR 60.135(a) factors (SCP Section 8.3.4.2.1.1)

Background and SCP Plans. This design activity was intended to explicitly show that the factors specified in 10 CFR 60.135(a) and listed as parameters in the associated information need would be considered in waste package design.

Changes and Status. The current Program approach was consistent with that described in the design activity.

Application of results (SCP Section 8.3.4.2.1.2)

Background and SCP Plans. This section stated that analysis results under the associated information need would be used to show explicitly that the factors enumerated in 10 CFR 60.135(a) were considered and that properties or interactions do not compromise repository performance, waste package functions, or the geologic setting.

Changes and Status. Information obtained to address the associated information need is being used in a manner consistent with that described in the SCP section.

Information Need 1.10.2: Reference waste package designs (SCP Section 8.3.4.2.2)

Background and SCP Plans. This information need provided an approach to developing reference waste package designs. Parameters are listed and the planned logic process briefly described.

Changes and Status. Because of changes in program direction and demands for higher performance, waste package designs have been modified from those referenced in this section of the SCP. (Chapter 5 of this progress report describes current designs.) All physical characteristics identified are still applicable. The number of waste packages as a function of time is available by waste si[illegible]n analysis (CRWMS M&O, 1996c). Configurations of packages for viability assessment des[illegible] are available, but only without tolerances. Maximum waste package weights for advanced conceptual designs are available; weights for design to support the

1998 viability assessment are under development. Mechanical and thermal properties of component materials are available in the literature. Both output characteristics identified in the SCP are still applicable. Techniques are available to calculate both the heat generation rate and ionizing radiation flux.

Application of Results (SCP Section 8.3.4.2.2.1)

Background and SCP Plans. This section stated how reference and alternative waste package design information would be used.

Changes and Status. The strategy for application of waste package design results is basically unchanged. But alternative waste package designs are no longer being carried as planned in the SCP because of increased confidence in the adequacy of current designs.

Information Need 1.10.3: Reference waste package emplacement configurations (SCP Section 8.3.4.2.3)

Background and SCP Plans. This information need described the reference waste package conceptual design and information needed for further design development. Specific parameters are listed and a general logic process is discussed.

Changes and Status. The logic of the current program approach is consistent with the approach presented in the information need. The emplacement configuration, however, has been changed to multibarrier waste packages emplaced in drifts. This change is discussed further in Section A.4.1 of this appendix. In addition, alternative designs are no longer being carried because of increased confidence in the adequacy of current designs. Although the reference thermal loading has changed (CRWMS M&O, 1996e), thermal loading is still an important consideration as predicted in the SCP. The changes in the emplacement configuration cause corresponding changes in the list of parameters. The various borehole parameters listed in the SCP are irrelevant because there are no boreholes in current designs. Significant parameters now include waste package spacing, emplacement drift layout and dimensions, and configuration of waste package support hardware, invert, and other components of the underground facilities. Because the project baseline has been extended to include waste forms other than commercial spent nuclear fuel and glass waste forms, information on emplacement configuration for waste package types must also be extended to include these waste forms.

Application of results (SCP Section 8.3.4.2.3.1)

Background and SCP Plans. This section stated how reference and alternative emplacement configuration design information would be used.

Changes and Status. The current program approach uses information obtained for this information need in a manner consistent with that described in this SCP section. However, alternative designs are no longer being carried as planned in the SCP because of increased confidence in the adequacy of current designs.

Information Need 1.10.4: Postemplacement near-field environment (SCP Section 8.3.4.2.4)

Background and SCP Plans. This information need was intended to evaluate the attributes of the near-field environment and to establish the extent of physical and chemical interactions expected between the waste package materials and water present in or mobilized from the repository host rock. Parameters to be addressed are listed. The section also provided a planned logic, which included a list of attributes that affect water chemistry.

Changes and Status. This information need was intended to ensure that interactions with the emplacement environment do not compromise the function of the waste packages. Compositions and amounts of water that may contact the waste package are of critical importance in evaluations of waste package performance. The investigation collects and analyzes data and develops and exercises models to determine the amount and composition of the water that may contact the waste packages. This information will be used to evaluate design configurations as well as containment and controlled release performance issues.

Significant advances in collecting the information required for this information need have been made. The G-Tunnel test was completed at the Nevada Test Site to improve understanding of the thermal-hydrological process in an underground environment and to evaluate prototype instruments and test methodologies. Laboratory experiments have been conducted and continue using core and small block samples for the determination of thermohydrologic properties, mineral kinetics, rock-water interactions, and coupled processes. Numerical analyses of hydrothermal, thermomechanical, and thermochemical interactions in the near-field environment are ongoing. A survey of introduced material interactions and a preliminary assessment of microbial populations have been completed. The Near-Field and Altered Zone Environment Report (Revision 1, Volume II) (Wilder, 1996) documents the status and results obtained to date on this information need. Drift scale testing in the ESF and the large block test will be initiated.

As the draft study plans pertaining to this information need were written and revised, the associated studies and activities were reorganized. Study 1.10.4.1 was split into two studies (itself and 8.3.4.2.4.6, Introduced Materials). During the study plan writing process, the work was redistributed among activities in the four original studies. The cross linkage was originally described in several revisions of the Site Design and Test Requirements Document (DOE, 1995f). However, study plan objectives are not included in the current revision of the Site Design and Test Requirements Document. Instead, the documentation of the cross linkage between original and current activities will be maintained in this appendix to the semiannual progress reports, as described in the following sections.

Study 1.10.4.1: Characterize Chemical and Mineralogical Changes in the Postemplacement Environment (SCP Section 8.3.4.2.4.1)

Background and SCP Plans. This study established the compositional features of water that might contact the waste packages by determining the effects of chemical reactions on the rock-water system. The study had seven activities.

Changes and Status. Before writing the study plan, the study was divided into two studies (near-field geochemistry and introduced materials). The approach planned to be taken in the two studies developed from study 1.10.4.1 is consistent with the approach described in the Study 1.10.4.1 section of the SCP. When the near-field geochemistry study plan was drafted, the activities supporting the "new" Study 1.10.4.1 were organized differently than in the SCP. To avoid confusion between similarly numbered "old" and "new" activities, the "new" activities were renumbered with higher numbers. The cross linkage of the original activities to the current activities is described in the following sections. The status of the current activities is provided in Chapter 5 of this progress report

Activity 1.10.4.1.1: Rock-water interactions at elevated temperatures (SCP Section 8.3.4.2.4.1.1)

Background and SCP Plans. This activity, which was intended to establish the identity and abundance of reaction products that form during hydrothermal interaction of tuff and reference ground water at elevated temperatures, was deleted by a change to the Site Design and Test Requirements Document (DOE, 1995f). The objectives of the activity were moved to new Activities 1.10.4.1.8, 1.10.4.1.9, and 1.10.4.1.11.

Changes and Status. The breadth of this activity, as captured in the current activities, has increased. Some regions of the repository are expected to become saturated for various lengths of time; this activity will consider these situations. Some experiments will be done at lower temperatures than the 90°C stated because of advances in experimental capabilities. Water chemistries modified from the representative vadose water will be considered; these modifications are caused by the heat and the mobilization of water. Additional techniques such as flow-through reactors will be used, in addition to the Dickson-type rocking autoclave experiments. Experiments will include crushed tuff as well as wafers, and solid reaction products will be considered in the experiments.

Activity 1.10.4.1.2: Effect of grout, concrete, and other repository materials on water composition (SCP Section 8.3.4.2.4.1.2)

Background and SCP Plans. This activity was intended to test rock-water interaction in the presence of repository materials.

Changes and Status. This activity is now reported under Activity 1.10.4.5.1 because of changes to the Site Characterization Program Baseline, Revision 8 (DOE, 1995a). The change was made because, as alternatives to the SCP waste package design were proposed, numerous alternative materials for design elements have been considered. Subsequent to this change, an additional study has been identified (1.10.4.5) to characterize the effects of man-made/introduced materials on chemical and mineralogical changes in the post-emplacement environment. The approach planned to be taken in Activity 1.10.4.5.1 to address the objectives of Activity 1.10.4.1.2 is consistent with the approach described for the Activity 1.10.4.1.2 in the SCP.

Activity 1.10.4.1.3: Composition of vadose water from the waste package environment (SCP Section 8.3.4.2.4.1.3)

Background and SCP Plans. This activity was intended to characterize the composition of vadose water in the unsaturated, preemplacement waste package environment.

Changes and Status. The objectives of this activity are met by Study 8.3.1.2.2.7. (See Section A.1.1.2 of this appendix.) The approach planned to be taken in Study 8.3.1.2.2.7 to address the objectives of Activity 1.10.4.1.3 is consistent with the approach described for Activity 1.10.4.1.3 in the SCP.

Activity 1.10.4.1.4: Dissolution of phases in the waste package environment (SCP Section 8.3.4.2.4.1.4)

Background and SCP Plans. This activity was intended to determine the dissolution kinetics of the phases present in the waste package environment

Changes and Status. The objectives of this activity were moved to new Activity 1.10.4.1.10. In addition to addressing all the work described in the original activity using an approach consistent with the SCP text, the current activity will consider two additional parameters, surface area and solution composition.

Activity 1.10.4.1.5: Effects of radiation on water chemistry (SCP Section 8.3.4.2.4.1.5)

Background and SCP Plans. This activity was intended to determine the composition of water in the presence of a radiation field under postemplacement conditions.

Changes and Status. The objectives of this activity were moved to new Activities 1.10.4.1.12 and 1.10.4.5.7. The approach planned to be taken in the current activities to address the objectives of Activity 1.10.4.1.5 is consistent with the approach described for Activity 1.10.4.1.5 in the SCP.

Activity 1.10.4.1.6: Effects of container and borehole liner corrosion products on water chemistry (SCP Section 8.3.4.2.4.1.6)

Background and SCP Plans. This activity was intended to determine the effect of corrosion products on the composition of water in the waste package environment.

Changes and Status. The activity is reported under Activity 1.10.4.5.2 because of changes to the Site Characterization Program Baseline, Revision 8. This change was made because, as alternatives to the SCP waste package design have been proposed, numerous alternative materials for design elements have been considered. Subsequent to this change, an additional study has been identified (1.10.4.5) to characterize the effects of man-made/introduced materials on chemical and mineralogical changes in the post emplacement environment. In addition to addressing the ... the work described in the original activity using an approach consistent with the SCP text, the current activity will consider one additional parameter, initial water composition.

Activity 1.10.4.1.7: Numerical analysis and modeling of rock-water interaction (SCP Section 8.3.4.2.4.1.7)

Background and SCP Plans. This activity was intended to examine effects and processes in natural systems for time periods and chemical conditions not duplicated by laboratory studies.

Changes and Status. This activity is also reported under Activity 1.10.4.5.1 because the activity was divided between geochemistry and man-made material activities in Revision 8 of the Site Characterization Program Baseline. The geochemistry objectives were moved to new Activities 1.10.4.1.13, 1.10.4.1.14, and 1.10.4.1.15. The Project plans to perform work described in the original activity in a manner consistent with the approach described in the SCP. Other codes have also been evaluated, and some are being used, in addition to EQ3/6, because of the advances in geochemical computation capabilities. Reaction progress (in both the minerals and the fluid) along flow pathways is now being calculated in addition to reaction progress at a given location; this has also been made possible by advancements in the state of the art.

Study 1.10.4.2: Hydrologic Properties of Waste Package Environment (SCP Section 8.3.4.2.4.2)

Background and SCP Plans. This study was to establish the hydrologic properties of the near-field repository rock and the effect of thermal perturbations on those properties. Fracture versus matrix flow and gas-phase versus liquid-phase flow are addressed. The section describes how flow and transport models will be used, as well as how boundary conditions for waste package performance assessment will be developed.

Changes and Status. This study had three activities in the SCP (Activities 1.10.4.2.1, 1.10.4.2.2 and 1.10.4.2.3). When the study plan was written and subsequently revised, the material was organized differently than in the SCP. To avoid confusion between similarly numbered "old" and "new" activities, the "new" activities were renumbered with higher numbers (1.10.4.2.4, 1.10.4.2.5 and 1.10.4.2.6). The cross linkage of the original activities to the current activities follows. The status of the current activities is provided in Chapter 5 of this progress report.

Activity 1.10.4.2.1: Single-phase fluid system properties (SCP Section 8.3.4.2.4.2.1)

Background and SCP Plans. This activity was intended to establish the single-fluid-phase hydrologic properties of fractured and unfractured tuff under both isothermal conditions and a thermal gradient

Changes and Status. The objectives of this activity were moved to new Activities 1.10.4.2.4 and 1.10.4.2.5. The approach planned to be taken in the current activities to address the obje es of Activity 1.10.4.2.1 is consistent with the approach described for Activity 1.10.4.2. in the SCP.

Activity 1.10.4.2.2: Two-phase fluid system properties (SCP Section 8.3.4.2.4.2.2)

Background and SCP Plans. This activity, which was intended to establish the two-phase hydrologic properties of fractured and unfractured tuff under both isothermal conditions and a thermal gradient.

Changes and Status. The objectives of this activity were moved to new Activities 1.10.4.2.4 and 1.10.4.2.5. The approach planned to be taken in the current activities to address the objectives of Activity 1.10.4.2.2 is consistent with the approach described for Activity 1.10.4.2.2 in the SCP.

Activity 1.10.4.2.3: Numerical analysis of flow and transport in laboratory systems (SCP Section 8.3.4.2.4.2.3)

Background and SCP Plans. This activity was intended to use laboratory-scale tests for initial development and validation of the flow and transport in laboratory systems.

Changes and Status. The objectives of this activity were moved to new Activities 1.10.4.2.5 and 1.10.4.2.6. The approach planned to be taken in the current activities to address the objectives of Activity 1.10.4.2.3 is consistent with the approach described for Activity 1.10.4.2.3 in the SCP.

Study 1.10.4.3: Characterization of the Geomechanical Attributes of the Waste Package Environment (SCP Section 8.3.4.2.4.3)

Background and SCP Plans. This study establishes the mechanical attributes of the near field host rock.

Changes and Status. The original study from the SCP had one activity, 1.10.4.3.1 - Waste Package Environment Stress Field Analysis. When the study plan was written, the material was organized differently than in the SCP. The SCP activity was subdivided into three activities: (1) Block Stability Analysis, (2) Borehole Damage Analysis, and (3) Geomechanical Properties Analysis (Activities 1.10.4.3.1, 1.10.4.3.2, and 1.10.4.3.3, respectively). The cross reference between the original SCP activity and the current activities follows. The status of the current activities is provided in Chapter 5 of this progress report.

Activity 1.10.4.3.1: Waste package environment stress field analysis (SCP Section 8.3.4.2.4.3.1)

Background and SCP Plans. This activity was intended to estimate the time-dependent stress field and displacements of the rock in the waste package environment. This section listed five parameters to be addressed and described what evaluations will be performed.

Changes and Status. The Project plans to use the three current activities created to reorganize this activity to address the information described in the original activity in a manner consistent with the SCP text.

Study 1.10.4.4: Engineered Barrier System Field Tests (SCP Section 8.3.4.2.4.4)

Background and SCP Plans. This study was to bring about the field tests needed to validate and establish the applicability of laboratory studies to the repository block. The section discusses use of prototype tests to develop test procedures and protocols.

Changes and Status. The original study from the SCP had three activities: 1.10.4.4.1 - Repository Horizon Near-Field Hydrologic Properties, 1.10.4.4.2 - Repository Horizon Rock-Water Interaction, and 1.10.4.4.3 - Numerical Analysis of Fluid Flow and Transport in the Repository Horizon Near-Field Environment. When the study plan was written and subsequently revised, the material was organized differently than in the SCP. The current activity organization is: 1.10.4.4.1 - In Situ Testing, 1.10.4.4.2 - Sampling and Sample Analyses, and 1.10.4.4.3 - Pre- and Post-Test Calculations. The cross linkage of the original activities to the current activities follows. The status of the current activities is provided in Chapter 5 of this progress report.

Activity 1.10.4.4.1: Repository horizon near-field hydrologic properties (retitled In Situ Testing) (SCP Section 8.3.4.2.4.4.1)

Background and SCP Plans. This activity was intended to determine the in situ hydrologic properties of rock in the repository horizon under thermally perturbed conditions. This section listed eight parameters to be addressed and also discussed how instrumentation would be deployed and stated that laboratory-scale hydrologic studies would be performed.

Changes and Status The approach planned to be taken in the new activities to address the objectives of Activity 1.10.4.4.1 is consistent with the approach described for the activity in the SCP.

Activity 1.10.4.4.2: Repository horizon rock-water interaction (retitled Sampling and Sample Analysis) (SCP Section 8.3.4.2.4.4.2)

Background and SCP Plans. This activity was intended to determine the effect on water chemistry of thermal perturbation of the near-field environment. This section listed four parameters to be addressed and also described how instrumentation would be deployed and how tests would be performed. Finally, the section provided a listing of models and technical procedures planned to support the activity.

Changes and Status. The approach planned to be taken in the current activities to address the objectives of Activity 1.10.4.4.2 is consistent with the approach described for the activity in the SCP.

Activity 1.10.4.4.3: Numerical analysis of fluid flow and transport in the repository horizon near-field environment (retitled Pre- and Post-Test Calculations) (SCP Section 8.3.4.2.4.4.3)

Background and SCP Plans. This activity was intended to validate and calibrate fluid flow, temperature, and transport models using waste package-scale field studies. This section listed ten parameters to be addressed and also described in general terms the approach to be taken to addressing the activity, including studies to be performed and models planned to be used. The section also provided a list of technical procedures to be used to address the activity.

Changes and Status. Some changes from the SCP description of this activity have occurred. The last paragraph in the SCP description of this activity describes an in situ test to monitor the movement of sorbing and nonsorbing species; the activity includes numerical analysis of the test. Current plans for in situ tests do not include such a test before license application submittal. The use of tracers is not feasible in the drift-scale (heater) test because its instruments are primarily installed from boreholes drilled from the heated drift. Some tracer testing is being done as part of the large block test (in a surface outcrop of TSw2 tuff), but the lack of confining stress disqualifies these elements of the test from being "in situ." Therefore, transport aspects of the codes used in this activity will be benchmarked primarily to laboratory-scale testing, most of which was described in other parts of the SCP.

Study 1.10.4.5: Characterize the Effects of Introduced Materials on Water Chemistry in the Postemplacement Environment (new study added since the SCP)

Background. The objective of this study was to identify significant chemical modifications of the near-field environment from what would be expected under geological conditions. The modifications would be caused by the construction and operation of the repository and the postclosure conditions (e.g., radiation and thermal flux) as determined by repository design. In addition to construction materials, a complete picture of the modified chemical and hydrological system thus includes introduced air and water, the reintroduction of crushed tuff or muck rock (e.g., backfill), and the introduction of microbial populations.

Changes and Status. This study did not exist in the SCP. It was developed from aspects of the near-field geochemistry study (1.10.4.1) that included the effects of introduced materials and radiation from the waste packages. The original organization of the draft study plan included four activities. When the draft study plan was revised, the material was organized differently than in the first draft. To avoid confusion between similarly numbered activities in the initial draft (which was captured in the Site Design and Test Requirements Document) and the subsequent draft, the current activities were renumbered with higher numbers. The cross linkage of the original activities to the current activities is described below. The status of the new activities is provided in Chapter 5 of this progress report.

Activity 1.10.4.5.1: Effect of grout, concrete, and other repository materials on water composition (new activity added since the SCP)

Background. The objective of the activity was to conduct solubility, stability and reactivity experiments to determine the effect of grout, concrete, and other repository materials on water composition.

Changes and Status The objectives of this activity were moved to new Activities 1.10.4.5.5, 1.10.4.5.6, 1.10.4.5.7, 1.10.4.5.8, and 1.10.4.5.10.

Activity 1.10.4.5.2: Effects of container and borehole liner corrosion products on water chemistry (new activity added since the SCP)

Background. The objective of the activity was to conduct solubility, stability and reactivity experiments to determine the effect of container and borehole liner corrosion products on water chemistry.

Changes and Status. The objectives of this activity were moved to new Activities 1.10.4.5.6, 1.10.4.5.7, and 1.10.4.5.10.

Activity 1.10.4.5.3: Effects of introduced materials in presence of radiation field (new activity added since the SCP)

Background and SCP Plans. The objective of this activity was to conduct the interaction experiments described in Activities 1.10.4.5.1 and 1.10.4.5.2 in the presence of a radiation field to identify potential effects on the predicted natural chemical reactions.

Changes and Status. The objectives of this activity were moved to new Activity 1.10.4.5.7.

Activity 1.10.4.5.4: Numerical analysis and modeling of introduced materials/water interaction (new activity added since the SCP)

Background and SCP Plans. The objective of this activity was to develop the necessary codes and to conduct predictions and simulations of experiments and repository performance with respect to introduced materials effects on the near-field environment.

Changes and Status The objectives of this activity were moved to new Activity 1.10.4.5.11.

Application of results (SCP Section 8.3.4.2.4.5)

Background and SCP Plans. This section describes which information needs and investigations would be addressed using information from the activities preceding this section.

Changes and Status. The Project plans to use the information in the manner described in this SCP section

Schedule fc~ postclosure waste package characteristics (SCP Section 8.3.4.2.5)

Background and SCP Plans. This section of the SCP provides a schedule for addressing information needs and studies for postclosure waste package characteristics.

Changes and Status. The schedule for obtaining information for many key activities has been revised as described in the semiannual progress reports. This method of documenting changes is consistent with the text in the SCP section. The Program has not, however, undertaken to ensure the schedule revisions for all the specific items in Table 8.3.4.2.-5 are included in the progress reports. The schedules presented in the 1988 SCP were based on the DOE's June 1987 Mission Plan Amendment (DOE, 1987a and 1987b), which assumed the license application for the repository would be submitted to the NRC in 1995. In 1989, the Secretary of Energy assessed the progress and needs of the site characterization program, and a new schedule was adopted that delayed license application submittal to 2001. The Program Plan (DOE, 1994a) supporting the 2001 submittal, which was issued in December 1994, contains a schedule for accomplishing major Program activities, though it does not explicitly revise the schedule for all SCP activities and studies. Scheduled completion dates for SCP activities may be further revised as a result of new developments in the site characterization program, changes in Program priorities, or changes in funding profiles These changes will be discussed, as appropriate, in future progress reports; the Project, however, does not plan to necessarily address how and why each SCP schedule item has changed.

Issue resolution strategy for Issue 2.6: Have the characteristics of the waste packages been adequately established to (a) show compliance with the preclosure design criteria of 10 CFR 60.135 and (b) provide information for the resolution of the performance issues? (SCP Section 8.3.4.3)

Background and SCP Plans. This section provided the approach to resolving the issue of compliance with preclosure design criteria of 10 CFR 60.135. Figure 8.3.4.3-1 provided a logic diagram of the process planned to address the issue. Table 8.3.4.3-1 listed the major preclosure functions or characteristics derived from the regulatory criteria for the waste packages.

Changes and Status. The general approach to resolving Issue 2.6 still follows the description in the SCP, but the following changes have occurred. Waste package requirements are currently documented in the Engineered Barrier Design Requirements Document (DOE, 1995i), which has a broader scope than the requirements document envisioned by the SCP in that it also includes requirements for components of the engineered barrier other than waste package. However, requirements from the Engineered Barrier Design Requirements Document have been incorporated at a higher level in the MGDS Requirements Document. When Revision 3 of the MGDS Requirements Document is approved, the Engineered Barrier Design Requirements Document will be removed from Level 2 Change Control Board control. Development of waste packages (shown in Figure 8.3.4.3-1a) is now governed by the Waste

Package Development Technical Document (CRWMS M&O, 1996ff). There have also been several changes to the quantitative performance goals given in the SCP (Table 8.3.4.3-1). The goal for containment is now that 99 percent of waste packages should remain intact for 1000 years (CRWMS M&O, 1996c); the preclosure goal is that the probability of breach of an individual waste package should be less than 1×10^{-6} per year (CRWMS M&O, 1996c). Legibility of the waste package identifiers to the end of the period of retrievability is still a requirement (DOE, 1995i). Current waste package designs for commercial spent nuclear fuel will accommodate about 96 percent of such fuel; other approaches (such as different package designs, package derating, or aging) will be developed for other fuel. This approach provides coverage of all waste but limits costs for most waste packages. The goal for retrieval is that all waste should be retrievable for 100 years after the beginning of emplacement (DOE, 1995i). This change was made because the Project has pursued a more focused approach that will include fewer studies than previously planned. The longer retrievability period will allow a longer period of performance confirmation and therefore increased confidence that the more limited scope of site characterization has provided adequate understanding of predicted site and repository performance.

Information Need 2.6.1: Design information needed to comply with preclosure criteria from 10 CFR 60.135(b) for materials, handling, and identification of waste packages (SCP Section 8.3.4.3.1)

Background and SCP Plans. This information need provided the general approach to obtaining design information needed to comply with preclosure criteria from 10 CFR 60.135(b). The section listed and described four parameters to be addressed.

Changes and Status. The design criteria of 10 CFR 60.135(b)(1) through (4) concern the types of materials that may be used in a waste package, design for handling, and unique identification. These criteria are still in effect and are being considered. Commercial spent nuclear fuel and high-level waste glass are in compliance with these requirements (DOE, 1995i). Additional work is in progress on other waste forms. The approach described in the information need is consistent with the present Program approach.

Application of results (SCP Section 8.3.4.3.1.1)

Background and SCP Plans. This section described very briefly how the results of analyses performed for the associated information need would be used.

Changes and Status. The application of results as indicated in the SCP is consistent with the current program approach.

Information Need 2.6.2: Design information needed to comply with preclosure criteria from 10 CFR 60.135(c) for waste forms (SCP Section 8.3.4.3.2)

Background and SCP Plans. This information need was to obtain design information to comply with preclosure criteria from 10 CFR 60.135(c) for the waste form. The section listed the specific regulatory-based parameters to be addressed and described the logic planned. Also mentioned was a requirement that high-level waste be placed in sealed containers.

Changes and Status. The approach being taken to address this information need is consistent with the approach described in the SCP. The design criteria from 10 CFR 60.135(c) address the solidification and consolidation of waste forms and the presence of combustible materials in waste forms. Analysis of each waste form to demonstrate compliance is still planned. Commercial spent nuclear fuel and defense high-level waste are in compliance, but other waste forms still require analysis. Plans to use sealed containers for each waste form or canistered waste form are still in effect.

Application of results (SCP Section 8.3.4.3.2.1)

Background and SCP Plans. This section briefly explained how information obtained to address the associated information need would be used.

Changes and Status. The application of results as indicated in the SCP is consistent with the current Program approach.

Information Need 2.6.3: Waste acceptance specifications (SCP Section 8.3.4.3.3)

Background and SCP Plans. This information need was to develop specifications for acceptance at the repository of various waste forms. The section listed the parameters involved, which are acceptance specifications for unreprocessed spent fuel, West Valley high-level waste, and DOE defense high-level waste. The section provided a basic logic planned to be used in addressing the information need.

Changes and Status. The present program approach is consistent with the approach presented in the information need. In addition to the waste types described in the information need, acceptance specifications will need to be developed for DOE-owned spent fuel, which has been added to the Program baseline since the SCP was written.

Application of results (SCP Section 8.3.4.3.3.1)

Background and SCP Plans. This section briefly explained how information obtained to address the associated information need would be used.

Changes and Status. The application of results as indicated in the SCP is consistent with the current program approach.

Schedule for preclosure waste package characteristics (SCP Section 8.3.4.3.4)

Background and SCP Plans. This section of the SCP provided a schedule for addressing information needs and studies for preclosure waste package characteristics.

Changes and Status. The schedule for obtaining information for many key activities has been revised as described in the semiannual progress reports. This method of documenting changes is consistent with the text in the SCP section. The Program has not, however, undertaken to ensure the schedule revisions for all the specific items in Table 8.3.4.3-2 are included in the progress reports. The schedules presented in the 1988 SCP were based on the DOE's June 1987 Mission Plan Amendment (DOE, 1987a and 1987b), which assumed the license application for the repository would be submitted to the NRC in 1995. In 1989, the Secretary of Energy assessed the progress and needs of the site characterization program, and a new schedule was adopted that delayed license application submittal to 2001. The Program Plan (DOE, 1994a) supporting the 2001 submittal, which was issued in December 1994, contains a schedule for accomplishment of major Program activities, but it does not explicitly revise the schedule for all SCP activities and studies. Scheduled completion dates for SCP activities may be further revised as a result of new developments in the site characterization program, changes in Program priorities, or changes in funding profiles. These changes will be discussed, as appropriate, in future progress reports; the Project, however, does not plan to necessarily address how and why each SCP schedule item has changed.

Issue resolution strategy for Issue 4.3: Are the waste package production technologies adequately established for the resolution of the performance issues? (SCP Section 8.3.4.4)

Background and SCP Plans. This section provided the approach to resolving the issue of whether waste package production technologies are adequately established. The approach was shown graphically in Figure 8.3.4.4-1.

Changes and Status. This section and its subsections discuss three design activities intended to show that waste packages can be produced with reasonably available technology. These activities are equally applicable to both the SCP design and the current designs. As is discussed above for Issue 2.6 (SCP Section 8.3.4.3), waste package requirements are currently documented in the Engineered Barrier Design Requirements Document (DOE, 1995i). However, requirements from the Engineered Barrier Design Requirements Document have been incorporated at a higher level in the MGDS Requirements Document. When Revision 3 of the MGDS Requirements Document is approved, the Engineered Barrier Design Requirements Document will be removed from Level 2 Change Control Board control. Formal trade-off studies described in the SCP, in which several candidate approaches are ranked against selection criteria, have not been performed and are not planned because industrial experience with production of large, thick-walled vessels is considered sufficient to allow selection of suitable technologies. Instead, experience from production of thick-walled vessels is used to choose one or sometimes two approaches for further study. Tests on full-scale prototypes have not been performed but are still planned. Prototypes may have full-scale diameter but reduced length, because much of the length of the cylindrical part of the containment barriers will be unnecessary in demonstrating fabricability. The logic diagram for resolution of Issue 4.3 (Figure 8.3.4.4-1) is still applicable with the following modifications: The branch at the bottom of the diamond labeled "Is viable process option available?" should be removed; testing is required. As described previously, the step "Select fabrication process" may simply require documentation that the one candidate process is suitable.

Information Need 4.3.1: Identification and evaluation of production technologies for fabrication, closure, and inspection of the waste package (SCP Section 8.3.4.4.1)

Background and SCP Plans. This information need was to provide general information regarding identification and evaluation of waste package fabrication, closure, and inspection technologies. This section does not describe a specific strategy or process.

Changes and Status. The section is still applicable as written.

Design Activity 4.3.1.1: Waste package fabrication process development (SCP Section 8.3.4.4.1.1

Background and SCP Plans. This design activity was to determine the processes to be used in fabricating the nonwaste form waste package components. The section listed parameters to be addressed and described planned processes.

Changes and Status. The present Program approach is different from the approach presented in the design activity, including the list of parameters. Because of their multiple containment barriers, fabrication of waste packages to current designs is more complex than fabrication to the SCP design (as discussed in this design activity). Nevertheless, the processes identified are applicable to both designs. As is noted in the Appendix A discussion for Issue 4.3 (SCP Section 8.3.4.4), selection criteria and candidate processes have not been formally developed and development is not planned. To date, the production of materials, forming and joining, heat treating, and nondestructive evaluation have been considered. Packaging, shipping, and storage as discussed in the SCP will be considered later.

Design Activity 4.3.1.2: Waste package closure process development (SCP Section 8.3.4.4.1.2)

Background and SCP Plans. This activity was to determine the final closure process for waste package containers. This section listed parameters to be addressed and described the closure process.

Changes and Status. The present Program approach differs from the approach presented in the design activity. Closure is more complicated for a multibarrier package than a single-barrier package. The greater thicknesses specified in current designs also contribute to the complexity of closure operations. As is discussed previously for Issue 4.3 (SCP Section 8.3.4.4), selection criteria and candidate processes has not been formally developed and development is not planned. Plans still state that closure will occur in a hot cell by remote control. Qualification of a welding process by monitoring process variables as discussed in the SCP is not considered practical and will not be pursued. Instead, each closure weld will be inspected.

Design Activity 4.3.1.3: Waste package closure inspection process development (SCP Section 8.3.4.4.1.3)

Background and SCP Plans. This activity was to determine the process to be used in inspecting the final closure of the waste package containers. The section listed six parameters to be addressed and briefly described the planned process.

Changes and Status. The present Program approach differs from the approach presented in the design activity. Closure inspection is as important now as when the SCP was written. As is discussed previously for Issue 4.3 (SCP Section 8.3.4.4), selection criteria and candidate processes has not been formally developed and development is not planned. Current plans are that each closure weld will be visually inspected and ultrasonically tested, both by remote means. Demonstration of these techniques is still planned.

Application of results (SCP Section 8.3.4.4.1.4)

Background and SCP Plans. This section briefly described how information from the study would be used.

Changes and Status. The application of results as indicated in the SCP is consistent with the current Program approach.

Schedule for waste package production technologies (SCP Section 8.3.4.4.2)

Background and SCP Plans. This section of the SCP provide a schedule for addressing design activities for waste package production technologies.

Changes and Status. The schedule for obtaining information for many key activities has been revised as described in the semiannual progress reports. This method of documenting changes is consistent with the text in the SCP section. The Program has not, however, undertaken to ensure the schedule revisions for all the specific items in Table 8.3.4.4-1 are included in the progress reports. The schedules presented in the 1988 SCP were based on the DOE's June 1987 Mission Plan Amendment (DOE, 1987a and 1987b), which assumed the license application for the repository would be submitted to the NRC in 1995. In 1989, the Secretary of Energy assessed the progress and needs of the site characterization program, and a new schedule was adopted that delayed license application submittal to 2001. The Program Plan (DOE, 1994a) supporting the 2001 submittal, which was issued in December 1994, contains a schedule for accomplishment of major Program activities, but it does not explicitly revise the schedule for all SCP activities and studies. Scheduled completion dates for SCP activities may be further revised as a result of new developments in the site characterization program, changes in Program priorities, or changes in funding profiles. These changes will be discussed, as appropriate, in future progress reports; the Project, however, does not plan to necessarily address how and why each SCP schedule item has changed.

A.5 PERFORMANCE ASSESSMENT PROGRAM (SCP SECTION 8.3.5)

This section summarizes the performance assessment plans in the SCP (DOE, 1988), changes in the performance assessment program from the SCP, and the current status of that program. Performance assessment technology exists to evaluate both the preclosure radiological safety and the postclosure waste isolation performance of the MGDS, although considerable improvements in that technology are expected as new site data and laboratory research results become available.

The following factors have influenced and changed the performance assessment program from what was planned in the SCP:

- Changes in the regulatory framework, including the definition of design basis events for preclosure radiological safety and a potential radiological risk-based standard for postclosure performance (10 CFR Part 60; NAS, 1995)

- The planned replacement of detailed technical guidelines of 10 CFR Part 960 by new system guidelines with respect to both preclosure and postclosure higher level findings and NRC siting criteria (61 FR 66157)

- New understanding of the site, including surface water infiltration, fracture flow, thermal-hydrological processes, and the importance of the saturated zone (DOE, 1996a)

- Waste package and repository design changes, principally the change to high thermal loading and from vertical borehole emplacement of small thin-walled waste packages to horizontal in-drift emplacement of large double-walled waste packages (CRWMS M&O, 1996b)

- The DOE's waste containment and isolation strategy (DOE, 1996i).

The factors listed above are reflected in the following status and changes in the performance assessment program:

- The definition of design basis accidents for preclosure performance assessments (CRWMS M&O, 1996b and 1996q)

- The need to revise the approach for potential waste package retrieval (CRWMS M&O, 1996b and in prep.[g])

- Increased integration of abstractions of detailed process models for postclosure performance assessments of the overall repository system (CRWMS M&O, 1996gg and 1996hh)

- Waste package materials being tested, including corrosion-allowance and corrosion-resistant materials, the consideration of different environmental conditions, and related model development efforts (CRWMS M&O, 1996b and 1996c; McCright, 1995 and in prep.; Van Konynenburg and McCright. 1995)
- Minor changes in the waste form testing and related model development (Stout and Leider, 1994; Stout et al. 1996)
- The need for remote operations for performance confirmation and shift of some activities from the site characterization phase to the post-license application period (CRWMS M&O, 1996z and in prep.[h])
- The availability of a suite of mathematical models and computer codes for preclosure and postclosure performance assessments, with improvements expected as new site and laboratory data become available (see Appendix I of this report).

Summary descriptions of the status and changes for each of the SCP performance assessment sections follow.

A.5.1 Preclosure Performance Assessment (SCP Sections 8.3.5.1, 8.3.5.3, 8.3.5.4, and 8.3.5.5)

The four preclosure performance assessment sections of the SCP (Sections 8.3.5.1, 8.3.5.3, 8.3.5.4, and 8.3.5.5) are addressed together because of their interdependence and because proposed NRC regulations may eliminate some of the distinctions with respect to the required evaluations. Following are summaries of the current applicability of each of these preclosure performance assessment SCP sections and their related information needs.

The strategy for addressing projected releases of radioactive materials to restricted and unrestricted areas and the resulting radiation exposure to the general public and workers during the preclosure phase is addressed by SCP Section 8.3.5.1 "Strategy for Preclosure Performance Assessment." With the impending NRC rule change regarding design basis events, this section essentially summarizes the strategy for the other three preclosure performance assessment SCP Sections (8.3.5.3, 8.3.5.4, and 8.3.5.5); these sections address the specific analyses required for predicting preclosure radiological exposures of workers and the public from accidents and from routine repository operation.

Strategy for Preclosure Performance Assessment (SCP Section 8.3.5.1)

Background and SCP Plans. SCP Section 8.3.5.1 addresses the development of the preclosure performance assessment strategy for resolving Key Issue 2. This issue asks whether the projected releases of radioactive materials to restricted and unrestricted areas and the resulting radiation exposures of the general public and workers during repository operation, closure, and decommissioning at Yucca Mountain would meet the applicable requirements set forth in 10 CFR Part 20, 10 CFR Part 60, 10 CFR Part 960, and 40 CFR Part 191.

The resolution of this issue centered around the development of a preclosure risk assessment methodology (PRAM) which would have consisted of (a) developing the methods, mathematical models/computer codes, and databases for assessing both radiological and nonradiological risks to the workers and general public in the preclosure phase, (b) identifying the structures, systems and components important to preclosure radiological safety for the Q-List (DOE, 1997d), (c) recommending preventative and mitigative measures to the MGDS design, (d) demonstrating compliance with regulatory requirements (10 CFR Part 20, 10 CFR Part 60, 10 CFR Part 960, 40 CFR Part 191, and DOE orders); and (e) informing the public on preclosure repository safety. The development and implementation of the PRAM was to have been led by a working group of all three repository programs (salt, basalt and tuff) existing before the issuance of the SCP; the cancellation of the salt and basalt repository programs by the Nuclear Waste Policy Amendments Act of 1987 (NWPAA, 1987) eliminated the coordination need.

Changes and Status. The preclosure risk assessment methodology (PRAM) program and working group described in the SCP no longer exist as formal entities. A new strategy was developed in support of the viability assessment. This strategy is documented in the Management Plan for the Development of a Project Integrated Safety Assessment (DOE, 1997a). The strategy considers potential regulatory changes in 10 CFR Part 60 with respect to the definition of design basis events. Where possible, the methodologies to predict the consequences of preclosure radioactive releases are being taken from previously successful license applications and environmental impact statements.

Since the SCP was written, the NRC has proposed to refer to normal and accident events as "design basis events." The term "design basis event" is introduced in the proposed 10 CFR Part 60 rule change and is defined as follows:

1. Those natural and human-induced events that are reasonably likely to occur regularly, moderately frequently, or one or more times before permanent closure of the geologic repository operations area

2. Other natural and man-induced events that are considered unlikely, but sufficiently credible to warrant consideration, taking into account the potential for significant radiological impacts on public health and safety.

Design basis events meeting the first definition are referred to as frequency "Category 1" design basis events those meeting number 2 are classified as frequency "Category 2" design basis events. Using these definitions, "Public Radiological Exposures - Normal Conditions" (SCP Section 8.3.5.3) and "Worker Radiological Safety - Normal Conditions" (SCP Section 8.3.5.4) are category 1 design basis events, but "Accidental Radiological Releases" (SCP Section 8.3.5.5) may be category 1 or category 2 design basis events. As a result, normal exposures (public and worker) and accidental exposures are being grouped together (with similar models for a given category of design basis events) and radiation dose limits vary depending on the frequency category of the design basis event.

A comprehensive set of candidate design basis events was defined in Preliminary MGDS Hazards Analysis (CRWMS M&O, 1996q) and also reported in the MGDS Advanced Conceptual Design Report (CRWMS M&O, 1996b). Data are being obtained and updated as they are generated by the site program and by the MGDS design activities. FY-1997 activities are concentrating on the needs of the Project Integrated Safety Assessment in support of the viability assessment.

In past analyses, the computer codes GENII, MACCS, MCNP, and DORT-TORT have been used (see Appendix Table I-1 for capabilities and references). A new biosphere radiological assessment model is being developed that will also support the postclosure radiation dose estimation and that will have the capability to evaluate long-term bioaccumulation impacts of the preclosure radioactive releases.

Public Radiological Exposures: Normal Conditions (SCP Section 8.3.5.3)

Background and SCP Plans. SCP Section 8.3.5.3 addresses Issue 2.1, which asks whether during repository operation, closure, and decommissioning (a) the expected average radiation dose received by members of the public within any highly populated area will be less than a small fraction of the allowable limits and (b) the expected radiation dose received by any member of the public in an unrestricted area will be less than the allowable limits as required by 10 CFR 60.111, 40 CFR 191 Subpart A, and 10 CFR Part 20. The first part refers to the total population dose (in man-rem exposure) in a highly populated area as defined by 10 CFR 960.2, while the second part refers to the radiation dose of individuals in the site vicinity. Assessments were to be conducted periodically as the MGDS design progresses in order to provide feedback to the design. The SCP approach to resolving Issue 2.4 is addressed by one information need.

Information Need 2.1.1: Site and design information needed to assess preclosure radiological safety (SCP Section 8.3.5.3.1). The SCP lists the following three performance assessment activities to fill this information need:

Performance Assessment Activity 2.1.1.1 - Refinement of Site Data Parameters Required for Issue 2.1. The objective of this activity is to refine the population, agricultural, surface water, meteorological, host rock, and offsite nuclear installation data needed for determining preclosure radiological exposures to members of the public resulting from normal repository operations.

Performance Assessment Activity 2.1.1.2 - Development of Performance Assessment Activities Through the Preclosure Assessment Risk Assessment Methodology Program. The objective of this activity is to benefit from the performance assessment methods development efforts for the preclosure risk assessment methodology program. A secondary objective is to use the information developed in this activity to assist in refining the site parameters list for SCP Issue 2.1 (Performance Assessment Activity 2.1.1.1).

Performance Assessment Activity 2.1.1.3 - Advanced Conceptual Design Assessment of the Public Radiclogical Safety During the Normal Operations of the Potential Yucca Mountain Repository. The objective of this activity is to perform a public radiological safety assessment of the advanced conceptual design of a potential Yucca Mountain repository. Secondary objectives are (a) to provide information for the refinement of the site data parameters list for SCP Issue 2.1 (Performance Assessment Activity 2.1.1.1) and (b) to provide feedback to the preclosure risk assessment methodology program for future methods development activities (Performance Assessment Activity 2.1.1.2).

Changes and Status. Efforts are in progress and will continue to demonstrate compliance with 10 CFR 60.111, 10 CFR Part 20, and the planned replacement for 40 CFR 191 Subpart A. Site data are being collected in the environmental, geological, and hydrological site programs. Design information is being obtained from the MGDS advanced conceptual design (CRWMS M&O, 1996b). Atmospheric dispersion of potential radionuclide releases was modeled to assess the radiological effects of inhalation, using NRC Regulatory Guide 1.25 for guidance. The site program started a review of biosphere radiological assessment models for evaluating long-term bioaccumulation impacts of preclosure radioactive releases. The Preliminary MGDS Hazards Analysis report (CRWMS M&O, 1996q) identified a comprehensive list of possible events, both internal and external initiating events, which were then screened for relevancy to preclosure radioactive releases at the potential repository. The Source Terms for Design Basis Event Analyses report (CRWMS M&O, 1996v) presents bounding radionuclide release terms. Pilot analyses will continue for both the surface and subsurface portions of the potential repository to evaluate whether the consequences from candidate design basis events are within regulatory limits.

Worker Radiological Safety: Normal Conditions (SCP Section 8.3.5.4)

Background and SCP Plans. SCP Section 8.3.5.4 addresses Issue 2.2, which asks whether the repository can be designed, constructed, operated, closed, and decommissioned in a manner that ensures the preclosure radiological safety of workers under normal operations as required by 10 CFR 60.111 and 10 CFR Part 20.

Resolution of this issue assumed that the MGDS would be designed to limit the normal radiation doses to workers during construction, operation, closure, and decommissioning of the repository to less than the limits specified by 10 CFR Part 20. An iterative process of analyses and design were planned to achieve radiation doses as low as reasonably achievable (ALARA). The SCP approach to resolving Issue 2.2 is addressed by two information needs.

Information Need 2.2.1: Determination of radiation environment in surface and subsurface facilities due to natural and manmade radioactivity (SCP Section 8.3.5.4.1) and Information Need 2.2.2: Determination that projected worker exposures and exposure conditions under normal conditions meet applicable requirements (SCP Section 8.3.5.4.2). The SCP lists the following five performance assessment activities to fill these two information needs:

Performance Assessment Activities 2.2.1.1 and 2.2.2.1- Refinement of Site Data Parameters Required for Issue 2.2. The objectives of these two activities, respectively, are to refine (a) the data needed on the subsurface radiation environment due to natural and man-made radioactivity and (b) the meteorological, host rock, and ground-water data needed for determining radiological exposures to workers resulting from normal repository operations.

Performance Assessment Activities 2.2.1.2 and 2.2.2.3 - Advanced Conceptual Design Assessment of the Worker Radiological Safety During Normal Operations of the Potential Yucca Mountain Repository. The objectives of these activities are to perform a worker radiological safety assessment of the advanced conceptual design for a potential Yucca Mountain repository considering natural and man-made sources of radioactivity. Secondary objectives are (a) to provide information for the refinement of the site data parameters list for SCP Issue 2.2 (Performance Assessment Activities 2.2.1.1 and 2.2.2.1) and (b) to provide feedback to the preclosure risk assessment methodology program for future methods development activities (Performance Assessment Activity 2.2.2.2).

Performance Assessment Activity 2.2.2.2 - Development of Performance Assessment Activities through the Preclosure Risk Assessment Methodology Program. The objective of this activity is the development of performance assessment activities to benefit from the preclosure risk assessment methodology program. A secondary objective is to use the information developed in this activity to assist in refining the site data parameters list for SCP Issue 2.2 (Performance Assessment Activities 2.2.1.1 and 2.2.2.1).

Changes and Status. Site data for these analyses are being collected in the environmental, geological, and hydrological site programs. Radiation doses are being calculated for candidate category 1 design basis events. Some analyses are being conducted to meet specific needs for the environmental impact statement, which may be more extensive than the NRC requirements.

Accidental Radiological Releases (SCP Section 8.3.5.5)

Background and SCP Plans. SCP Section 8.3.5.5 addresses Issue 2.3, which asks whether the repository can be designed, constructed, operated, closed, and decommissioned in such a way that credible accidents do not result in projected radiological exposures of the general public at the nearest boundary of the unrestricted area, or workers in the restricted area, in excess of applicable limiting values.

Resolution of this issue would have included an analysis of the adequacy of structures, systems and components provided for the prevention of accidents and mitigation of consequences. These analyses were to be presented to the NRC in the Safety Analysis Report (SAR) of the license application and regulatory closure would occur with the NRC issuing a favorable Safety Evaluation Report (SER) on the license application. The SCP approach to resolving Issue 2.3 is addressed by two information needs.

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Information Need 2.3.1: Determination of credible accident sequences and their respective frequencies applicable to the repository (SCP Section 8.3.5.5.1) and Information Need 2.3.2: Determination of the predicted releases of radioactive material and projected public and worker exposures under accident conditions and that these exposures meet applicable requirements (SCP Section 8.3.5.5.2). The SCP lists the following seven performance assessment activities to fill these two information needs:

Performance Assessment Activities 2.3.1.1 and 2.3.2.1 - Refinement of Site Data Parameters Required for Issue 2.3. The objective of these activities is to refine the population, agricultural, surface-water, and meteorological data needed (a) for determining credible accident sequences and their respective frequencies, (b) for developing candidate design basis accidents, and (c) for determining preclosure radiological exposures to members of the public and to workers as a result of credible accidental radiological releases.

Performance Assessment Activity 2.3.1.2 - Determination of Credible Accident Sequences and their Frequencies Applicable to the Potential Yucca Mountain Repository. The objective of this activity is to develop a comprehensive list of accidents that are both credible and applicable to a potential Yucca Mountain repository

Performance Assessment Activity 2.3.1.3 - Development of Candidate Design Basis Accidents for the Potential Yucca Mountain Repository. The objective of this activity is to develop a set of candidate design basis accidents to be analyzed as part of the total safety analysis.

Performance Assessment Activity 2.3.2.2 - Consequence Analyses of Credible Accidents at the Potential Yucca Mountain Repository. The objective of this activity is to determine the consequences of credible accidents in terms of radiation doses to the essential repository workers and the public.

Performance Assessment Activity 2.3.2.3 - Sensitivity and Importance Analyses of Credible Accidents at the Potential Yucca Mountain Repository. The objectives of this activity are (a) to quantify uncertainties and sensitivities in the accident risk assessment and (b) to establish importance rankings for systems, structures, and components of a potential Yucca Mountain repository with respect to radiological safety.

Performance Assessment Activity 2.3.2.4 - Documentation of Results of Safety Analyses and Comparison to Applicable "Limiting" Values. The objectives of this activity are (a) to produce documentation of the results of the accident risk assessment in the necessary format and (b) to make comparisons of the results to applicable limiting values. This activity will complete the resolution of SCP Issue 2.3 at the end of the license application design.

Changes and Status. Site data for these analyses are being collected in the environmental, geological, and hydrological site programs. Candidate category 2 design basis events were defined in the Preliminary MGDS Hazards Analysis report (CRWMS M&O, 1996q) considering the proposed 10 CFR Part 60 rule change. The candidate design basis events are being grouped by potential radioactive release magnitude or consequence severity to identify the bounding design basis event in each group. To help identify possible issues, a small subset of the candidate design basis events is being evaluated in a pilot analysis. The Preliminary MGDS Hazards Analysis report (CRWMS M&O, 1996q) and Source Terms for Design Basis Event Analyses report (CRWMS M&O, 1996v) were issued. The pilot analyses (surface and subsurface) to quantify the radiological consequences for the initial events considered as design basis events are expected be issued in FY 1997.

A.5.2 Waste Retrievability (SCP Section 8.3.5.2)

Background and SCP Plans. SCP Section 8.3.5.2 addresses Issue 2.4, which asks whether the repository can be designed constructed, operated, closed, and decommissioned so that the option of waste retrieval would be preserved as required by 10 CFR 60.111.

The requirement to preserve the option to retrieve is defined in Section 122 of the Nuclear Waste Policy Act of 1982 (NWPA, 1983), if necessary (a) to protect the public health and safety, or the environment, or (b) to recover economically valuable contents of the spent fuel. According to the SCP, the decision to retrieve for reason (a) will be made as a result of the performance confirmation program.

The retrieval position and concepts presented in the SCP and supporting documents are based on vertical borehole emplacement of small waste packages at an areal thermal loading of 57 kW/acre. No further work was done with respect to retrievability until the development of the current MGDS advanced conceptual design (CRWMS M&O, 1996b).

The SCP approach to resolving Issue 2.4 is addressed by six information needs. The current applicability of each information need is summarized below.

Information Need 2.4.1: Site and design data required to support retrieval (SCP Section 8.3.5.2.1). Site data are being collected in the site program and retrieval design data will be developed after design requirements for the preliminary MGDS design (which follows the advanced conceptual design) have been formulated by the FY 1997 retrievability study (CRWMS M&O, in prep.[g]).

Information Need 2.4.2: Determination that access to the waste emplacement boreholes can be provided throughout the retrieval period for normal and credible abnormal conditions (SCP Section 8.3.5.2.2). This need still exists because it addresses access from the surface facilities to the emplacement locations, although borehole emplacement is not planned. To provide access, backfill would not be placed in any area underground until after the need to maintain the retrievability option in that area will cease. The Retrieval Conditions Evaluation report (CRWMS M&O, 1995g) evaluated temperatures existing during potential retrieval operations. Ventilation to reduce temperatures and/or remotely operated retrieval may be necessary.

Information Need 2.4.3: Determination that access to the waste packages can be provided throughout the retrieval period for normal and credible abnormal conditions (SCP Section 8.3.5.2.3). This need, which addresses emplacement borehole design, does not exist for the current advanced conceptual design.

Information Need 2.4.4: Determination that the waste can be removed from the emplacement boreholes throughout the retrieval period for normal and credible abnormal conditions (SCP Section 8.3.5.2.4). This need, which addresses waste package and equipment design for retrieval from boreholes, still exists, although borehole emplacement is not planned. Instead, this need will be considered in the preliminary MGDS design after its design requirements for retrievability have been formulated.

Information Need 2.4.5: Determination that the waste can be transported to the surface and delivered to waste-handling surface facilities for normal and abnormal conditions (SCP Section 8.3.5.2.5). This need, which addresses the transport of waste packages from their emplacement locations to surface facilities, still exists. The need will be considered in the preliminary MGDS design after its design requirements for retrievability have been formulated.

Information Need 2.4.6: Determination that the retrieval requirements set forth in 10 CFR 60.111(b) are met using reasonably available technology (SCP Section 8.3.5.2.6). This generic requirement remains and will be considered in the FY 1997 retrievability study and in the preliminary MGDS design.

Changes and Status. Preliminary retrieval concepts are described in Section 9.2 of the MGDS Advanced Conceptual Design Report (CRWMS M&O, 1996b). The potential retrieval is expected to be significantly different from the SCP conceptual design of the repository and waste package (SNL, 1987) because of the change to high thermal loading, horizontal in-drift emplacement, and different canister designs.

The general five-step approach defined in the SCP for resolving Issue 2.4, however, is not expected to change. The five steps are as follows:

1. Evaluate regulations and data - evaluate regulatory requirements and existing site data, designs and analyses to determine what functions and processes must be performed to not preclude retrieval.

2. Allocate performance - establish performance measures and goals (design criteria) for the processes that contribute to performing those functions.

3. Identify retrieval conditions - identify normal and credible abnormal conditions for retrieval-related operations and identify input items needed from Issue 4.4. (Are the technologies of repository construction, operation closure, and decommissioning adequately established to support resolution of performance issues? See discussion of SCP Section 8.3.2.5 in Section A.2.2 of this appendix.)

4. Identify input items - identify and request site parameters necessary to meet the goals of related issues for common system elements or develop the reference preclosure repository design, operations plan, supporting analyses and demonstrations requested to support resolution of all related issues.

5. Conduct compliance analysis - conduct a compliance analysis to critically evaluate whether the appropriate retrieval conditions have been considered, whether the input items provided by Issue 4.4 are complete and sufficient, and whether the performance goals are met.

A retrievability study is being conducted in FY 1997, including the formulation of related MGDS design requirements (CRWMS M&O, in prep.[g]). Using the MGDS advanced conceptual design, this study is identifying scenarios that may require retrieval, identifying retrieval options, recommending design features to facilitate retrieval, and performing compliance analyses to determine whether Issue 2.4 can be resolved. The compliance analyses are considering the proposed NRC rule changes with respect to design basis events and preclosure radiological safety analyses.

A.5.3 Higher Level Findings and NRC Siting Criteria (SCP Sections 8.3.5.6, 8.3.5.7, 8.3.5.17, and 8.3.5.18)

The three higher level findings sections (SCP Sections 8.3.5.6, 8.3.5.7, and 8.3.5.18) and the NRC siting criteria section of the SCP (SCP Section 8.3.5.17) are discussed together because of their interdependence and because proposed revisions of 10 CFR Part 960 would affect all of them in a related manner.

Higher level findings and NRC siting criteria refer to criteria in DOE and NRC regulations for assessing the acceptability of specific aspects of a candidate repository site and the acceptability of the overall performance of a repository that would be constructed at the site. The NRC siting criteria are specified in 10 CFR 60.122. These criteria are defined in terms of favorable conditions and potentially adverse conditions that must be investigated and analyzed. Higher level findings are findings with respect to qualifying conditions and disqualifying conditions that are specified by the DOE's siting guidelines in 10 CFR Part 960. These findings must be made before the DOE can recommend a site for development as a repository. The qualifying and disqualifying conditions are defined in terms of preclosure and postclosure "system guidelines" and "technical guidelines." The system guidelines specify requirements for the overall performance and characteristics of a geologic repository, and the technical guidelines identify requirements for specific attributes of the site that contribute to the overall performance and characteristics. The technical guidelines incorporate favorable conditions and potentially adverse conditions that correspond closely to the NRC's siting criteria in 10 CFR Part 60. The qualifying conditions must be satisfied for a site to be acceptable and a site is unacceptable if any of the disqualifying conditions apply.

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Since the SCP was published in 1988, the regulatory framework for site selection has changed significantly. In particular, the Nuclear Waste Policy Amendments Act of 1987 (NWPAA, 1987) directed the DOE to cease characterization of two other candidate sites and to characterize the Yucca Mountain site only. This legislation rendered moot requirements in 10 CFR Part 960 for comparative site evaluations. In addition, the Energy Policy Act of 1992 (EPAct, 1992) directed the U.S. Environmental Protection Agency (EPA) to develop site-specific standards for the performance of a repository at Yucca Mountain and directed the NRC to conform its implementing standards in 10 CFR Part 60 with the EPA's new performance standards.

In response to the legislative changes and in consideration of the knowledge gained about the Yucca Mountain site, the DOE prepared a draft Notice of Proposed Rulemaking to amend the general guidelines for site recommendation in 10 CFR Part 960. The amended rule would retain the existing guidelines for potential future use at other sites and would, in a new subpart, clarify and focus the guidelines to be used in evaluating the suitability of the Yucca Mountain site. Two system guidelines would be applied to Yucca Mountain: (1) a postclosure system guideline that addresses waste containment and isolation and (2) a preclosure system guideline that addresses radiological safety. Each system guideline would have an associated qualifying condition. The DOE published the Notice of Proposed Rulemaking on December 16, 1996 (61 FR 66157), to amend 10 CFR Part 960 by adding a new site-specific subpart for Yucca Mountain. Public comments are currently being taken, and the public comment period is scheduled to close next period.

The work described in the SCP is organized around the resolution of a number of technical issues, including the making of higher level findings and the demonstrations required by the NRC siting criteria. The SCP does not define specific "information needs" and "performance assessment activities" for this purpose. Any changes from the SCP and the status of the work related to these issues is summarized next.

Higher-Level Findings for Preclosure Radiological Safety (SCP Section 8.3.5.6)

Background and SCP Plans. This section addresses Issue 2.5, which asks whether the higher-level findings required by 10 CFR Part 960 can be made for the qualifying condition of the preclosure radiological safety system guideline and the qualifying and disqualifying conditions of the technical guidelines for population density and distribution, site ownership and control, meteorology, and offsite installations and operations. Resolution of this issue would require presenting sufficient evidence to support either a positive or negative higher-level finding for each qualifying and disqualifying condition associated with preclosure radiological safety.

Changes and Status. The DOE's proposed amendment to 10 CFR Part 960 would retain, for the Yucca Mountain site, a preclosure radiological system guideline and its associated qualifying condition and would eliminate evaluation of specific technical guidelines. However, the information required to assess compliance with the technical guidelines would have to be collected and analyzed to assess compliance with the system guideline. Assessment of compliance with 10 CFR Part 960 is scheduled for completion in FY 1999.

Higher Level Findings for Ease and Cost of Construction (SCP Section 8.3.5.7)

Background and SCP Plans. This section addresses Issue 4.1, which asks whether higher level findings required by 10 CFR Part 960 can be made for the preclosure system guideline for ease and cost of siting, construction, operation, and closure and for the qualifying and disqualifying conditions of the technical guidelines for surface characteristics, rock characteristics, hydrology, and tectonics. The guidelines of this section address whether construction of a repository is technically feasible, based on reasonably available technology, and whether repository costs would be reasonable in comparison with other siting options. Resolution of this issue would require presenting sufficient evidence to support either a positive or negative higher-level finding for each qualifying and disqualifying condition associated with the preclosure guideline on ease and cost of repository construction, operation, and closure.

Changes and Status. Under the proposed amendments to 10 CFR Part 960, no findings would be required for these guidelines for the Yucca Mountain site. Technical feasibility would be addressed implicitly in the design process. The comparative cost criterion was rendered moot by the NWPAA.

Higher Level Findings for Postclosure System and Technical Guidelines (SCP Section 8.3.5.18)

Background and SCP Plans This section addresses Issue 1.9, which asks whether higher level findings can be made for the postclosure system guideline for waste containment and isolation and the qualifying and disqualifying conditions of the technical guidelines for geohydrology, geochemistry, rock characteristics, climatic changes, erosion, dissolution, tectonics, and human interference. Resolution of this issue would entail presenting sufficient evidence to support either a positive or negative higher-level finding for each qualifying and disqualifying condition associated with postclosure repository performance.

Changes and Status. The proposed amendments to the siting guidelines would, for the Yucca Mountain site, retain a postclosure system guideline for waste containment and isolation and an associated qualifying condition and would eliminate evaluation of specific technical guidelines. However, the information addressed in the technical guidelines will be integrated into the total system performance assessments that the DOE will conduct to evaluate compliance with the postclosure system guideline.

NRC Siting Criteria (SCP Section 8.3.5.17)

Background and SCP Plans. This section addresses Issue 1.8, which asks whether demonstrations for favorable and potentially adverse conditions can be made as required by 10 CFR 60.122. The SCP defines detailed steps for two separate strategies for resolving this issue with respect to demonstrations required for (1) favorable and (2) potentially adverse conditions. Both are strongly tied with resolving Issue 1.1, which addresses the NRC's overall system postclosure performance objective (10 CFR 60.112)

Changes and Status. These demonstrations will be included in the license application, currently scheduled for completion in FY 2002. Specifics may be different because of potential changes in the postclosure performance objectives resulting from the issuance of new EPA regulations to replace 40 CFR Part 191.

A.5.4 Postclosure Performance Assessment and Pre-Waste-Emplacement Ground-Water Travel Time (SCP Sections 8.3.5.8, 8.3.5.12, 8.3.5.13, 8.3.5.14, and 8.3.5.15)

The principal postclosure performance assessment sections and the pre-waste emplacement ground-water travel time section of the SCP (Sections 8.3.5.8, 8.3.5.12, 8.3.5.13, 8.3.5.14, and 8.3.5.15) are covered together because of their interdependence and because the revised total system performance assessment approach addresses them in an integrated manner.

Since the issuance of the SCP, two major changes have occurred. The first change had been driven by the expected changes in regulatory performance measures and the second by a change in analysis philosophy.

The primary change in the expected regulatory criteria is from a radionuclide release-based standard to a radiation dose-based standard. In this instance, the final representation changes from a complementary cumulative distribution function of radionuclide release to some measure of radiation dose to an individual or population. From a performance assessment standpoint, this also changes the relative importance of certain components of the total system (such as the increased importance of the details of the saturated zone). From an analysis standpoint, the primary change would be the need for analyses tools for the prediction of radiation doses from all potential pathways (only drinking water ingestion and carbon-14 inhalation needed to be analyzed previously) and the analysis of biosphere radionuclide transport and radiation exposures to humans.

The overall postclosure performance assessment approach has moved from using a suite of different and uncoupled mathematical models and computer codes to assess the various subsystem and total system requirements to a more integrated approach. The interdependence of the various processes important to performance still requires that each of the subsystem requirements be assessed in the context of the total system. For instance, the radionuclide releases from the waste package are completely dependent upon the evolution of the nonisothermal ground-water flow field. The current plan is to develop a single total system performance tool. This tool will reflect the current understanding of the site and design using alternative conceptual models and parameter distributions that reflect both their variability and uncertainty. A set of model abstraction and testing activities are in progress that will develop the mathematical representation for each important process within the total system. These activities (listed below) will then be synthesized into the total system analysis tool.

To address any subsystem or total system performance measure, the appropriate analyses will be run as a part of the total system performance assessment to preserve the integrity of the process interdependencies. The results for each subsystem will simply be pulled from the appropriate point within the total system analyses. For the ground-water travel time, work on fast-path flow has been explicitly incorporated in the development of the unsaturated and saturated zone fluid flow and radionuclide transport elements (Ho et al., 1996). Both pre-waste emplacement ground-water travel time and post-waste emplacement ground-water travel time have been assessed and reported previously (Arnold et al., 1995; Altman et al., 1996). These specific analyses can be updated together with other work on relevant processes in the context of the total system analysis development.

The postclosure performance assessment approach just described has been developed through iterative total system performance assessments in 1991 (Barnard et al., 1992; Eslinger et al., 1993), 1993 (Andrews et al., 1994; Wilson et al., 1994), and 1995 (CRWMS M&O, 1995e); testing of model abstractions (CRWMS M&O, 1996hh), and scenario development (G. E. Barr et al., 1996).

In FY 1997, a new postclosure performance assessment iteration was started for the overall MGDS system in support of the viability assessment. The major activities for this purpose are as follows (CRWMS M&O, 1996gg):

- Scenario development
- Unsaturated zone flow testing and abstraction
- Unsaturated zone transport testing and abstraction
- Saturated zone flow and transport testing and abstraction
- Thermohydrologic flow testing and abstraction
- Waste package degradation testing and abstraction
- Waste form degradation testing and abstraction
- Waste form mobilization testing and abstraction
- Near-field environment testing and abstraction
- Biosphere testing and abstraction
- Disturbed processes testing and abstraction
- Total system performance assessment tools and methodology
- Performance assessment support to design
- Performance assessment support to site
- Performance assessment support to oversight and other external interactions.

Following are summaries of the current applicability of each postclosure performance assessment and the pre-waste emplacement ground-water travel time SCP section and related information needs.

Strategy for Postclosure Performance Assessment (SCP Section 8.3.5.8)

Background and SCP Plans. This section addresses the development of the postclosure performance assessment strategy for resolving Key Issue 1. This issue asks whether the MGDS at Yucca Mountain would isolate the radioactive waste from the accessible environment after closure in accordance with the requirements of 10 CFR Part 60, 10 CFR Part 960, and 40 CFR

Part 191. The SCP does not define specific "information needs" and "performance assessment activities" for the development of the postclosure performance assessment strategy.

The detailed plans for assessing postclosure performance are described in SCP Sections 8.3.5.9 through 8.3.5.18, which address the resolution of Issues 1.1 through 1.9. These issues are based on the postclosure performance requirements of 10 CFR Part 60, 19 CFR Part 960, and 40 CFR Part 191. The overall strategy defined in the SCP includes (a) the interrelationships of these issues for resolving the Key Issue 1 and (b) sequential steps for conducting iterative assessments. Iterative assessments are planned to provide feedback to the site program, to MGDS design, and to affect conceptual and mathematical model improvements. These steps are (paraphrased from the SCP):

1. Compile site and design data for the analyses and define their uncertainties

2. Define conceptual models and scenarios and boundaries for the calculations

3. Evaluate the adequacy of the data for the next step and define additional data needs if the data are not adequate

4. Test and validate conceptual and mathematical models, including computer codes

5. Again evaluate the adequacy of the data for the next step and define additional data needs if the data are not adequate

6. Calculate performance measures, including uncertainties, and compare with regulatory criteria

7. Again evaluate the adequacy of the data for the next step and define additional data needs if the data are not adequate

8. Propose resolution of the issue.

Although the questions in the SCP on the adequacy of the data do not specify this aspect, the adequacy of the MGDS design, the scenario formulations, the conceptual models, the mathematical models, and the computer codes, is implicit in these questions. Consequently, improvements or changes in the MGDS design and in the conceptual/mathematical models and computer codes may also be necessary in this stepwise process. The whole process is repeated iteratively during the site characterization phase until sufficient confidence in meeting the regulatory criteria is achieved to submit a license application to the NRC.

Changes and Status. Postclosure performance assessment activities have been revised in anticipation of possible new EPA standards for a potential repository at Yucca Mountain. The current strategy is defined in the Total System Performance Assessment - Viability Assessment (TSPA-VA) Plan (CRWMS M&O, 1996gg), which is based on the waste containment and isolation strategy (DOE, 1996i), total system performance assessments conducted to date

(Barnard et al. 1992; Eslinger et al., 1993; Andrews et al., 1994; Wilson et al., 1994; CRWMS M&O, 1995e), the Description of Performance Allocation (CRWMS M&O, 1996p), and numerous other Project reports (summarized in Chapter 6 of this and previous progress reports).

Ground-Water Travel Time (SCP Section 8.3.5.12)

Background and SCP Plans. This section addresses Issue 1.6, which asks whether the site will meet the performance objective for pre-waste-emplacement ground-water travel time as required by 10 CFR 60.113. The SCP approach to resolving Issue 1.6 is addressed by five information needs. The planned resolution of Issue 1.6 centered around the development of ground-water flow models for the unsaturated and saturated zones and the calculation of the ground-water travel time with these models.

Changes and Status. A comprehensive analysis of pre-waste-emplacement ground-water travel time has been completed (Altman et al., 1996) and no new analyses are planned because of expected changes in the NRC regulations. Post-waste-emplacement ground-water travel time analyses will continue as new site data are collected and the MGDS design evolves to evaluate thermal-hydrological regime in support of postclosure performance assessments of the overall repository system.

Total System Performance (SCP Section 8.3.5.13)

Background and SCP Plans. This section addresses Issue 1.1, which asks whether the MGDS would meet the system performance objective for limiting radionuclide releases to the accessible environment as required by 10 CFR 60.112 and 40 CFR 191.13. This issue would be resolved by identifying potentially disruptive scenarios, developing models of these scenarios and the affected natural and engineered barrier system processes, and then modeling these scenarios and processes in order to develop the cumulative complementary distribution function required by 40 CFR 190.13 and Appendix B.

Changes and Status. Analyses, including potentially disruptive scenarios, have been included in past iterations of postclosure performance assessments of the overall repository system. Although analyses of radionuclide transport to the accessible environment will continue if a radiological risk-based standard is adopted, the integration of radionuclide release over the boundary of the accessible environment for 10,000 years and the calculation of an empirical complementary cumulative distribution function would no longer be needed.

Individual Protection (SCP Section 8.3.5.14)

Background and SCP Plans. This section addresses Issue 1.2, which asks whether the MGDS would meet the requirements for limiting individual radiation doses in the accessible environment for 1000 years after waste disposal as required by 40 CFR 191.15. This issue would be resolved through the calculation of radioactive releases from the waste packages in the first 1000 years following repository closure, of the transport of aqueous radionuclides through the unsaturated and saturated zone to the boundary of the accessible environment, of the transport of carbon-14 to the ground surface, and of radiation doses to the maximally exposed individual through drinking of the contaminated water and inhaling the contaminated air. The issue would be resolved if the calculated doses would be below the limits set by 40 CFR 191.15

Changes and Status. The analyses of radiation doses from drinking contaminated water and from carbon-14 releases will become a component of the calculation of postclosure radiological risk from all environmental pathways if a radiological risk standard is adopted. The most recent calculations of radiation doses from drinking water and carbon-14 were included in the 1993 total system performance assessment (Andrews et al., 1994; Wilson et al., 1994).

Ground-Water Protection (SCP Section 8.3.5.15)

Background and SCP Plans. This section addresses Issue 1.3, which asks whether the MGDS would meet the requirements for the protection of special sources of ground water for 1000 years after waste disposal as required by 40 CFR 191.16. This issue would be resolved through the same calculations as above with respect to calculating radioactive releases from the engineered barrier system and aqueous radionuclide transport to the accessible environment, and then comparing the radionuclide concentrations in the ground water with the limits set by 40 CFR 190.16.

Changes and Status. The analyses of radionuclide concentrations in the ground water of the saturated zone in the accessible environment will become a component of the calculation of postclosure radiological risk from all environmental pathways if a radiological risk standard is adopted. The most recent calculations of radionuclide concentrations in the ground water of the saturated zone in the accessible environment were included in the 1993 total system performance assessment (Andrews et al., 1994; Wilson et al., 1994).

A.5.5 Containment by Waste Package/Waste Package Materials Testing and Model Development (SCP Section 8.3.5.9)

The SCP lists activities that address Issue 1.4, which asks whether the waste package would meet the performance objective for containment as required by 10 CFR 60.113. The SCP objective for Issue 1.4 was to "provide total containment of the enclosed waste for the containment period under anticipated repository conditions recognizing technological limitations and residual uncertainties." The SCP notes that "the performance of the waste package during the containment period would be best achieved by minimizing the residual uncertainties. The residual uncertainties in predicting performance are caused by several factors: (a) the inherent limitations associated with manufacturing, handling, and emplacement operations, (b) the uncertainty in developing a complete understanding of the behavior of waste package materials, and (c) the uncertainty in predicting the future environment of each waste package." Accordingly, this issue is closely coupled with Issue 4.3 (Are the waste package production technologies adequately established for the resolution of the performance issues?) and Issue 1.10 (Have the characteristics and configurations of the waste packages been adequately established to (a) show compliance with the postclosure design criteria of 10 CFR 60.135, and (b) provide information for the resolution of performance issues?). Issues 4.3 and 1.10 are discussed for SCP Sections 8.3.4.4 and 8.3.4.2, respectively, in Section A.4 of this appendix.

Background and SCP Plans. The SCP describes the approach to resolving Issue 1.4 within the logic of five information needs: (1) waste package design features that affect the performance of the container, (2) material properties of the container, (3) scenarios and models needed to predict the rate of degradation of the container material, (4) estimates of the rates and mechanisms of container degradation in the repository environment for anticipated and unanticipated processes and events, and calculation of the failure rate of the container as a function of time, and (5) determination of whether the set of waste packages meets the performance objective for substantially complete containment for anticipated processes and events.

Changes and Status. Although the waste package design concept has been modified from single barrier container approach of the SCP Conceptual Design Report (SNL, 1987) to the current multiple barrier approach of the MGDS advanced conceptual design (CRWMS M&O, 1996b), considerable linkage still exists between the SCP and the current metal barriers selection and test program. SCP Issue 1.4 and its information needs remain fundamentally unchanged. The current waste package container designs include families of materials other than the copper-base materials and the iron to nickel-base "austenitic" materials that were the subject of the SCP Conceptual Design. Of the candidate materials identified in the SCP, only nickel-base Alloy 825 (ASTM B 424 N08825) and copper-nickel Conceptual Design Analysis 715 (ASTM B171) remain among candidates for the advanced conceptual design evaluations. The testing and modeling program has been expanded to encompass corrosion allowance, corrosion resistant, and intermediate materials; and the test environments have been expanded to bracket the range of temperatures and environments that may be encountered for the different waste package and repository design options

The SCP mentions that "alternative" designs, including multiple metallic barriers, might be considered, but it does not discuss which materials and how they might be configured. While many of the same individual corrosion degradation modes discussed in the SCP apply to multiple barrier containers, the interaction among the barriers, which is so important to overall performance, is a major element of the current program that was not foreseen in the SCP. Accordingly, the testing and modeling work has been moved from the single-metal system activities to bimetallic system activities, which address not only individual degradation mechanisms, but also the interactions between the outer corrosion allowance barrier and the inner corrosion resistant barrier.

The performance modeling activities for the calculation of waste package containment times and the determination of whether the set of waste packages meets the performance objective remain consistent with the approach described in SCP Sections 8.3.5.9.4 and 8.3.5.9.5. The following sections have been moved to the design sections: SCP Section 8.3.5.9.1.1, Integrate Design and Materials Information (Metal Container), Subactivities 1.4.1.1.4 and 1.4.1.1.5, dealing with state of stress and weld integrity, and SCP Section 8.3.5.9.1.2, Integrate

Design and M ials information (Alternate Barriers Investigations), Subactivity 1.4.1.2.5, dealing with nondestructive characterization.

Changes to the metal barrier selection and testing program result primarily from major changes in the technical scope of the waste package activities that have occurred in the advanced conceptual design phase of the Project. In particular, the shift from the SCP conceptual design single barrier container to the advanced conceptual design multiple barrier concept has resulted in a more "robust" waste package, comprising two or more metallic barriers, as well as additional engineered barriers, that might better be demonstrated to meet the containment objectives.

The SCP conceptual waste package design is described in the SCP Conceptual Design Report (SNL, 1987). The multiple-barrier approach for waste packag· ·ontainer design is discussed in the Controlled Design Assumptions Document (CRWMS M&O, 1996c) and the "bimetallic" option currently being pursued is described in the MGDS Advanced Conceptual Design Report (CRWMS M&O, 1996b). The Metal Barrier Selection and Testing Scientific Investigation Plan (McCright, 1996) documents the changes to SCP Sections 8.3.5.9.1 through 8.3.5.9.3, in response to the advanced conceptual design multibarrier approach to waste package containers. Results from the activities completed to date in this investigation are documented in the Engineered Materials Characterization Report (McCright, in prep.).

A.5.6 Engineered Barrier Release Rates/Waste Form Testing and Model Development (SCP Section 8.3.5.10)

Background and SCP Plans. The SCP approach consists of activities that address Issue 1.5, which asks whether the waste package and the engineered barrier system would meet the performance objective for radionuclide release rates as required by 10 CFR 60.113. The activities include waste form characterization, alteration, dissolution, and radionuclide release, as well as model development and utilization to determine compliance.

Changes and Status. The current approach is essentially the same as that given in the SCP. The current effort is detailed in scientific investigation plans and the Waste Form Characteristics Reports (Stout and Leider, 1994; Stout et al., 1996) for the waste form testing and modeling. Related performance assessment activities are given in companion documents. Most of the changes deal with deferring activities because of reduced need for the activity indicated by information collected to date. The following discusses the five information needs and the changes, if any, between the SCP and the current approach.

Information Need 1.5.1: Waste package design features that affect radionuclide release (SCP Section 8.3.5.10.1). The activity for this information need deals with integration of waste form data. The activity is essentially the same as planned in the SCP except that the vehicle for information transfer has become the Controlled Design Assumptions Document (CRWMS M&O, 1996c) and the Waste Form Characteristics Reports (Stout and Leider, 1994; Stout et al., 1996), rather than the Spent Fuel Working Group described in the SCP. The Spent Fuel Working Group is no longer active.

Information Need 1.5.2: Material properties of the waste form (SCP Section 8.3.5.10.2). The two activities for this information are (1) characterization of the spent nuclear fuel waste form and (2) characterization of the high-level waste glass forms. These activities address dissolution and oxidation of spent nuclear fuel, zircaloy, hardware and carbon-14 release, and leaching of high-level waste glass. The current program has focused on testing spent nuclear fuel and high-level waste glass. The testing of hardware and carbon-14 has been deferred until FY 1998. The failure of zircaloy cladding is being evaluated this fiscal year; the experimental effort, however, if needed, has been deferred until FY 1998. There has been no cooperative testing with waste producers, as planned in the SCP, and none is planned.

Information Need 1.5.3: Scenarios and models needed to predict the rate of radionuclide release from the waste package and engineered barrier system (SCP Section 8.3.5.10.3). The five activities for this information need are (1) the integration of scenarios for radionuclide releases from the waste packages, (2) the development of a geochemical speciation and reaction model, (3) the development of models for radionuclide release from the spent nuclear fuel, (4) the development of models for radionuclide release from the high-level waste glass forms, and (5) the development of waste package performance assessment models. Scenarios for waste package criticality have been developed as part of the waste package development efforts. There has been little other work on scenario and related model development, with the exception of water contact and radionuclide release mechanism assumptions made in the total system performance assessments (Barnard et al., 1992; Eslinger et al., 1993; Andrews et al., 1994; Wilson et al., 1994; CRWMS M&O 1995e). Future work will be performed as part of total system performance assessments, including in support of the viability assessment. Also included is the development of the thermodynamic data base GEMBOCHS and the geochemical computer code EQ3/6 (Daveler and Wolery, 1992; Wolery 1992a and 1992b; Wolery and Daveler, 1992). The GEMBOCHS work has concentrated on augmenting the data base with data from worldwide sources as they become available. Recent EQ3/6 modeling work has been limited and focused on simulating geochemical speciation and the behavior of spent nuclear fuel and high-level waste glass. The GEMBOCHS and EQ3/6 activities closely follow the plan in the SCP. Detailed mathematical models are being developed for waste form dissolution and radionuclide release from spent nuclear fuel and high-level waste glass on the basis of the experimental results. These detailed models are synthesized in the engineered system performance assessment computer code YMIM (Gansemer and Lamont, 1995), the waste package performance assessment code AREST (Liebetrau et al., 1987, Buxbaum and Engel, 1991; Engel and McGrail, 1993), and the waste package degradation computer code WAPDEG (Atkins and Lee, 1996; Lee et al., 1996a and b).

Information Need 1.5.4: Determination of the release rates of radionuclides from the waste package and engineered barrier system for anticipated and unanticipated events and processes (SCP Section 8.3.5.10.4). The two activities for this information are (1) deterministic and (2) probabilistic calculations of radionuclide releases from the waste packages. The current work closely follows the plan in the SCP. Recent analyses of releases have been part of total system performance assessments (Barnard et al., 1992; Eslinger et al., 1993; Andrews et al., 1994; Wilson et al., 1994; CRWMS M&O, 1995e). Scoping analyses are conducted in support of the waste form and waste package barrier experimental work and in support of waste package development

Information Need 1.5.5: Determination of the amount of radionuclides leaving the near-field environment of the waste package (SCP Section 8.3.5.10.5). The two activities for this information need are (1) the determination of radionuclide transport parameters and (2) radionuclide transport modeling in the near-field environment. More specifically, these two activities involve (1) experimental measurements of radionuclide distributions in tuff wafers and cores and (2) near-field radionuclide transport model validation and applications. Previous experimental work is documented in the Near-Field and Altered-Zone Environment Report (Wilder, 1996); no new experimental work is planned. Radionuclide transport parameter research is also part of the site program. There has been no model validation other than that the detailed process models are based on experimental results. Model applications include sensitivity studies, support of engineered barrier system studies, and components of total system performance assessments.

A.5.7 Seal Performance (SCP Section 8.3.5.11)

Background and SCP Plans. SCP Section 8.3.5.11 addresses whether the design of the seal system will meet the requirements of 10 CFR 60.134(a) and (b) and how seal performance will contribute to the engineered barrier system performance in accordance with 10 CFR 60.113(a)(1). The seal system is defined as being composed of shafts, ramps, exploratory boreholes and their seals, and the sealing components of the underground facility.

Changes and Status. The overall goals of sealing have not changed, which are to (a) minimize water flow to the waste packages through man-made openings in the host rock, (b) minimize gaseous radionuclide releases to the ground surface through these openings, and (c) minimize aqueous radionuclide transport from the waste packages to the saturated zone through these openings. Preliminary analyses of seal performance, seal test planning, and evaluations of sealing components have been completed (Fernandez and Freshley, 1984; Fernandez, 1985; Fernandez et al., 1987; Licastro et al., 1990; Fernandez et al., 1993; Van Sambeek et al., 1993; Fernandez et al., 1994.; Fernandez and Richardson, 1994). Because of uncertainties in new regulations for postclosure MGDS performance, the goals and performance measures listed in the SCP, however, may no longer be relevant. Consequently, the seal performance goals, the possibility to seal selectively with respect to needed seal performance and locations, and the need to seal at all from a postclosure waste isolation performance standpoint have to be revisited.

A systems study is in progress that will identify how components of the sealing systems will meet the expected regulations and what additional work will need to be performed before licensing. Pending the results of this study, additional work on seals has been deferred. A substantial portion of the sealing design information was not intended to be developed until the performance confirmation period. Sealing of boreholes is possibly the exception because some boreholes may be sealed before the repository becomes operational.

Additional detail is provided in the Repository section of this appendix that addresses SCP Investigation 8.3.3.2.2 (materials and characteristics of seals for shafts, drifts and boreholes).

A.5.8 Performance Confirmation (SCP Section 8.3.5.16)

SCP Section 8.3.5.16 addresses Issue 1.7 on performance confirmation, which is directly related to the performance confirmation program requirements of 10 CFR 60.137 and Subpart F (consisting of §60.140 through §60.143).

Background and SCP Plans. The SCP (DOE, 1988) described preliminary plans for a performance confirmation program that would encompass two major phases: (1) the baseline phase and (2) the confirmation phase. The submittal of the license application marks the division between the two phases.

The baseline phase would consist of acquiring and developing information during site characterization. This phase would include (a) developing information on subsurface conditions and natural systems important to the performance assessment to be provided in the license application and those aspects of design integral to the assessment and (b) monitoring and analyzing changes in this baseline information as a result of site characterization and predicting changes resulting from construction and operation.

The confirmation phase would consist of in situ monitoring, laboratory and field testing, and associated analyses required to confirm (a) assumptions regarding the actual subsurface conditions at the site, and (b) the functioning of the engineered and natural systems and components as predicted by the performance assessment calculations presented in the license application.

A subset of the testing conducted during site characterization would provide the baseline data needed for performance confirmation. In Tables 8.3.5.16-1 and 8.3.5.16-2, the SCP listed specific monitoring and testing activities planned during site characterization and testing activities planned to be continued for performance confirmation. These activities were not intended to be complete, but rather to indicate the monitoring and testing tentatively identified at that time as being useful for performance confirmation.

Changes and Status. Preliminary plans for the performance confirmation program have been documented in the Performance Confirmation Concepts Study Report (CRWMS M&O, 1996z) and plans are being refined with a Performance Confirmation Plan (CRWMS M&O, in prep [h]) to be issued at the end of FY 1997. Currently, there is little difference between the overall approach and the testing, measurement, monitoring, observation, and evaluation concepts identified in these reports and the SCP. Some differences exist because the SCP addressed an Exploratory Shaft Facility in contrast to the ESF being built. Most of the parameters and most of the monitoring and testing activities listed in the SCP are identified as performance confirmation parameters and concepts in the referenced study. The comparison of specific activities, however, is not complete.

A.5.9 Essentially Completed Analytical Techniques and Analytical Techniques Requiring Significant Development (SCP Sections 8.3.5.19 and 8.3.5.20)

The SCP sections on essentially completed analytical techniques and on analytical techniques requiring significant development are covered together because of their interdependence and because techniques are available now for all processes to be modeled for a potential repository at Yucca Mountain (although model development and improvements are not yet completed as mentioned below and in other sections of this progress report).

Background and SCP Plans. The SCP defined "essentially completed analytical techniques" as "those that already exist and could be used, with little additional work or only minor modifications, to conduct performance assessment analyses." This included computer codes that have not yet been fully verified and mathematical models that have not yet been validated for application to the conditions at Yucca Mountain. Analytical techniques requiring significant development were "those for which analysis approaches are still being formulated, solution methods are still being developed, or codes are still being written or tested." The SCP listed computer codes considered essentially completed at the time the SCP was written.

Changes and Status. Appendix I of this progress report lists computer codes that have been used by the Project in the past, are being used at present, and that remain candidates for future use. Some of the computer codes listed in the SCP have been dropped in favor of others that reflect advances in (a) understanding the conditions at Yucca Mountain, (b) engineering design methods, (c) numerical analyses techniques, and (d) computer hardware capabilities.

Appendix Table I-1 also indicates (with an asterisk) which computer codes and versions have been approved for use in activities subject to the Quality Assurance Requirements and Description (DOE, 1997b). These computer codes can be used for ESF and MGDS design and for performance assessments in support of a license application. To date, this has included principally computer codes that are being used in the ESF and MGDS design; most of these are proprietary codes acquired from commercial vendors. Only a few of the computer codes currently being used for performance assessments and related analyses have been approved for use in activities subject to the Quality Assurance Requirements and Description.

Approval of computer codes for use in activities subject to the Quality Assurance Requirements and Description requires verification of the computer codes and control of the use of the codes in accordance with quality assurance procedures that implement the Quality Assurance Requirements and Description. This approval does not require validation of the conceptual and mathematical models embedded in the computer codes. According to the SCP, "verification studies are used to demonstrate that the numerical values produced by a computational procedure correspond to the mathematical formulas on which they are based." No change has occurred in this approach.

No documented plan exists at present for mathematical model validation. To date, the approach has been generally to develop new mathematical models in parallel with experimental work (e.g., waste form and waste package barrier degradation models) and to attempt to replicate laboratory and field measurements with existing models (e.g., ground-water flow and contaminant transport models, including coupled thermal-hydrological models). Additional, site-specific validation will be part of the performance confirmation program. This validation will entail (a) predicting natural and engineered barrier system conditions expected in the preclosure phase, (b) measuring these conditions in the preclosure phase, (c) comparing the predictions with the measurements, (d) and evaluating the validity of the models accordingly. This approach is considered adequate to establish the validity of the mathematical models.

Future model development will consist principally of (a) improving the currently used detailed process models to better represent conditions at Yucca Mountain as new site and laboratory data become available, (b) developing new models to fill gaps identified by the new information, (c) abstracting simplifications of the detailed process models for use in total system performance assessments, and (d) integrating the abstractions into the total system performance assessment approach and software. This process is documented in the total system performance assessment plan for the viability assessment (CRWMS M&O, 1996gg). In addition, model modifications or development may also be necessary to respond to changes in regulatory requirements.

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APPENDIX B

Regulatory and Management Document Progress

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APPENDIX B

Regulatory and Management Document Progress

This appendix summarizes in tabular form the status of selected important regulatory and management documents related to the Yucca Mountain Site Characterization Project. Progress on each document since the last progress report is described, followed by a forecast of future activity related to that document. Documents discussed include the Mined Geologic Disposal System Requirements Document, the Technical Management Implementation Plan, and the Test and Evaluation Plan. Other requirements documents and management plans are also discussed.

Changes to several documents are on hold pending the completion of the current revision of the Mined Geologic Disposal System Requirements Document. Once Revision 3 of the Mined Geologic Disposal System Requirements Document is approved, several of these documents will be removed from Level 2 Change Control Board control. As listed in this appendix, information reflects the approved versions of documents during the reporting period.

Documents cited in this appendix are included in the consolidated reference list for this progress report (Appendix L).

Table B-1. Regulatory and Management Document Progress

Document	Progress or Change	Forecast
	Regulatory Documents	
Mined Geologic Disposal System Requirements Document (DOE, 1996b)	Revision 3 draft completed to coincide with Revision 3 of the higher level Civilian Radioactive Waste Management Systems Requirements Document, the Technical Baseline Streamlining intiative (BCP 00-96-0009), and the current waste containment and isolation strategy	Complete Revision 3, which includes completion of the Management and Operating Contractor review, submittal to the U.S. Department of Energy for acceptance review, and approval by the Level 2 Change Control Board.
Repository Design Requirements Document (DOE, 1994f)	No change.	After Revision 3 of the Mined Geologic Disposal System Requirements Document is approved, the Repository Design Requirements Document will be removed from Level 2 Change Control Board control.
Engineered Barrier Design Requirements Document (DOE, 1995i)	No change.	After Revision 3 of the Mined Geologic Disposal System Requirements Document is approved, the Engineered Barrier Design Requirements Document will be removed from Level 2 Change Control Board control.
Site Design and Test Requirements Document (DOE, 19[illegible])	No change.	No revision planned.
Exploratory Studies Facility Design Requirements (DOE, 1996h)	No change.	No revision planned.

Table B-1. Regulatory and Management Document Progress (continued)

Document	Progress or Change	Forecast
Surface-Based Testing Facilities Requirements Document (DOE, 1996j)	No change.	No revision planned.
Controlled Design Assumptions Document (CRWMS M&O, 1996c)	Revision in process to incorporate key assumptions to support the viability assessment.	Revision planned to incorporate changes to the technical baseline during the last half of fiscal year (FY) 1997.
Site Characterization Program Baseline (DOE, 1995a)	No change. See Appendix H of this progress report for a history of changes to the Site Characterization Program Baseline.	No revision planned.
Management Documents		
Project Management Plan (DOE, 1995k)	No change.	No revision planned.
Environmental Management Plan (DOE, 1993d)	Revision under review.	Review scheduled for completion during FY 1997.
Project Work Breakdown Structure (DOE, 1995m)	Minor changes made to reflect the current Program direction.	No revision planned. Minor changes will be made as necessary during fiscal year planning.
Systems Engineering Management Plan (DOE, 1994i)	No change.	No revision planned.

Table B-1. Regulatory and Management Document Progress (continued)

Document	Progress or Change	Forecast
Project Test and Evaluation Plan	Developing the Viability Assessment Test and Evaluation Plan, which supports the viability assessment by demonstrating a viable plan to integrate Project testing for all Project test programs as described in the Office of Civilian Radioactive Waste Management (OCRWM) Test and Evaluation Master Plan (Revision 0).	Viability Assessment Test and Evaluation Plan is scheduled for completion at the end of FY 1997.

APPENDIX C

Project Change Control Board Actions

APPENDIX C

Project Change Control Board Actions

This appendix contains a summary of significant Change Control Board actions to the Project Baseline and the Project Cost and Schedule Baseline.

Proposed changes to quality affecting and nonquality affecting documents that are listed in the Change Control Board Register, are submitted using a Change Request in accordance with procedure YAP-3.5Q, Change Control Process. A Change Request is reviewed, and if acceptable in form and content, is processed by Configuration Management, evaluated by the Change Control Board Members, and dispositioned by the Change Control Board Chairperson. A Directive is issued with instructions that the change be implemented by Affected Organizations in accordance with corresponding procedures.

Cost Schedule and Work Scope Changes

Title	Change De[illegible]on/Disposition	Status
Initial Baseline for fiscal year (FY) 97 Work Scope for WBS 1.2.1.10	Provided a plan/strategy for inclusion of Plutonium waste forms into Federal Waste Management System.	Closed
Reduce Project Administrative Scope and Budget	Rescheduled and reduced work scope in administrative areas to make budget available for use in technical elements. Scope changes were made at levels below the Planning System Summary Account.	Closed
Viability Assessment Risk Management Plan	Added planning packages for the scopes and budgets that are presented in the Yucca Mountain Site Characterization Project Viability Assessment Risk Mitigation Plan	Closed
Modification of Pr[illegible] Cost and Schedule Baseline	Reconciled the Level II Milestone data with the Level III data in the fiscal year 1997 Project Cost and Schedule Baseline. Also proposed Level 1 Milestone additions and deletions per the Office of Civilian Radioactive Waste Management direction.	Closed
Phase I Planning for the Addition of a New Borehole to the Crest of Yucca Mountain	Provided critical stratigraphic, structural and rock property characteristics data needed to integrate the geologic description of the western block with the description of the geologic system developed from data collected at other areas of the potential repository block.	Closed
Revise Project Cost and Schedule Baseline Document to Multiyear Baseline Configuration (Level 1, Level 2 and Level 3)	Updated the Project Cost and Schedule Baseline to a multiyear configuration with baseline data for Levels 1, 2 and 3.	Closed

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Cost Schedule and Work Scope Changes (continued)

Additional Regulatory Consulting Team Support	Request for funding to enhance the Project's confidence in Licensing strategy and the License Application Plan (one of four key deliverables at viability assessment), as well as other regulatory and technical documents, plans, and strategies.	Open
Web-Based information System (WBIS) Prototype	Transfer of funds from WBS 1.2.5.X to the Management and Operating Contractor 1.2.5.2.4 for the use of the Hypertext Markup Language (HTML software language on the Project).	Open

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APPENDIX D

Interactions with the U.S. Nuclear Regulatory Commission and Other Organizations

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APPENDIX D

Interactions with the U S. Nuclear Regulatory Commission and Other Organizations

This appendix documents interactions among the U.S. Department of Energy (DOE) and other organizations associated with the Yucca Mountain Site Characterization Project. Most of these interactions are held for the purpose of communicating with the U.S. Nuclear Regulatory Commission (NRC) or the Nuclear Waste Technical Review Board (NWTRB). Other interested parties, such as the State of Nevada, frequently participate in these interactions with the NRC and the NWTRB.

Appendix D consists of a table presenting interactions that occurred during the six-month reporting period of this progress report, including the following:

- Organization with whom the interaction occurred
- Date of the interaction
- Location of the interaction
- Type of interaction (Technical Exchange, Management Meeting, etc.)
- Short summary of the subject and purpose of each interaction.

Interactions with the U.S. Nuclear Regulatory Commission and Other Organizations

Organization	Date	Type	Location	Subject/Purpose
NRC	10/23/96	Management Meeting	Washington, DC, Rockville, MD, San Antonio, TX, and Las Vegas, NV (video conference)	Provide a forum for DOE and NRC managers to discuss current activities and concerns and resolve identified issues. Discussion topics included an update of the Program plan and budget, the legislative process, an update of Office of Waste Acceptance and Storage and Transportation activities, status of 10 CFR Part 960, an update on DOE documentation of decisions, Seismic Topical Report III, an update of the Licensing Support System, and NRC quality assurance concerns.
NRC	12/16/96	Technical Meeting	Washington, DC and Las Vegas, NV (video conference)	Identify issues, propose resolutions, and resolve issues related to the design, testing, and construction of the Exploratory Studies Facility (ESF).
NRC	1/15/97	Management Meeting	Washington, DC and Las Vegas, NV (video conference)	Provide a forum for DOE and NRC managers to discuss current activities and concerns and resolve identified issues. The purpose of this meeting was for the NRC staff to provide an overview of the NRC High-Level Radioactive Waste Program Annual Report for Fiscal Year 1996 before its distribution.
NRC	2/5/97	Appendix 7 Meeting	Washington, DC	Criticality: Discuss DOE's proposed postclosure disposal criticality analysis methodology, understand and address NRC staff concerns and questions on the methodology and on the Disposal Criticality Analysis Methodology Technical Report, better understand the NRC staff's views on issues regarding the disposal criticality rule, and seek NRC staff feedback on the likelihood of acceptance of the planned criticality analysis methodology.

Interactions with the U.S. Nuclear Regulatory Commission and Other Organizations (continued)

Organization	Date	Type	Location	Subject/Purpose
NRC	2/6/97	Appendix 7 Meeting	Rockville, MD	Level of Design Detail: Discuss the design detail for the license application; bring NRC participants up to date on the repository design; provide an overview of the approach the DOE plans to take to determine and develop the appropriate level of design detail for the license application; provide examples of application of that approach; and to seek NRC feedback on the approach.
NRC	2/25-26/97	Technical Exchange	Rockville, MD	Igneous Activity Program: Achieve issue definition on the approach to considering igneous activity in total system performance assessment for the viability assessment and identify areas of agreement and disagreement on the relevant geologic data, the probability of volcanism, models for calculating consequences, and performance assessment models of igneous activity.
NRC	2/27/97	Appendix 7 Meeting	Rockville, MD	Seismic Methodology: Discuss NRC's review comments on DOE's seismic design methodology and revisions to Seismic Topical Report II.
NRC	3/13/97	Technical Meeting	Rockville, MD, San Antonio, TX, and Las Vegas, NV (video conference)	Identify issues, propose resolutions, and resolve issues related to the design, testing, and construction of the ESF.

Interactions with the U.S. Nuclear Regulatory Commission and Other Organizations (continued)

Organization	Date	Type	Location	Subject/Purpose
NRC's Advisory Committee on Nuclear Waste (ACNW)	10/22-23/96	87th ACNW Meeting	Rockville, MD	The agenda for this meeting mostly dealt with ACNW administrative topics, future Committee activities and plans, and preparation of ACNW reports. One topic of interest discussed was the Branch Technical Position on Requirements for Radioactive Waste Land Burial Sites Authorized Under Former 10 CFR 20.302, 20.304 and current 20.2002.
ACNW	11/12-13/96	88th ACNW Meeting	Rockville, MD	To conduct a planning session during which the Committee discussed (a) the conduct of its activities, internal operations and methods for formulating advice; and (b) priority issues for ACNW consideration. The meeting was originally planned as a retreat and thus was primarily concerned with issues internal to the Committee.
ACNW	1/28-30/97	89th ACNW Meeting	Rockville, MD	To discuss possible ACNW reports relevant to Yucca Mountain, including Radionuclide Transport at Yucca Mountain, Critical Group and Reference Biosphere for a Waste Disposal Facility Performance Assessment, and Time of Compliance in Low-Level Waste Disposal. Also discussed were the status of site characterization at the proposed Yucca Mountain repository, status of the NRC staff's efforts to revise 10 CFR Part 60, status of 10 CFR Part 960 options paper, and status of Environmental Protection Agency high-level waste standards.

Interactions with the U.S. Nuclear Regulatory Commission and Other Organizations (continued)

Organization	Date	Type	Location	Subject/Purpose
ACNW	3/20-21/97	90th ACNW Meeting	Rockville, MD	To discuss the options paper for 10 CFR 960, Siting Guidelines, defense in-depth philosophy, Phase II of the Biosphere Model Validation Study (BIOMOVS II) (NRC presentations); biosphere modeling associated with the International Atomic Energy Agency-sponsored BIOMASS theme (Electric Power Research Institute presentation); ACNW report preparation and development of future meeting agenda. The ACNW met with the NRC directors of the Division of Waste Management and Spent Fuel Projects Office to discuss the division's priorities and highlight issues for ACNW consideration.
NWTRB	10/9-10/96	Full Board Meeting	Arlington, VA	Discussions included the following: an update on Yucca Mountain program and status; status of planning efforts from the long-range plan through license application including viability assessment, plus fiscal year (FY) 1996 accomplishments and FY 1997 objectives of the unsaturated zone conceptual flow model; sensitivity analyses to evaluate alternative unsaturated zone conceptual flow models and approach to integrate a total system performance assessment with the viability assessment; mined geologic disposal system operations; retrievability issues; waste package physical characteristics; subsurface remote operations and drift stability and maintenance; and an update on the evolution of the program's thermal management strategy. A round-table discussion followed the presentations on the second day and covered topics presented during the meeting.

Interactions with the U.S. Nuclear Regulatory Commission and Other Organizations (continued)

Organization	Date	Type	Location	Subject/Purpose
NWTRB	1/28-29/97	Full Board Meeting	Pahrump, NV	Discussion included the following on total system performance assessment and transportation. Total system performance assessment: DOE's total system performance assessment transparency efforts; NRC on making performance assessments understandable and credible; changes in the French nuclear waste program, and key objectives of their technical program and making them understandable; National Research Council's view of understanding risk; Nevada on the meaning of total system performance assessment to the public. Transportation: DOE's transportation privatization initiative; Nevada's critical transportation issues; affected units of local government on privatization. Additional topics: status of Yucca Mountain program activities; Nevada's concerns with the DOE's proposed new siting guidelines and the viability assessment; DOE's topical safety analysis report on an interim storage facility; saturated zone flow and unsaturated zone/saturated zone transport studies; hydraulic/conservative tracer testing and transport/reactive tracer testing at C-hole complex; flow and [illegible]sport models; thermal and underground testing; Nye County's technical program; and, DOE's plans to reduce hydrologic uncertainty.

APPENDIX E

Status of U.S. Nuclear Regulatory Commission Analysis Open Items

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APPENDIX E

Status of U.S. Nuclear Regulatory Commission Site Characterization Analysis Open Items

This appendix documents the resolution status of U.S. Nuclear Regulatory Commission (NRC) concerns as documented in the Site Characterization Analysis (SCA) (NRC, 1989). The SCA documents the NRC staff's concerns resulting from its review of the U.S. Department of Energy (DOE) Site Characterization Plan (DOE, 1988) for Yucca Mountain. The SCA consists of objections, comments, and questions. Open items are objections, comments, and questions that have not yet been resolved. The DOE tracks the status of these open items through closure, as indicated by formal NRC acceptance of DOE's resolution actions.

For each objection, comment, and question, Appendix E provides a short description of the item and its date of closure (if closed). It also briefly describes actions in progress to address the items that are still open.

Status of Site Characterization Analysis Open Items

Item ID	Item Description	Status	Action Description
Objection 1	Adequacy of Title I design control process.	Closed 11/2/92	NRC letter lifting Objection 1. NRC considers this objection closed.
Objection 2	Acceptability of DOE Quality Assurance Program.	Closed 3/2/92	NRC letter lifting Objection 2. NRC considers this objection closed.
Comment 1	A systematic, iterative approach to identify and collect data during site characterization to support a license application not demonstrated to be in place.		Submit a supplemental response to the NRC. This response will be used to close Comments 10, 18, 49, and 60.
Comment 2	Performance Assessment: Confidence in performance.		Submit a supplemental response to the NRC.
Comment 3	Reliance on expert judgment to supply licensing information.		Supplemental response submitted to the NRC on 6/1/95. Awaiting NRC concurrence. Guidance on closure provided by NRC on 12/26/96.
Comment 4	Rationale for the testing needs; integration of testing with design and performance assessment needs.		Develop parametric calculations to refine parameter goals. Develop plans for collecting all necessary data. Supply NRC with the information in semiannual progress reports. Submit a supplemental response to the NRC.
Comment 5	Waste Package: Interpretation of substantially complete containment.	Closed 7/11/94	NRC Evaluation of DOE response. NRC considers this comment closed.
Comment 6	Performance Assessment: Hypothesis Testing Table and alternative conceptual models.		Submit a supplemental response to the NRC.

Status of Site Characterization Analysis Open Items (continued)

Item ID	Item Description	Status	Action Description
Comment 7	Use of expe.. judgment versus peer review.		Supplemental response submitted to the NRC on 7/12/93. Awaiting NRC concurrence. Guidance on closure provided by NRC on 12/26/96.
Comment 8	Alternative Tectonic Models.		Study Plan 8.3.1.17.4.12, Rev. 1 "Tectonic Models and Synthesis" submitted to the NRC on 12/19/94.
Comment 9	*Use of expert judgment during the development of Hypothesis Testing Table.*		*Submit a supplemental response to the NRC.*
Comment 10	Assessment of significance of site hydrologic characteristics.		Resolve concerns in Comment 1. Resolution of Comment 1 will address the cross-issues for this comment.
Comment 11	No hypothesis on the thermal effects of waste emplacement in the hydrologic environments presented.		Submit a supplemental response to the NRC.
Comment 12	Porous flow in the Calico Hills unit.	Closed 11/2/92	NRC letter lifting Objection 1. NRC considers this comment closed.
Comment 13	Surface Hydrology: Surface water gaging station locations and the natural infiltration measurements.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 14	Hydrologic properties of the tuffaceous beds of the Calico Hills nonwelded unit.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.

Status of Site Characterization Analysis Open Items (continued)

Item ID	Item Description	Status	Action Description
Comment 15	Solitario Canyon horizontal borehole activity is inadequate to discriminate between the hypotheses that faults are barriers to fluid flow in non-welded tuff units or faults are conduits for liquid-water flow.	Closed 9/15/94	NRC evaluation of Study Plan 8.3.1.2.2.4. NRC considers this comment closed
Comment 16	Characterization of the hydrologic properties of the Calico Hills unit.	Closed 11/2/92	NRC letter lifting Objection 1. NRC considers this comment closed.
Comment 17	Multi-purpose borehole testing near the shafts.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 18	Initial hydrologic modeling studies are not supported by planned studies.		Resolve concerns in Comment 1. Resolution of Comment 1 will address cross issues for this comment.
Comment 19	Saturated Zone: Work is not adequate for saturated zone characterization.		Develop and submit plan to define sufficient testing of the saturated zone. Submit a supplemental response to the NRC.
Comment 20	Saturated Zone: Potentiometric surface will not adequately be defined.		Submit a supplemental response to the NRC.
Comment 21	Saturated Zone: technetium-199 and iodine-129 are not included to be characterized in the groundwater flow and radionuclide analysis background concentrations.		Supplemental response submitted to the NRC on 1/7/93. Awaiting NRC concurrence.
Comment 22	Saturated Zone: Hydrochemical samples.		Supplemental response submitted to the NRC on 1/7/93. Awaiting NRC concurrence.

Status of Site Characterization Analysis Open Items (continued)

Item ID	Item Description	Status	Action Description
Comment 23	Unsaturated Zone: Evaluation of *radionuclide concentrations on fracture surfaces.*	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 24	Approaches are not sufficient for determining reliable thermodynamic properties.		Study Plan and supplelental response sent to NRC on 10/31/96. Awaiting NRC concurrence.
Comment 25	Waste Package: Rationale on additional testing on waste and interactions between and among *radionuclides on sorption.*		Submit Study Plan 8.3.4.2.4.1 "Characterization of Chemical and Mineralogical Changes in Post-Emplacement Environment" to NRC. *Submit a supplemental response to the NRC.*
Comment 26	Sorption Batch Studies.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 27	Batch Sorption Measurements.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 28	Sorption on Particulates and Colloids.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 29	Biological Sorption and Transport.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 30	Solubility Modeling.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 31	Some parameters and conditions under fracture flow are not planned and need to be determined.		Supplemental response sent to the NRC on 10/29/96. Awaiting NRC concurrence.

Status of Site Characterization Analysis Open Items (continued)

Item ID	Item Description	Status	Action Description
Comment 32	Rock characteristics program: Geophysical integration is insufficient.		Geophysical Integration Group needs to develop a plan to implement integration. *Submit a supplemental response to the NRC.*
Comment 33	Engineering rock parameters are not adequately integrated to develop three-dimensional rock characteristics models.		Study Plan 8.3.1.4.3.1 "Systematic Acquisition of Site Specific Data" submitted to the NRC on 1/11/93. Study Plan 8.3.1.4.2.3 "Three-Dimensional Geologic Modeling" and supplemental response submitted to the NRC on 9/27/96. Awaiting NRC response.
Comment 34	Drilling Program: It is unclear how data from various drill holes will be used in support of various studies, how uncertainties in core retrieval and data analyses will be handled, and how the large volume of existing information will be used to plan the drilling program.		Supplemental response submitted to the NRC on 3/3/92. Awaiting NRC concurrence.
Comment 35	Adequacy of lithological, structural, and drifting activities to characterize the site.	Closed 11/2/92	NRC letter lifting Objection 1. NRC considers this comment closed
Comment 36	Rationale for Investigation 8.3.1.4.2 may not be accurate for the perimeter drift defining lower concentrations of faults.		Supplemental response submitted to the NRC on 6/16/94. Awaiting NRC concurrence.
Comment 37	Identification of blast fractures.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 38	Characterization of faults in the subsurface.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.

Status of Site Characterization Analysis Open Items (continued)

Item ID	Item Description	Status	Action Description
Comment 39	Systematic Dri ng Program: No assessment is provided to support the estimated maximum range of statistical correlation for porosity and air permeability.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 40	Systematic Drilling Program: Spacing of the 30 sample borehole pairs in a range of up to 10,000 feet may represent a lower bound for geostatistical analysis.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 41	Systematic Drilling Program: Tight clustering of sample locations USW SD-8 and USW SD-12 has not been justified.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 42	Adequacy of evaluation of escarpment retreat.	Closed 2/29/96	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 43	Adequacy of numerical goals in erosion, postclosure tectonics, and preclosure tectonics performance assessment tables.	Closed 2/17/95	NRC evaluation of the 7/23/92 DOE supplemental response provided in 2/17/95 letter from Bell to Milner. NRC considers this comment closed.
Comment 44	Waste Package. Overall goal is not consistent with substantially complete containment.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 45	Volcanic rate calculations independent of underlying volcanic-tectonic processes.		Supplemental response submitted to the NRC on 7/12/93. Awaiting NRC concurrence.

Status of Site Characterization Analysis Open Items (continued)

Item ID	Item Description	Status	Action Description
Comment 46	Postclosure Tectonics.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 47	Waste Package: Relationship of postclosure tectonics to the waste package and the engineering barrier system requirements.		Supplemental response submitted to the NRC on 6/9/93. Awaiting NRC concurrence.
Comment 48	Use of fault slip rates on the repository facilities are not conservative.		Prepare and issue topical report "Seismic Design Criteria" in accordance with the Seismic Hazards Issue Resolution Group's Issue Resolution Action Plan. Submit a supplemental response to the NRC.
Comment 49	Volcanism: Results from investigations on basaltic volcanism may fail to meet overall system performance.	Closed 9/14/94	NRC evaluation of Study Plan 8.3.1.8.1.2. NRC considers this comment closed.
Comment 50	Effects of faulting may be underestimated.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers the comment closed.
Comment 51	Adequacy of Geophysics program to determine deep and shallow crustal features.		Geophysical Integration group needs to develop a plan to implement integration.
Comment 52	Use of Geophysics to identify volcanic/igneous features.		Completed assessment by independent consultant of planned and potential geophysical studies that contribute to resolution of volcanism issue. Consultant's preliminary findings were submitted to the NRC on site representative. Submit a supplemental response to the NRC.

Item ID	Item Description	Status	Action Description
Comment 53	Adequacy of natural resource assessment; consideration of ore deposition models		Supplemental response submitted to the NRC on 2/5/93 in Study Plan 8.3.1.9.2.1 NRC Letter 2/18/94 Holonich to Shelor partially closing Site Characterization Analysis Comment 53. Supplemental response submitted to the NRC on 10/07/94. Awaiting NRC concurrence.
Comment 54	Inconsistencies in Site Characterization Plan Chapter 8.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 55	Adequacy of geostatistical approach to geomechanical and thermal properties.		Study Plan 8.3.1.15.1.3, Rev. 1, "Rock Characteristics Program," submitted to the NRC on 6/5/95. Supplemental response submitted to the NRC 9/23/96 recommending closure of this comment. Awaiting NRC concurrence.
Comment 56	Validation of models for mechanical and thermal properties.		Submitted SP 8.3.1.15.1.5, Rev. 1 "Excavation Investigations," to NRC on 5/5/94. Submit 8.3.1.15.1.6 "In Situ Thermomechanical Properties," and 8.3.1.15.1.7, "In Situ Mechanical Properties" to the NRC. The Review of Performance Allocations for Activity 8.3.1.15 "Rock Characteristics Program" needs to be completed. Submit a supplemental response to the NRC.
Comment 57	Design verification does not consider alternative methods of excavation.	Closed 11/2/92	NRC letter lifting Objection 1. NRC considers comment closed.
Comment 58	Descriptions in the in situ design verification section do not include tests to verify design reports.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.

Status of Site Characterization Analysis Open Items (continued)

Item ID	Item Description	Status	Action Description
Comment 59	Description of tectonic and igneous events do not allow for determination of actual investigations to be conducted, and sequencing of activities.		Submit a supplemental response to the NRC.
Comment 60	Performance Assessment: Adequacy of preclosure design and performance goals and characterization parameters.		Resolve concerns in Comment 1. Resolution of Comment 1 will address cross-issues of this comment.
Comment 61	Assumption that future faulting will follow previous faulting.		Submit a supplemental response to the NRC.
Comment 62	The studies of faulting at the surface facilities do not indicate how DOE is proposing to use standoff distances.		Submit a supplemental response to the NRC.
Comment 63	Use of pre-existing and unavailable information for the preclosure tectonics program and the surface facilities.		Submit a supplemental response to the NRC which will describe where in the study plan and the "Test and Evaluation Plan" the concerns of the NRC are addressed.
Comment 64	Adequacy of faults study for design and performance.		Submit a supplemental response to the NRC.
Comment 65	Use of domains to define areas of faulting potential	Closed 7/31/96	NRC evaluation of DOE response. NRC considers this comment closed.

Status of Site Characterization Analysis Open Items (continued)

Item ID	Item Description	Status	Action Description
Comment 66	Release via a single event 10,000 year cumulative slip earthquake.		Complete detailed study to show the facility can conservatively withstand an event exceeding the design basis ground motion. Submit a supplemental response to the NRC.
Comment 67	Data on earthquakes having a cutoff of a magnitude 5.5 may not be sufficient to support an evaluation of the effects of site geology on surface and subsurface motion.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 68	Adequacy of treatment on detachment faulting effects.		Study Plan 8.3.1.17.4.12, Rev. 1 "Tectonic Models and Synthesis" submitted to the NRC on 12/19/94. Awaiting NRC concurrence.
Comment 69	Synthesis of data on the northwest trending faulting.		Study Plan 8.3.1.17.4.12 "Tectonic Models and Synthesis" submitted to the NRC on 12/19/94.
Comment 70	Blast control procedures less important to post-closure performance are not justified.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 71	Adequacy of technologies in assessing faulting for construction, operation, and closure.		Submit a supplemental response to the NRC.
Comment 72	Adequacy of the seal program.	Closed 11/2/92	NRC letter lifting Objection 1. NRC considers this comment closed.

Status of Site Characterization Analysis Open Items (continued)

Item ID	Item Description	Status	Action Description
Comment 73	Performance Assessment: Adequacy of required backfill hydraulic conductivity.		Resume work on the seals program investigation. Prepare the study plan for the measurement of the hydraulic conductivity (currently no numeric designator for this study plan). Submit a supplemental response to the NRC.
Comment 74	Testing of Seal Components: No indication is given as to whether and when the testing to evaluate the behavior of selected sealing components under in situ test conditions will be initiated.		Prepare Study Plan 8.3.3.2.2.3 "In Situ Testing of Seal Components." Submit a supplemental response to the NRC.
Comment 75	Definition of and inconsistent use of geologic setting.	Closed 12/30/93	NRC Evaluation of DOE Responses. NRC considers this comment closed.
Comment 76	NRC reviews cannot be relied on as peer reviews.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 77	Adequacy of considerations of retrieval operations in evaluating the effects of credible accidents on radiological exposure.		Evaluate the effects of credible accidents on radiological exposures during retrieval operation of the Advanced Conceptual Design. Submit a supplemental response to the NRC.
Comment 78	10 CFR Part 20 requirements need to be considered for postclosure.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.

Item ID	Item Description	Status	Action Description
Comment 79	Waste Package: Adequacy of waste package corrosion tests for the repository.		Complete the reviews and revisions of Study Plan 8.3.4.2.4.1 "Characterization of Chemical and Mineralogical Changes in the Post Emplacement Environment" and submit to the NRC. The Lawrence Livermore National Laboratory report, "Metal Barrier Selection and Testing," LLNL SIP CM-01, Rev. 2 was submitted to the NRC on 1/31/95. Submit a supplemental response to the NRC.
Comment 80	Performance goals consistent with interpretation and intent of substantially complete containment.	Closed 3/7/95	NRC Evaluation of the 9/20/94 supplemental response. NRC considers this item closed.
Comment 81	Waste Package: Adequacy of program in stress corrosion cracking behavior of waste packages.		The metals barriers scientific investigation plan was submitted to the NRC on 1/31/95. Evaluation of the extended dry concept with drift emplacement needs to be completed which may make this concern moot. The metals barrier scientific investigation must be initiated and preliminary results released. Submit a supplemental response to the NRC.
Comment 82	Waste Package: There is an inadequate discussion on how the waste package performance may be verified at the time of license application.		Prepare Study Plan 8.3.4.2.4.4 "Engineered Barrier System Field Test" and submit to the NRC. Submit a supplemental response to the NRC.
Comment 83	The term "uniform corrosion" is misleading.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.

Status of Site Characterization Analysis Open Items (continued)

Item ID	Item Description	Status	Action Description
Comment 84	Issue resolution strategy and testing package for the waste package and engineering barrier system do not take into account the full range of likely natural conditions that might affect performance of the barrier.		Consider the effect of unanticipated processes and events on the overall system in the ongoing issue resolution process. Submit a supplemental response to the NRC.
Comment 85	Performance Assessment: Temporal changes in the state of stress due to corrosion of the container is not accounted for.		The metals barriers scientific investigation plan to be completed. Evaluation of the extended dry concept with drift emplacement needs to be completed which may make this concern moot. The metals barrier scientific investigation must be initiated and preliminary results released. Submit a supplemental response to the NRC.
Comment 86	Waste Package: Degradation modes of copper-based alloys do not appear to agree with scientific literature.		Complete the degradation modes surveys for candidate materials and test plans for promising materials. Submit a supplemental response to the NRC.
Comment 87	Waste Package: Adequacy of effects of dissimilar metal contacts causing corrosion.		Advance the waste package design that will narrow the waste package option down to three designs. Describe the use of data from galvanic testing in the waste package design plan. Submit a supplemental response to the NRC.
Comment 88	Waste Package: Assumption of reduced uncertainties because of the unsaturated zone.		The Lawrence Livermore National Laboratory scientific investigation SIP-CM-01 (Rev. 1), "Metal Barrier Selection and Testing" was submitted to the NRC on 1/31/95. Awaiting NRC concurrence.

Status of Site Characterization Analysis Open Items (continued)

Item ID	Item Description	Status	Action Description
Comment 89	Waste Package: Construction materials may change the local pH and affect the corrosion of the metal containers and the leach rates of radionuclides from the glass.		Prepare Study Plan 8.3.4.2.4.5 "Manmade Materials" and submit to the NRC. Submit a supplemental response to the NRC.
Comment 90	Waste Package: Consideration of varying oxygen concentrations on the corrosion of metal containers.		Provide details on how the effects of oxygen on the waste package will be considered. These details will be described in the metal barriers investigation plan. Complete evaluation of the drift emplacement alternative. This alternative would make this concern moot. Submit a supplemental response to the NRC.
Comment 91	Waste Package/Performance Assessment: Consideration of alternative canisters for carbon-14 releases.		Evaluate and describe performance of alternative waste package designs to be considered in advanced conceptual design. Review the new U.S. Environmental Protection Agency standards when they become available. Alternative waste package scenarios need to be developed. A robust design may make this concern moot. Submit a supplemental response to the NRC.
Comment 92	Disturbed Zone: Boundary definition does not include properties affected by heat generated by waste emplacement.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 93	Performance Assessment: Will the site meet the performance objective for prewaste emplacement.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.

Status of Site Characterization Analysis Open Items (continued)

Item ID	Item Description	Status	Action Description
Comment 94	Performance Assessment: Assumption about features, events, processes related to the hydraulic systems in the modeling strategy.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 95	Performance Assessment: Logic used to develop and screen scenarios and its implementation appear to be deficient.		NRC evaluation of DOE response (Letter Austin to Milner; 3/28/96) NRC considers this comment open.
Comment 96	Adequacy of the use of Kd for modeling heterogeneous medium.		Study Plans 8.3.1.3.4.1 "Sorption Study" and 8.3.1.3.4.3 "Development of Sorption Models" were submitted to the NRC on 8/26/94; Study Plan 8.3.1.3.5.1 "Dissolved Species Concentration Limit" was submitted to the NRC on 9/17/93. Submit a supplemental response to the NRC.
Comment 97	Adequacy of evidence to eliminate iodine as an important radionuclide.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 98	Performance Assessment: Appropriateness of weighting Complementary Cumulative Distribution Functions by expert judgment.		Continue the development of the alternative conceptual models. Address the complementary cumulative distribution functions through the iterative total system performance assessment (TSPA) process. Prepare and provide the NRC with documentation on the TSPA and sensitivity studies (related to schedule in Comment 9). Submit a supplemental response to the NRC.
Comment 99	Performance Assessment. Quantification of all releases.		Supplemental response submitted to the NRC on 8/4/94. Awaiting NRC concurrence.

Status of Site Characterization Analysis Open Items (continued)

Item ID	Item Description	Status	Action Description
Comment 100	Performance Assessment: Adequacy of considerations of faulting release scenarios.	Closed 2/8/93	NRC evaluation of DOE responses. The NRC considers this comment closed.
Comment 101	Performance Assessment: Appropriateness of equation used to estimate the partial performance for the 4th scenario class involving release along the water pathway.	Closed 3/28/96	NRC evaluation of DOE Responses. The NRC considers this comment closed.
Comment 102	Performance Assessment: Adequacy of Ross sequences in comparison to the hydrologic flow model.		Supplemental response submitted to the NRC on 8/4/94. Awaiting NRC concurrence.
Comment 103	Performance Assessment: Ross sequences address anticipated conditions and not scenarios.	Closed 3/28/96	NRC evaluation of DOE Responses. The NRC considers this comment closed.
Comment 104	Performance Assessment: Ross sequences address spent fuel but not vitrified waste form.	Closed 2/8/93	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 105	Performance Assessment: Rationale for elimination of scenarios.		NRC evaluation of DOE responses (Letter Austin to Milner 3/28/96) NRC considers this comment open.
Comment 106	Performance Assessment: Missing coupling term for calculation of liquid phase radionuclide transport.	Closed 2/8/93	NRC evaluation of DOE responses. NRC considers this comment closed.

Status of Site Characterization Analysis Open Items (continued)

Item ID	Item Description	Status	Action Description
Comment 107	Performance Assessment: Awaiting time in calculation is OK but care needs to be taken in the empirical complementary cumulative distribution functions in approximating	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 108	Performance Assessment: Use of the estimated partial performance measures to screen scenarios and establish goals.	Closed 2/8/93	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 109	Performance Assessment: Adequacy of treatment of coupling time between matrix and fracture flow in hypothesis testing tables.		Continue total system performance analysis activity that will continue to analyze the coupling times for the transfer of radionuclides between matrix and fracture flow. Submit a supplemental response to the NRC.
Comment 110	Performance Assessment: Adequacy of dealing with human intrusion in the complementary cumulative distribution function.	Closed 2/8/93	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 111	Inconsistencies exist in the Site Characterization Plan on total system performance.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 112	Adequate discussion of state variables as constants or as random variables.	Closed 2/8/93	NRC evaluation of DOE responses. NRC considers this comment closed.

Status of Site Characterization Analysis Open Items (continued)

Item ID	Item Description	Status	Action Description
Comment 113	Consistency of definition of complementary cumulative distribution function and the unit step function.	Closed 2/8/93	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 114	The term "independent" is used instead of "mutually exclusive."	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 115	Adequacy of expanding of complementary cumulative distribution function in terms of scenario classes.	Closed 3/28/96	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 116	Individual exposures via potable water may need to be expanded.		Issuance by the U..S. Environmental Protection Agency of a new Yucca Mountain-specific standard (40 CFR Part 197) for individual exposure standards per the Energy Policy Act of 1992. Revise issue resolution strategy for Site Characterization Plan Issue 1.2. Prepare additional response to NRC. Submit revised issue resolution strategy and response to NRC.
Comment 117	individual exposure rate of carbon-14 may need to consider advective and diffusive flow rates.		Submit a supplemental response to the NRC.
Comment 118	The monitoring and testing activities should include long-term in situ and long-term waste package activities.		Determine testing requirements after site characteristics have advanced far enough to define the performance program. Submit a supplemental response to the NRC.

Status of Site Characterization Analysis Open Items (continued)

Item ID	Item Description	Status	Action Description
Comment 119	Performance Confirmation The information presented is insufficient to determine if the confirmation program meets the requirements of 10 CFR Part 60.		Conduct NRC-DOE interaction on the performance confirmation program. Prepare Study Plan 8.3.3.2.2.3 "In Situ Testing of Seal Components" and then submit to the NRC for acceptance. Prepare Study Plan 8.3.1.15.1.6 "In Situ Thermomechanical Properties" and submit to the NRC. Prepare Study Plan 8.3.4.2.4.4 "Engineered Barrier Field Tests" and submit to the NRC. Submit a supplemental response to the NRC.
Comment 120	Model and computer code validation studies.		Prepare and provide to the NRC the model and computer code validation strategy. Submit a supplemental response to the NRC.
Comment 121	Exploratory Shaft Facility: Adequacy of seismic design of Exploratory Shaft Facility.		Exploratory Studies Facility Design Requirements submitted on 9/9/94. Awaiting NRC concurrence.
Comment 122	Demonstration and acceptability of the dry coring method.		Supplemental response submitted to the NRC on 3/30/94. Awaiting NRC concurrence.
Comment 123	Assessment of effects of ventilation on the Exploratory Shaft Facility.	Closed 6/21/94	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 124	Potential causes for a reduction in the drainage capacity.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 125	Existing data used in the licensing process needs to be qualified.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 126	Items covered by 10 CFR Part 60 (G) are incomplete.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.

Status of Site Characterization Analysis Open Items (continued)

Item ID	Item Description	Status	Action Description
Comment 127	Design Acceptability Analysis.	Closed 11/2/92	NRC letter lifting Objection 1. NRC considers this comment closed.
Comment 128	Requirements applicable to the Exploratory Shaft Facility.	Closed 11/2/92	NRC letter lifting Objection 1. NRC considers this comment closed.
Comment 129	Design Acceptability Analysis and the Exploratory Studies Facility Design Requirements do not consider 10 CFR Part 60 requirements.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 130	Only 22 of fifty-two (52) requirements applicable to the Exploratory Shaft Facility were focused on in the Title I design. The rigor and completeness of the Design Acceptability Analysis are questioned.		Supplemental response submitted to the NRC on 3/3/92. Additional supplemental response submitted to the NRC on 9/25/95. Awaiting NRC concurrence.
Comment 131	Design Acceptability Analysis.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 132	Design Acceptability Analysis.	Closed 11/2/92	NRC letter lifting Objection 1. NRC considers this comment closed.
Comment 133	Design Acceptability Analysis.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Question 1	Integration of mapping efforts.	Closed 12/30/93	NRC evaluation of DOE responses. NRC considers this question closed.

Status of Site Characterization Analysis Open Items (continued)

Item ID	Item Description	Status	Action Description
Question 2	Performance Assessment: Relation between mechanical and hydraulic apertures.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question 3	Repository Design: Rationale used for selecting the total repository area is not presented.		Supplemental response submitted to the NRC on 5/17/94. Awaiting NRC concurrence.
Question 4	Adequacy of temperature logging to evaluate anomalously low heat flow.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question 5	Adequacy of vertical boreholes for evaluation of faults and fractures.		Submitted supplemental response to the NRC on 6/16/94. Awaiting NRC concurrence.
Question 6	Meaning of statement in last paragraph page 8.3.1-75.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question 7	Face mapping of exploratory drifts restricted to areas of anomalous conditions.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question 8	Rock Properties: Level of detail and uncertainty in three-dimensional model.		Submitted Study Plan 8.3.1.4.3.1 "Systematic Acquisition of Site-Specific Subsurface Information" to the NRC for review on 1/19/93. Submit Study Plan 8.3.1.4.3.2 "Three-Dimensional Rock Characteristics Models" to the NRC for review. Submit a supplemental response to the NRC.
Question 9	Systematic Drilling Program: Adequacy of sampling same sequences for rock properties.		Submitted Study Plan 8.3.1.4.3.1 "Systematic Acquisition of Site-Specific Subsurface Information" to the NRC for review on 1/19/93. Submit a supplemental response to the NRC.

Status of Site Characterization Analysis Open Items (continued)

Item ID	Item Description	Status	Action Description
Question 10	How will three-dimensional block model account for variability in the block?	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question 11	Rationale to start drilling prior to approval of study plans.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question 12	Rationale for exclusion of lunar crater b[illegible]ic field as natural analog.		Submitted supplemental response to the NRC on 6/9/93. Awaiting NRC concurrence.
Question 13	Basis for statements made about the migration, structural boundaries, and stage of volcanism.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question 14	Natural Resources: Adequacy of evaluation of previous mining and drilling leases.	Closed 2/18/94	NRC evaluation of DOE responses. NRC considers this question closed.
Question 15	Resource exploration and mineral resource potential.	Closed 2/18/94	NRC evaluation of DOE responses. NRC considers this question closed.
Question 16	Methods for determining the impact of ground motion from underground nuclear explosions.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question 17	Rock Properties: Activities to investigate effects on.	Closed 4/21/93	NRC evaluation of DOE responses. NRC considers this question closed.
Question 18	Allowable movements on joints related to rock mass strength.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question 19	Side Looking Airborne Radar (SLAR).	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.

Status of Site Characterization Analysis Open Items (continued)

Item ID	Item Description	Status	Action Description
Question 20	Repository Design: Discussion of vertical or horizontal emplacement.		Supplemental response submitted to the NRC on 6/16/94. Awaiting NRC concurrence.
Question 21	Process to assure the parameters for performance goal C2 (radiation shielding of rock) is comprehensive enough, and expected values, realistic.		Further develop the advanced conceptual design. Submit a supplemental response to the NRC.
Question 22	Parameters related to repository construction and operation.		Supplemental response submitted to the NRC on 3/30/94. Awaiting NRC concurrence.
Question 23	Computer code verification and validation.		Submit a supplemental response to the NRC.
Question 24	Justification that the shaft liner does not provide structural support for the formation.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question 25	Heterogeneous air flow characteristics for seal program.		Supplemental response submitted to the NRC on 4/13/93. Awaiting NRC concurrence.
Question 26	Inconsistency between tentative Design Goals and Design Performance Goals.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question 27	Storage capacity at base of shaft for attaining the tentative design goals.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question 28	ES-1 penetration of the Calico Hills Unit: Impacts of the current sealing program and issue resolution strategy 4.4.		Supplemental response submitted to the NRC on 3/3/92. Awaiting NRC concurrence.

Status of Site Characterization Analysis Open Items (continued)

Item ID	Item Description	Status	Action Description
Question 29	Justification that references cited present results representative of conditions at Yucca Mountain.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question 30	Waste Package: Water quality as related to waste package design.		The metal barriers scientific investigation plan was submitted to the NRC on 1/31/95. Complete evaluation of the drift emplacement alternative needs. Submit a supplemental response to the NRC.
Question 31	Waste Package: Integrity of spent fuel cladding.		Supplemental response submitted to the NRC on 9/16/92. Awaiting NRC concurrence.
Question 32	Waste package: Container "similarity" for borosilicate glass waste vs. spent fuel.		Advance the waste package design and narrow the waste package options down to three designs. Submit a supplemental response to the NRC.
Question 33	Waste Package: Emplacement hole drainage concerns.		Evaluate water-vapor interface, crevice corrosion, and galvanic corrosion testing in the metal barriers scientific investigation plan during advanced conceptual design. Complete evaluation of the drift emplacement alternative. This alternative would make this concern moot. Submit a supplemental response to the NRC.
Question 34	Waste Package/Performance Assessment: Meaning of undetected defective closures.		Submit a supplemental response to the NRC.
Question 35	Waste Package: Acceptance criteria for helium leak results	Closed 3/7/95	NRC Staff evaluation of the 12/02/94 supplemental response. NRC considers this item closed.

Status of Site Characterization Analysis Open Items (continued)

Item ID	Item Description	Status	Action Description
Question 36	Waste Package: Contact of canisters with corrosive elements during shipping and handling.		Advance the waste package design and narrow options down to three designs. Submit a supplemental response which will further address the issue of eliminating corrosion elements during manufacture of the container to the NRC.
Question 37	Waste package: Basis for 10 cm of free fall for caniste and contents.	Closed 3/7/95	NRC evaluation of the 11/23/94 supplemental response. NRC considers this question closed.
Question 38	What is the basis for the 1-mm thinning criterion for waste package scratching.		Submitted a supplemental response to the NRC on 7/12/93. Awaiting NRC concurrence.
Question 39	Waste Package: Defining "unusual process history" of canister.		Advance the design of the waste package. Submit a supplemental response to the NRC.
Question 40	Waste Package: Basis for factor of 2 on borehole liner in comparison to container material.		Study effects of water containing liner corrosion products on degradation of the container in accordance with the metal barriers scientific investigation plan. Submit a supplemental response to the NRC.
Question 41	Reposito[illegible] [illegible]deration of 10 CFR 60.132 (a) in resolution of Issue 2.4.		Conduct engineering studies to evaluate the waste throughput requirements. Submit a supplemental response to the NRC.
Question 42	Repository: Assumption of stability of vertical emplacement hole.		Advance the advanced conceptual design. Drift emplacement may make this comment moot. Submit a supplemental response to the NRC.
Question 43	Waste Package: Anticipated operational occurrences considered part of normal conditions on the preclosure design and analysis.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.

Status of Site Characterization Analysis Open Items (continued)

Item ID	Item Description	Status	Action Description
Question 44	Waste Package/Performance Assessment: Basis for assumed numbers of breached assemblies or canisters.		Provide information on failures of waste forms in multiple locations. Prepare and provide the NRC with documentation on the Total System Performance Assessment. Advance the Advanced Conceptual Design and narrow options to two candidate designs. Submit a supplemental response to the NRC.
Question 45	Waste Package: Investigation of particulate source terms, retention factors, and plate-out of waste package during accident conditions.		Supplemental response submitted to the NRC on 11/8/94. Awaiting NRC concurrence.
Question 46	Waste Package: Basis for stricter containment of long half-life isotopes.	Closed 7/11/94	NRC evaluation of DOE response. NRC considers this question closed.
Question 47	Waste Package: Assumption on breached waste containers.	Closed 3/7/95	NRC evaluation of the 9/20/94 supplemental response. NRC considers this question closed.
Question 48	Waste Package: Selection of peer review panel on waste package.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question 49	Waste Package. Effects of low temperature oxidation on containers.		Advance the design of the waste package to three options. The metal barriers scientific investigation plan was submitted to the NRC on 1/31/95.
Question 50	Waste Package: Assumption that stress propagation results in corrosion.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.

Status of Site Characterization Analysis Open Items (continued)

Item ID	Item Description	Status	Action Description
Question 51	Design second research criteria for accepting waste from Idaho National Engineering Laboratory and Hanford.	Closed 11/8/94	NRC evaluation of DOE responses. NRC considers this question closed.
Question 52	Waste Package: Leaching properties specification will require the producer to control leaching characteristics of the glass waste	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question 53	Waste Package: Specification of cooling rate of the glass waste.	Closed 3/7/95	NRC evaluation of the 10/07/94 supplemental response. NRC considers this question closed.
Question 54	Waste Package: Release rates of radionuclides from spent fuels.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question 55	Exploratory Shaft Facility: Interference at the Exploratory Shaft Facility by waste storage tanks, septic field, and waste water lagoon.		Submit a supplemental response to the NRC.
Question 56	Basis for 5 cm of fault displacement in waste package environment.		Supplemental response submitted to the NRC on 5/17/94. Awaiting NRC concurrence.
Question 57	Effects of drilling multipurpose boreholes.		Supplemental response submitted to the NRC on 3/24/93. Awaiting NRC concurrence.
Question 58	Flexibility of the Exploratory Shaft Facility design to accommodate in situ testing of the waste package, if required.		Supplemental response submitted to the NRC on 1/31/94. Awaiting NRC concurrence.

Status of Site Characterization Analysis Open Items (continued)

Item ID	Item Description	Status	Action Description
Question 59	Basis for length of in situ thermal tests.		Prepare Study Plan 8.3.1.15.1.6 "In Situ Thermomechanical Properties" and submit to NRC. *[illegible] a supplemental response to the NRC.*
Question 60	Exploratory Shaft Facility: Timing of Exploratory Shaft Facility radial borehole test.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question 61	Exploratory Shaft Facility: Accommodation of design changes during Exploratory Shaft Facility construction.	Closed 11/2/92	NRC letter lifting Objection 1. NRC considers this question closed.
Question 62	Repository: Basis for 500 feet of separation from Exploratory Shaft Facility and waste emplacement panel.		Submit a supplemental response to the NRC.
Question 63	Certifying Training Attendance Record reviewers were not principal investigators.	Closed 7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.

PROGRESS REPORT #16

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APPENDIX F

Determination of Importance Evaluations

PROGRESS REPORT #16

APPENDIX F

Determination of Importance Evaluations

This appendix lists determination of importance evaluations performed during this reporting period. Performance of a determination of importance evaluation is the mechanism established by the Project to evaluate proposed field activities with respect to their potential for adverse impact on Q-List (DOE, 1997b) items or site characterization testing. Because the natural barriers are included in the Q-List, each determination of importance evaluation essentially comprises both a waste isolation evaluation and a test interference evaluation for the proposed activity. Where a reasonable potential for adverse impact is identified, the evaluation establishes appropriate quality assurance (QA) controls for the activity to prevent or limit the adverse impact. These controls are then transcribed into the applicable documents for implementing the activity; for example, field work packages, design packages, specifications, and drawings.

The determination of importance evaluation process is controlled by an Implementing Line Procedure. Provision for a determination of importance evaluation is an integral part of the planning process for all site-disturbing activities, including testing activities as well as design and construction activities. Temporary, non-quality-affecting items are evaluated to the extent that their placement, construction/erection, or operation/utilization presents a potential for adverse impact on Q-List items or site characterization testing. Any proposed use of tracers, fluids, or materials is specifically required to be evaluated. The safety assurance department, which prepares determination of importance evaluations, receives requests for evaluations of site-disturbing activities from all Project participants.

The determination of importance procedure (NLP-2.0, Determination of Importance Evaluations) provides for flexibility in evaluating site impacts through the use of category definitions. Category I evaluations are for activities that would not reasonably impact Q-List items or site characterization testing. Category II evaluations are for activities where the potential impacts are encompassed by existing evaluations such that no new QA controls are warranted. Category III evaluations are used for activities that present a potential for adverse impact but have not been previously evaluated. Category III determination of importance evaluations establish new QA controls for those activities as required.

Documents cited in this appendix are included in the consolidated reference list for this progress report (Appendix L).

The following determination of importance evaluations and revisions were completed or substantially completed during this reporting period.

PROGRESS REPORT #16

Exploratory Studies Facility (ESF) Determination of Importance Evaluations

- Category II Determination of Importance Evaluation for Testing in the ESF Thermal Testing Facility Heated Drift, (CRWMS M&O, 1996ii): This evaluation was prepared to support testing activities to be performed in the Thermal Testing Facility for the drift-scale heater test. Water use associated with the wet drilling of boreholes needed for equipment and test instrumentation emplacement was included in the evaluation. The evaluation concluded that one additional site-specific QA control was warranted to clarify existing requirements as applied to this specific activity, and that the activity was otherwise bounded by the conclusions contained in the existing Category III Determination of Importance Evaluation for the Subsurface ESF (CRWMS M&O, 19[illegible]). Thus, the site-specific control contained in this determination of importance evaluation, co[illegible] with the requirements contained in the existing Category III Determination of Importance Evaluation for the Subsurface ESF, are adequate to limit any potential for adverse test interference or waste isolation impacts.

- Revision to the Category II Determination of Importance Evaluation for Testing in the ESF Thermal Testing Facility Heated Drift (CRWMS M&O, 1996ii): This revision incorporated the proposed addition of a concrete liner (to be tested), a concrete invert floor (to facilitate testing), and a thermal bulkhead in the heated drift of the Thermal Testing Facility, and the actual heating of the heated drift. The evaluation concluded that one additional site-specific QA control was warranted to clarify existing requirements as applied to this specific activity, and that the activity was otherwise bounded by the conclusions contained in the existing Category III Determination of Importance Evaluation for the Subsurface ESF (CRWMS M&O, 1997v). Thus, the site-specific control contained in this determination of importance evaluation, coupled with the requirements contained in the existing Category III Determination of Importance Evaluation for the Subsurface ESF, are adequate to limit any potential for adverse test interference or waste isolation impacts.

- Revision to the Category II Determination of Importance Evaluation for Phase I Testing in the Topopah Spring Main Drift Thermal Testing Facility (CRWMS M&O, 1996jj): This revision revised the scope of the evaluation to remove testing activities associated with the sequential drift mining of the access and observation drift of the Thermal Testing Facility such that water used to drill boreholes beyond the location of the thermal-mechanical alcove could be more suitably evaluated as a part of the larger heated-drift test block. The conclusions of the evaluation were unchanged; i.e., that the existing Category III Determination of Importance Evaluation for the Subsurface ESF (CRWMS M&O, 1997v) contains adequate QA controls to limit any potential for adverse test interference or waste isolation impacts.

- Revision to the Category III Determination of Importance Evaluation for the Subsurface ESF (CRWMS M&O, 1997v): This revision was prepared primarily to incorporate recent changes to the subsurface hydrologic water model and to address water reporting in the subsurface ESF after holeout of the tunnel boring machine. Numerous other changes were made to the evaluation, including the incorporation of five existing Category II determination of importance evaluations. The overall conclusions of the evaluation remained unchanged, and there were only minor changes to the QA controls required to prevent or minimize test interference and waste isolation impacts.

- Revision to the Category III Determination of Importance Evaluation for the Surface ESF (CRWMS M&O, 1997v): This revision was prepared to revise the evaluation of reclamation materials to consider biodegradability; to prohibit the use of a particular dust suppression compound within the Conceptual Controlled Area Boundary without additional evaluation (required because of a recent change to the main chemical constituent of this compound); to make changes to the text as appropriate based on a review of the use of certain words having precise definitions within the argot of the Project's QA Program (e.g., "surveillance," "inspection," "monitoring"); to update references as appropriate; and to make various minor editorial, grammatical, and/or typographical changes throughout. The overall conclusions of the evaluation remained unchanged, and there were only minor changes to the QA controls required to prevent or minimize test interference and waste isolation impacts.

- Category II Determination of Importance Evaluation for Confirmation Drilling in the Exploratory Studies Facility (CRWMS M&O, 1997x): This evaluation addressed the drilling of two boreholes in the left rib of Alcove #1. One was to be drilled wet and the second to be drilled dry. The evaluation concluded that the existing Category III Determination of Importance Evaluation for the Subsurface ESF (CRWMS M&O, 1997v) contains adequate QA controls to limit any potential for adverse test interference or waste isolation impacts.

- Category II Determination of Importance Evaluation for the ESF Drift-Scale Flux and Niche Study (CRWMS M&O, 1997y): This evaluation was prepared to support the construction of two niches to be excavated in the west (right) rib of the main drift of the Topopah Spring loop and subsequent hydrology testing to be performed in the niches. The evaluation indicates that additional site-specific QA controls are warranted to clarify existing requirements as applied to these specific activities and that the activities are otherwise bounded by the conclusions contained in the existing Category III Determination of Importance Evaluation for the Subsurface ESF (CRWMS M&O, 1997v). Thus, the site specific controls contained in this determination of importance evaluation, coupled with the requirements contained in the existing Category III Determination of Importance Evaluation for the Subsurface ESF, are adequate to limit any potential for adverse test interference or waste isolation impacts.

Surface-Based Testing Determination of Importance Evaluations

- Revision to the Category I Determination of Importance Evaluation for Remote Surface Seismic Monitoring of the ESF (CRWMS M&O, 1996kk): This revision was prepared to reflect a change in the planned location for one of the monitoring activities to be performed by Sandia National Laboratories and to add a new Los Alamos National

Laboratory monitoring activity involving the installation of seven seismometers and two magnetometers at eight sites. The conclusions of the evaluation remained unchanged (i.e., that the activities are limited in scope and duration such that the disturbances are negligible and that no impacts to waste isolation or site characterization ac· ·ities are expected).

- Revision to the Category II Determination of Importance Evaluation for Yucca Mountain Site Characterization Project Surface-Based Testing Reclamation Activities (CRWMS M&O, 1997z): This revision added interim reclamation activities to the scope of the evaluation, evaluated activities more generally with respect to their proposed physical location (inside or outside of the Test and Waste I· ·ation Evaluation Zone), and updated references as appropriate. The issuance of this re·ision supported the timely commencement of certain interim reclamation activities being conducted in Midway Valley. The "window" for performing those activities was of a limited duration, such that any delay in starting the work could not have been accommodated (the work would have to have been postponed for at least one year, and possibly for up to five years). The evaluation concluded that the existing Category III Determination of Importance Evaluation for the Surface ESF (CRWMS M&O, 1997aa) contains adequate QA controls to limit any potential for adverse test interference or waste isolation impacts.

APPENDIX G

Study Plan Status

APPENDIX G

Study Plan Status

This appendix shows the completion and review status of each study plan. Study plans are the means chosen to describe test plans, the methods to be used, the results expected, and how the results will be applied. They are the control mechanisms for the investigations that make up the site characterization program.

Information presented in Appendix G includes the study plan number and title, as well as the following dates:

- Date of submittal to the Yucca Mountain Site Characterization Office
- Date of approval by the Yucca Mountain Site Characterization Office
- Date of completion of U.S. Nuclear Regulatory Commission initial review with no objections
- Date of receipt of comments from the State of Nevada.

Study Plan Status

Study Plan Number	Study Plan Title	Submitted to YMSCO[a]	Approved by YMSCO[b]	Reviewed by NRC[c]	Reviewed by NV[d]
8.3.1.2.1.1	Characterization of the Meteorology for Regional Hydrology	6/26/90	3/13/91	10/21/91	12/10/91
8.3.1.2.1.2	Characterization of Runoff and Streamflow	3/27/89	8/21/90	5/14/91	4/12/91
8.3.1.2.1.3	Characterization of the Regional Ground-Water Flow System	3/1/90	1/18/91	10/4/91	3/19/93
8.3.1.2.1.4	Regional Hydrologic System Synthesis and Modeling	6/6/90	12/18/91	5/6/92	1/29/93
8.3.1.2.2.1	Characterization of Unsaturated-Zone Infiltration	3/9/90	1/18/91	5/31/91	
8.3.1.2.2.2, R0	Water Movement Test	9/23/87	11/9/89	4/8/93	
8.3.1.2.2.2, R1	Water Movement Test	10/17/91	2/10/93	4/8/93	
8.3.1.2.2.3	Characterization of Percolation in the Unsaturated Zone--Surface-Based Study	8/12/88	4/8/91	3/26/92	
8.3.1.2.2.4	Characterization of the Yucca Mountain Unsaturated Zone in the Exploratory Studies Facility (.4, .5, .7, .8, .9)	9/9/87	1/9/89	3/5/93	
8.3.1.2.2.4, R1	Characterization of the Yucca Mountain Unsaturated Zone in the Exploratory Studies Facility (.4, .5, .7, .8)	12/4/92	1/14/93	3/5/93	
8.3.1.2.2.4, R2	Characterization of the Yucca Mountain Unsaturated Zone in the Exploratory Studies Facility (.10)	3/16/93	6/2/94	9/15/94	
8.3.1.2.2.4, R3	Characterization of the Yucca Mountain Unsaturated Zone in the Exploratory Studies Facility (.1, .2)	4/29/94	5/15/96		
8.3.1.2.2.5	Diffusion Tests in the Exploratory Studies Facility	11/1/88	4/22/92	1/19/93	11/1/93

Study Plan Status (continued)

Study Plan Number	Study Plan Title	Submitted to YMSCO[a]	Approved by YMSCO[b]	Reviewed by NRC[c]	Reviewed by NV[d]
8.3.1.2.2.5, R1	Diffusion Tests in the Exploratory Studies Facitity	5/19/95	Waiting on Principal Investigator's revisions		
8.3.1.2.2.6	Characterization of Gaseous-Phase Movement in the Unsaturated Zone	6/12/89	6/11/91	10/7/91	5/1/92
8.3.1.2.2.6, R1	Characterization of Gaseous-Phase Movement in the Unsaturated Zone	4/6/93	9/30/93		
8.3.1.2.2.7	Hydrochemical Characterization of the Unsaturated Zone	10/24/88	9/18/90	5/1/92	12/28/92
8.3.1.2.2.7, R1	Hydrochemical Characterization of the Unsaturated Zone	12/1/92	9/9/93	1/26/94	
8.3.1.2.2.8	Fluid Flow in Unsaturated, Fractured Rock	9/7/90	8/12/92	1/28/93	
8.3.1.2.2.8, R1	Fluid Flow in Unsaturated, Fractured Rock	12/1/92	12/17/93	8/23/94	
8.3.1.2.2.9	Site Unsaturated-Zone Modeling and Synthesis	1/25/91	7/1/93	11/8/93	
8.3.1.2.3.1.1-6	Characterization of the Site Saturated-Zone Ground-Water Flow System	5/31/89	2/13/91	12/6/91	
8.3.1.2.3.1.7	Characterization of the Site Saturated-Zone Ground-Water Flow System	2/8/88	2/22/90	12/6/91	
8.3.1.2.3.2	Characterization of the Saturated-Zone Hydrochemistry	3/28/90	4/22/92	1/4/93	

Study Plan Status (continued)

Study Plan Number	Study Plan Title	Submitted to YMSCO[a]	Approved by YMSCO[b]	Reviewed by NRC[c]	Reviewed by NV[d]
8.3.1.2.3.3	Saturated-Zone Hydrologic System Synthesis and Modeling	9/4/90	1/14/93	6/16/93	
8.3.1.3.1.1	Ground-Water Chemistry Model	3/15/91	5/4/94		
8.3.1.3.2.1	Mineralogy, Petrology, and Chemistry of Transport Pathway	1/22/88	6/13/89	8/20/90	12/28/92
8.3.1.3.2.2	History of Mineralogical and Geochemical Alteration of Yucca Mountain	3/28/88	12/18/91	4/27/92	1/24/94
8.3.1.3.3.1	Natural Analog of Hydrothermal Systems in Tuff	No study plan to be developed, overlaps planned activities in Study Plans 8.3.4.2.4.1 and 8.3.1.20.1.1			
8.3.1.3.3.2	Kinetics and Thermodynamics of Mineral Evolution	3/25/94	10/23/96		
8.3.1.3.3.3	Conceptual Model of Mineral Evolution	Combined with Study Plan 8.3.1.3.3.2			
8.3.1.3.4.1	Batch Sorption Studies	10/28/9[illegible]	8/4/94		
8.3.1.3.4.2	Biological Sorption and Transport	12/12/8[illegible]	[illegible]25/92	3/25/93	
8.3.1.3.4.3	Development of Sorption Models	Combined with Study Plan 8.3.1.3.4.1			
8.3.1.3.5.1/2	Dissolved Species Concentration Limits and Colloid Behavior (8.3.1.3.5.1 and 8.3.1.3.5.2 have been combined)	9/7/90	9/9/93		
8.3.1.3.6.1	Dynamic Transport Column Experiments	3/10/93	9/30/96		
8.3.1.3.6.2	Diffusion	7/24/89	8/6/93	1/19/94	
8.3.1.3.7.1	Retardation Sensitivity Analysis	12/14/88	8/11/92	1/19/93	

Study Plan Status (continued)

Study Plan Number	Study Plan Title	Submitted to YMSCO[a]	Approved by YMSCO[b]	Reviewed by NRC[c]	Reviewed by NV[d]
8.3.1.3.7.2	Demonstration of Applicability of Laboratory Data to Repository Transport Calculations	Out year – under development			
8.3.1.3.8.1	Gaseous Radionuclide Transport Calculations and Measurements	No study plan to be developed Work Scope covered under Study Plan 8.3.1.2.2.6 and Activity 8.3.1.3.7.1.3.			
8.3.1.4.2.1	Characterization of the Vertical and Lateral Distribution of Stratigraphic Units Within the Site Area	4/12/90	6/9/92	12/14/92	
8.3.1.4.2.2	Characterization of the Structural Features Within the Site Area	9/4/87	2/2/89	2/8/93	
8.3.1.4.2.2, R1	Characterization of the Structural Features Within the Site Area (.3, .5)	2/27/90	4/22/92	2/8/93	
8.3.1.4.2.2, R2	Characterization of the Structural Features Within the Site Area (.3, .5)	11/18/92	12/22/92	2/8/93	2/11/94
8.3.1.4.2.3	Three-Dimensional Geologic Model	2/13/95	9/19/96		
8.3.1.4.3.1	Systematic Acquisition of Site-Specific Subsurface Information	3/27/90	12/8/92	7/19/93	
8.3.1.4.3.2	Three-Dimensional Rock Characteristics Models	5/4/94	9/18/95		
8.3.1.5.1.1	Characterization of Modern Regional Climate	6/24/93	7/25/94		
8.3.1.5.1.2	Paleoclimate Study: Lake, Playa, and Marsh Deposits	10/25/90	10/31/91	4/27/92	1/24/94
8.3.1.5.1.3	Climatic Implications of Terrestrial Paleoecology	2/11/91	1/17/92	8/27/92	1/24/94

Study Plan Status (continued)

Study Plan Number	Study Plan Title	Submitted to YMSCO[a]	Approved by YMSCO[b]	Reviewed by NRC[c]	Reviewed by NV[d]
8.3.1.5.1.4	Analysis of the Paleoenvironmental History of the Yucca Mountain Region	3/30/90	5/29/91	12/06/91	1/11/93
8.3.1.5.1.5	Paleoclimate-Paleoenvironmental Synthesis	2/2/95	3/15/96		
8.3.1.5.1.6	Characterization of the Future Regional Climate and Environments	12/29/93	6/15/94	10/18/94	
8.3.1.5.2.1	Characterization of the Quaternary Regional Hydrology (.3, .4, .5)	1/26/88	6/8/89	11/24/89	4/9/91
8.3.1.5.2.1, R2	Characterization of the Quaternary Regional Hydrology (.1)	9/25/90	11/10/92	6/24/93	11/1/93
8.3.1.5.2.2	Characterization of Future Regional Hydrology Due to Climate Changes	1/16/91	11/10/92	4/5/93	11/1/93
8.3.1.6.1.1	Distribution and Characteristics of Present and Past Erosion	No study plans to be developed, superseded by the Erosion Topical Report			
8.3.1.6.2.1	Influence of Future Climatic Conditions on Locations and Rates of Erosion				
8.3.1.6.3.1	Evaluation of the Effects of Future Tectonic Activity on Erosion at Yucca Mountain				
8.3.1.6.4.1	Development of a Topical Report on the Effects of Erosion				
8.3.1.8.1.1	Probability of Magmatic Disruption of the Repository	3/29/89	9/19/90	10/5/91	8/8/91
8.3.1.8.1.1, R3	Probability of Magmatic Disruption of the Repository	11/16/95	5/15/96		

Study Plan Status (continued)

Study Plan Number	Study Plan Title	Submitted to YMSCO[a]	Approved by YMSCO[b]	Reviewed by NRC[c]	Reviewed by NV[d]
8.3.1.8.1.2	Physical Processes of Magmatism and Effects on the Repository	10/21/92	9/21/93	9/14/94	
8.3.1.8.2.1	Analysis of Waste Package Rupture Due to Tectonic Processes and Events	12/15/89	11/16/92	11/19/93	
8.3.1.8.2.1, R1	Tectonic Effects: Evaluations of Changes in the Natural and Engineered Barrier Systems Resulting from Tectonic Processes and Events	2/18/94	5/9/96		
8.3.1.8.3.1	Analysis of the Effects of Tectonic Processes and Events on Average Percolation Flux Rates Over the Repository	These studies have been combined into 8.3.1.8.2.1 R1			
8.3.1.8.3.2	Analysis of the Effects of Tectonic Processes and Events on Changes in Water-Table Elevation				
8.3.1.8.3.3	Analysis of the Effects of Tectonic Processes and Events on Local Fracture Permeability and Effective Porosity				
8.3.1.8.4.1	Analysis of the Effects of Tectonic Processes and Events on Rock Geochemical Properties				
8.3.1.8.5.1	Characterization of Volcanic Features	12/14/88	4/18/90	8/20/90	2/21/91
8.3.1.8.5.2	Characterization of Igneous Intrusive Features	10/13/92	3/7/94	8/22/94	

Study Plan Status (continued)

Study Plan Number	Study Plan Title	Submitted to YMSCO[a]	Approved by YMSCO[b]	Reviewed by NRC[c]	Reviewed by NV[d]
8.3.1.8.5.3	Investigation of Folds in Miocene and Younger Rocks of the Region	No study plan to be developed			
8.3.1.9.1.1	An Evaluation of Natural Processes that Could Affect the Long-Term Survivability of the Surface Marker System at Yucca Mountain				
8.3.1.9.2.1	Natural Resource Assessment of Yucca Mountain, Nye County, Nevada	7/13/90	11/6/92	3/16/93	2/11/94
8.3.1.9.2.2	Water Resource Assessment of Yucca Mountain, Nevada	10/6/89	8/26/91	5/4/92	12/28/92
8.3.1.9.[illegible]	Evaluation of Data Needed to Support an Assessment of the Likelihood of Future Inadvertent Human Intrusion at Yucca Mountain as a Result of Exploration and/or Extraction of Natural Resources	No study plans to be developed			
8.3.1.9.3.2	An Evaluation of the Potential Effects of Exploration for, or Extraction of, Natural Resources on the Hydrologic Characteristics at Yucca Mountain				
8.3.1.12.2.1	Meteorological Data Collection at the Yucca Mountain Site	9/28/90	3/20/91	11/12/91	12/2/91
8.3.1.12.2.1, R1	Meteorological Data Collection at the Yucca Mountain Site	3/31/92	8/9/93		
8.3.1.12.2.1, R2	Meteorological Data Collection at the Yucca Mountain Site	5/20/96	7/1/96		
8.3.1.14.2	Studies to Provide Soil/Rock Properties of Potential Locations of Surface/Subsurface Facilities	7/15/91	10/01/91	1/24/92	4/6/92

Study Plan Status (continued)

Study Plan Number	Study Plan Title	Submitted to YMSCO[a]	Approved by YMSCO[b]	Reviewed by NRC[c]	Reviewed by NV[d]
8.3.1.16.1.1	Characterization of Flood Potential of the Yucca Mountain Site	3/30/89	9/17/90	5/8/91	1/22/91
8.3.1.16.2.1	Location of Adequate Water Supply for Construction, Operation, Closure, and Decommissioning of a Mined Geologic Disposal System at Yucca Mountain, Nevada	No study plan to be developed			
8.3.1.16.3.1	Determination of the Preclosure Hydrologic Conditions of the Unsaturated Zone at Yucca Mountain, Nevada	No study plan to be developed			
8.3.1.17.1.1	Potential for Ash Fall at the Site	No study plan to be developed			
8.3.1.17.2.1	Faulting Potential at the Repository	No study plan to be developed, combined with Study Plan 8.3.1.17.3.6.			
8.3.1.17.3.1	Relevant Earthquake Sources	8/1/90	12/18/91	5/18/92	1/13/93
8.3.1.17.3.1. R1	Relevant Earthquake Sources	2/18/94	5/15/96		
8.3.1.17.3.2	Underground Nuclear Explosion Sources	All activities rely on available data and are completed.			
8.3.1.17.3.3.1	Ground Motion from Regional Earthquakes	4/21/94	4/24/95		
8.3.1.17.3.3.2	Ground Motion from Underground Nuclear Explosions	2/2/94	9/6/94	12/22/94	
8.3.1.17.3.4	Effects of Local Site Geology on Surface and Subsurface Motions	7/6/90	11/14/91	6/8/92	1/11/93
8.3.1.17.3.5	Ground Motion at the Site from Controlling Seismic Events	10/4/90	7/9/93	11/2/93	
8.3.1.17.3.6	Probabilistic Seismic Hazards Analyses	10/17/94	4/12/95		

Study Plan Status (continued)

Study Plan Number	Study Plan Title	Submitted to YMSCO[a]	Approved by YMSCO[b]	Reviewed by NRC[c]	Reviewed by NV[d]
8.3.1.17.4.1	Historical and Current Seismicity	10/17/89	9/17/90	5/14/91	11/1/93
8.3.1.17.4.1, R1	Historical and Current Seismicity	11/16/93	11/9/94	2/17/95	
8.3.1.17.4.2	Location and Recency of Faulting Near the Prospective Surface Facilities	12/6/88	5/22/89	11/24/89	5/20/90
8.3.1.17.4.3	Quaternary Faulting Within 100 km of Yucca Mountain, Including the Walker Lane	3/25/92	1/21/93	9/2/93	3/3/94
8.3.1.17.4.4	Quaternary Faulting Proximal to the Site Within Northeast-Trending Fault Zones	3/3/92	3/18/93	9/2/93	
8.3.1.17.4.5	Detachment Faults at or Proximal to Yucca Mountain	5/1/90	7/20/92	2/1/93	1/24/94
8.3.1.17.4.6	Quaternary Faulting Within the Site Area	10/14/88	1/23/91	10/3/91	1/13/95
8.3.1.17.4.7	Subsurface Geometry and Concealed Extensions of Quaternary Faults at Yucca Mountain	No study plan to be developed, scope transferred to Study Plans 8.3.1.4.2.1 and 8.3.1.17.3.6			
8.3.1.17.4.8	Stress Field Within and Proximal to the Site Area	Cancelled. Scope transferred to Study Plan 8.3.1.17.4.12			
8.3.1.17.4.9	Tectonic Geomorphology of the Yucca Mountain Region	No study plan to be developed, scope transferred to Study Plans 8.3.1.5.1.4, 8.3.1.17.4.3, and 8.3.1.17.4.2			
8.3.1.17.4.10	Geodetic Leveling	3/30/90	1/18/91	10/4/91	2/1/93
8.3.1.17.4.11	Characterization of Regional Lateral Crustal Movement	No study plan to be developed, all activities were transferred to Study Plan 8.3.1.17.4.10			
8.3.1.17.4.12	Tectonic Models and Synthesis	4/30/93	11/18/94	2/6/95	

Study Plan Status (continued)

Study Plan Number	Study Plan Title	Submitted to YMSCO[a]	Approved by YMSCO[b]	Reviewed by NRC[c]	Reviewed by NV[d]
8.3.1.17.4.12, R1	Tectonic Models and Synthesis	4/13/95	6/13/95		
8.3.1.20.1.1	Characterization of the Altered Zone	1/30/95			
8.3.3.2.2.1	Seal Material Properties Development	2/2/96	8/9/96		
8.3.3.2.2.3	In Situ Testing of Seal Components	9/16/94	7/19/96		
8.3.4.2.4.1	Characterization of the Chemical and Mineral Changes in the Postemplacement Environment	8/8/94	in review		
8.3.4.2.4.2	Hydrological Properties of Waste Package Environment	12/20/93	2/27/95		
8.3.4.2.4.2, R1	Hydrological Properties of Waste Package Environment	2/28/95	9/27/96		
8.3.4.2.4.3	Characterization of the Geomechanical Attributes for the Waste Package Environment	6/28/89	12/11/92	4/21/93	
8.3.4.2.4.4	Engineered Barrier System Field Tests	7/9/93	10/17/95		
8.3.4.2.4.5	Effects of Man-Made Materials on Water Chemistry	4/28/94	in review		

[a]Submitted to Yucca Mountain Site Characterization Office (YMSCO) and under review.
[b]Completed YMSCO review.
[c]Completed U.S. Nuclear Regulatory Commission (NRC) initial review with no objections.
[d]Received comments from State of Nevada.
[e]R0, R1, etc., indicate revision number.

APPENDIX H

Site Characterization Program Baseline History

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APPENDIX H

Site Characterization Program Baseline History

This appendix discusses revisions that have been made to the Site Characterization Program Baseline. The baseline document provides the Program baseline against which changes to the plans for characterizing the Yucca Mountain site are documented. The baseline document also provides the objectives of each Site Characterization Plan study and information on test controls and testing constraints applicable to the Exploratory Studies Facility.

The following table shows the revision number of each of the 13 revisions that have been made to the Baseline and the date the revision was issued. The table also describes the scope and nature of each revision.

Site Characterization Program Baseline History

Revision	Issued	Revisions
0	2/22/91	Initial Issue
1	4/5/91	Updated information related to the Exploratory Studies Facility (ESF). Incorporated changes to program planning resulting from the "Exploratory Studies Facility Alternatives Study: Final Report."
2	10/2/91	Revised plans for testing in Site Characterization Plan Section 8.3.1.14. Consolidated all the expected studies under Investigation 8.3.1.14 into one Study Plan (8.3.1.14.2).
3	2/7/92	Changes to the objectives of Activities 1 and 4 in Study Plan 8.3.1.2.1.4 and Activity 4 in Study Plan 8.3.1.2.3.2. Added three drillholes to Study Plan 8.3.1.2.3.1. Deleted requirement for tagging surface dust suppression water with chemical tracer.
4	3/13/92	Incorporated changes in the objectives of Activities 1 and 3 in Study Plan 8.3.1.2.3.2.
5	7/15/92	Corrected references to integration of geophysical activities.
6	7/15/92	Updated Section 8.4 to be consistent with current Exploratory Studies Facility concept.
[illegible]	7/15/92	Deleted Activity 8.3.1.4.2.1.6 to eliminate redundancy.
8	9/24/92	Reorganized waste package near-field environment program.
9	10/2/92	Changed scope of the Site Characterization Program Baseline to delete activity descriptions that are controlled in the study plans; placed parameter tables in separate controlled document; removed hypothesis testing tables and analyses supporting test control from the Site Characterization Program Baseline. Changes made to Activities 8.3.1.2.2.4.6, 8.3.1.5.2.1.2, 8.3.1.5.2.2.1, 8.3.1.5.2.2.2, 8.3.1.5.2.2.3; changes made to Studies 8.3.1.3.7.2, 8.3.1.8.1.1, 8.3.1.8.1.2, 1.10.4.3; and changes made to Investigation 8.3.1.7.1.
10	1/14/93	Documented changes made to Study 8.3.1.2.2.4; Activities 8.3.1.8.5.2.2, 8.3.1.15.2.2, 8.3.1.17.4.3.2, 8.3.1.17.4.4.3; and Section 8.[illegible].5.13.

Site Characterization Program Baseline History (continued)

Revision	Issued	Revisions
11	8/3/94	Combined studies 8.3.1.8.2.1, 8.3.1.8.3.1, 8.3.1.8.3.2, 8.3.1.8.3.3, 8.3.1.8.4.1 within the postclosure tectonics program into one study (8.3.1.8.2.1, Revision 1). Activity 8.3.1.8.5.2.1 was deleted because data was too ambiguous and too general to be useful. Changed Activity 8.3.1.17.3.1.
12	1/20/95	Revision to Studies 8.3.1.5.1.6 and 8.3.1.15.1.1, editorial changes to Section 8.4 that responded to comments from the U.S. Nuclear Regulatory Commission. Incorporation of revised ESF/Repository interface drawings.
13	3/30/95	Removed the test objectives that were duplicated in the Site Design and Test Requirements Document and updated the design summary to reflect current terminology.

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PROGRESS REPORT #16

APPENDIX I

Tables of Technical Computer Codes

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APPENDIX I

Tables of Technical Computer Codes

This appendix lists computer codes that have been used, are being used, or could be used for design analysis, process control, scientific investigation, preclosure and postclosure performance assessments, and other technical activities.

Table I-1 lists the computer code names, including currently used or the most recent versions, a brief statement of the processes being modeled, past, current or potential applications in the Project, and references for documentation required for the approval of the computer code in accordance with the Quality Assurance Requirements and Description (DOE, 1997b). References for applications of the computer codes are not listed. Computer codes that currently meet the requirements of the Quality Assurance Requirements and Description are marked with an asterisk (*).

Table I-2 lists sections of Progress Report #16 where activities are described that identify the computer codes listed in Table I-1. To establish a one-to-one correspondence between these two tables, all computer codes listed in Table I-1 are also listed in Table I-2. Some report sections may not have identified the specific computer codes, however, that were used for the activities described.

In both tables, the names that have been added since Progress Report #15 are in bold type. No computer codes were deleted since Progress Report #15.

Only brief descriptions and captions are given for each computer code in Tables I-1 and I-2. Although this may give the appearance that some computer codes have the same capabilities, each computer code has unique capabilities needed for specific purposes. The distinctive capabilities of each computer code are evident from the references listed in Table I-1 and from the applications summarized in the progress report sections identified in Table I-2.

The appendix does not list computer software for support functions, such as operating systems, administrative and management software, system utilities, compilers and their associated libraries, word processors, spreadsheet programs, data base managers, graphing and visual display systems, statistical analysis tools, and software that is acquired or developed as an integral part of measuring and test equipment. An exception is made (i.e., software listed), if the support software has to meet the requirements of the Quality Assurance and Description because of the nature of its use in technical analyses.

Documents cited in this appendix are included in the consolidated reference list for this progress report (Appendix L).

Table I-1. **Analytical Techniques**

Names added since Progress Report #15 are in bold type. No computer codes were deleted, but some versions were retired.
* = one or more versions approved for work subject to the Quality Assurance Requirements and Description
See end of table for list of abbreviations and acronyms.

Name	Process	YMP Applications	Status
3DEC * Vs. 1.5* Sep 94	Three-dimensional analysis of underground opening stability and ground motion for jointed rock masses; distinct element method	ESF and repository excavation stability analyses	User's manual (Itasca, 1994a), vs. 1.5 qualification (CRWMS M&O, 1994c); maintained by Itasca Consulting Group, Inc.
ABAQUS Vs. N/A 1982	Soil and rock mechanics analysis	Geomechanical behavior of large-block test and ESF drift-scale test	Example problems manual (Hibbitt, 1982); maintained by Hibbitt, Karlsson and Sorenson, Inc.
ANSYS* Vs. 5.1 Sep 94 Vs. 5.1HP* Jul 95 Vs. 5.2 Aug 95 Vs. 5.2SGI* Feb 97 Vs. 5.3 1996 Vs. 5.4 1996	Multi-dimensional thermal-mechanical analysis of stress, strain, and heat conduction and radiation in solids; includes design optimization; finite element method	Thermal-mechanical analyses in support of waste package development, including the multi-purpose canister, thermal, mechanical, and seismic analysis in support of repository design	Vs. 5.1 user's manual (ANSYS, 1994a), vs. 5.1 verification (ANSYS, 1994b), vs. 5.1HP qualification (CRWMS M&O, 1995h), vs. 5.2SGI qualification (CRWMS M&O, 1997bb); newer user's manuals on CD-ROM; maintained by ANSYS, Inc.
AREST Vs. 1.0 Nov 93	Radionuclide release from waste package and engineered barrier system	Engineered barrier system performance analysis in support of total system performance assessments	Theory (Liebetrau et al., 1987; Engel and McGrail, 1993), user's manual (Buxbaum and Engel, 1991); software requirements Engel et al., 1993); maintained at Pacific Northwest National Laboratory; see also AREST-CT
AREST-CT working version 1995	Coupled reactive chemical transport, radionuclide release, and effects of near-field chemistry on radionuclide transport	Engineered barrier system performance analysis in support of total system performance assessments	In development; development aspects (Engel et al., 1994; 1995, in prep.); maintained by CRWMS M&O; see also AREST
A-TOUGH Vs. N/A 1993	Version of V-TOUGH with atmospheric interaction	Simulation of moisture removal from the repository by ventilation	User's manual (Multimedia, 1993); maintained by Multimedia Environmental Technology, Inc.; see also ITOUGH2, TOUGH/TOUGH2, and V-TOUGH

Table I-1. Analytical Techniques (continued)

Name	Process	YMP Applications	Status
BEALEP* Vs. 1.6 1994	Computes measure of saturated ground-water flow model linearity using output from MODFLOWP	Regional and site-scale saturated ground-water flow analysis in support of site characterization	Documentation (Hill, 1994); maintained by U.S. Geological Survey; see also MODFLOWP
CLIMATE working version 1996	Heat and mass transport within underground excavations, including water vapor and air ventilation	Analysis of ESF and repository drift ventilation	Development aspects (Danko et al., 1995, 1996)
CLIMSIM Vs. 2.0 1986	Climatic conditions in underground working areas considering heat sources, age, and wetness of airways	Analysis of climatic working conditions in ESF and repository drifts	User's manual (Mine Ventilation Services, 1986); maintained by Mine Ventilation Services, Inc.
COYOTE Vs. II 1994	Multi-dimensional nonlinear heat conduction and related general diffusion processes in solids	Analyses of rock temperatures surrounding the potential repository	Documentation (Gartling, 1982, Gartling and Hogan, 1994); maintained at Sandia National Laboratories
DIPS* Vs. 3.1* Jan 95 Vs. 4.0 1996	Plotting, analysis, and presentation of geologic structure using spherical projection techniques	Analysis of ESF fracture data (input to UNWEDGE)	User's manual (Diederichs and Hoek, 1996), vs. 3.1 qualification (CRWMS M&O, 1995t); maintained at University of Toronto
DORT-2D TORT-3D Vs. 2.12.14 Jan 95	Two- and three-dimensional discrete ordinates neutron and photon transport	Calculations of radiation doses in vicinity of waste packages	User's manual (ORNL, 1995a); maintained at Oak Ridge National Laboratory
Earthvision* Vs. 3.0 1995 Vs. 3.1* Nov 96	Three-dimensional geologic modeling	Basis of geologic framework model for Yucca Mountain	Vs. 3.0 user's manual (Dynamic Graphics, 1995), vs. 3.1 user's manual (CRWMS M&O, 1996mm), vs. 3.1 qualification (Clayton, 1996); maintained by Dynamic Graphics, Inc.
ELFPOINT working version 1992	Rock deformation resulting from shear and tensile faulting	Support of seismic ground-water pumping analysis to compute seismically induced elastic rock deformations	Theory (Okada, 1992)

Table I-1 Analytical Techniques (continued)

Name	Process	YMP Applications	Status
EQ3/6* Vs. 7.2a* Aug 94 Vs. 7.2b Aug 95	Speciation and solubility in aqueous solutions and geochemical reaction path/mass transfer	Analyses of ground-water chemistry data, calculations of solubility limits, and determination of certain reactions are in *equilibrium or disequilibrium states*	Theory and user's manual (Daveler and Wolery, 1992; Wolery, 1992a and b; Wolery and Daveler, 1992); maintained at *Lawrence Livermore National Laboratory*
FEHM Vs. 1.0 1988	Multi-dimensional multiphase flow and transport of water, water vapor, non-condensible gases, dissolved solids and heat in porous and fractured media; finite element method	Thermal-hydrologic and mass transport modeling of unsaturated and saturated zone; ground-water travel time calculations	Theory (Zyvoloski et al., 1988); verification (Zyvoloski and Dash, 1991); maintained at Los Alamos National Laboratory; see also FEHMN
FEHMN* Vs. 96-05-07-sun4 May 96	Multi-dimensional multiphase flow and transport of water, water vapor, non-condensible gases, dissolved solids, radionuclides, and heat in porous and fractured media; finite element method	Thermal-hydrologic and radionuclide transport modeling of unsaturated and saturated zone; ground-water travel time calculations	Theory (Zyvoloski et al., 1996), user's manual (Zyvoloski et al., 1997), verification and validation (Dash et al., 1996); maintained at Los Alamos National Laboratory; see also FEHM
FLAC* Vs. 3.22* Jun 93	Two-dimensional plastic deformation of soil, rock or other solid-material structures; finite difference method	Geomechanical analyses of ESF subsurface design and ESF tests	User's manual (Itasca, 1993a), qualification (CRWMS M&O, 1993e), maintained by Itasca Consulting Group, Inc.; see also FLAC3D
FLAC3D* Vs. 1.01* Jan 95	Three-dimensional plastic deformation of soil, rock or other solid-material structures, finite difference method	Geomechanical analyses of ESF subsurface design, including portal and opening stability	User's manual (Itasca, 1994b), vs. 1.01 qualification (CRWMS M&O, 1995j); maintained by Itasca Consulting Group, Inc.; see also FLAC
FRACMAN* Vs. 2.511	Data analysis (FracSys), geometric simulation and analysis (FracWorks), and stochastic continuum field generation (EdMesh) for three-dimensional discrete fracture networks	Simulation of geometry and hydrogeologic characteristics of fracture networks in Yucca Mountain hydrogeologic units (input to MAFIC)	User documentation (Dershowitz et al., 1995a,b; Lee et al., 1995), verification (Busse, 1995 a,b); maintained by Golder Associates, Inc.; see also MAFIC
GCM	Global climate modeling	Input to regional and local climate modeling	Maintained by National Center for Atmospheric Research

Table I-1. Analytical Techniques (continued)

Name	Process	YMP Applications	Status
GENESIS* Vs 2.01 1995	*Global climate modeling*	Provides regional boundary conditions for regional climate modeling by RegCM2	User's manual (Pollard and Thompson, 1995), validation (Thompson et al., in prep.); *maintained by National Center for Atmospheric Research*
GENII Vs N/A Dec 90 GENII-S Vs 1.485 1993	Biosphere radionuclide transport and radiation doses to humans by direct exposure, ingestion, and inhalation	Pre- and postclosure radiological exposure and risk calculations	Theory (Napier and Peloquin, 1988), user's manual (SNL, 1993); maintained at Pacific Northwest National Laboratory
GIMRT - see OS3D/GIMRT			
GWRAND working version 1996	Two-dimensional unsaturated ground-water particle tracking, random walk dispersion; semi-analytical method	Unsaturated zone ground-water travel time analyses	Theory (Lu, 1994), preliminary documentation (Altman et al., 1996a); maintained at Sandia National Laboratories
ITOUGH2* Vs 2.2 Oct 96 Vs 3.0 Dec 96	Calculation of TOUGH2 parameter values by automatic calibration with measured data; inverse analysis technique	Design and analysis of field and laboratory experiments	User's manual (Finsterle, 1993), vs. 2.2 qualification (Finsterle et al., 1996); maintained at Lawrence Berkeley National Laboratory; see also A-TOUGH, TOUGH/TOUGH2, and V-TOUGH
JAC JAC2D* Vs N/A 1993	Large deformation, temperature-dependent, quasi-static mechanics problems in two dimensions	Thermal-mechanical behavior of rock mass for north ramp design 2C package; also for setup of ESF thermal-mechanical tests	User's manual (Biffle, 1981); maintained at Sandia National Laboratories; see also JAC3D
JAC3D* Vs N/A 1993	Large deformation, temperature-dependent, quasi-static mechanics problems in three dimensions	Thermal-mechanical behavior of rock mass for north ramp design 2C package, also for ESF single-heater test as-built predictions	User's manual (Biffle, 1993); maintained at Sandia National Laboratories, see also JAC and JAC2D
LYNX System* Vs 1.0* May 94 Vs 1.1* Oct 94 Vs 3.06* Jan 95 Vs 3.10 1996 Vs 4.4 Sep 96	Three-dimensional modeling of geologic features and mine design	Geology and underground design modeling support of ESF and repository development and design	User's manual (Lynx, 1994, 1996), vs. 1.0 qualification (CRWMS M&O, 1994d), vs. 1.1 qualification (CRWMS M&O, 1994e), vs. 3.06 qualification (CRWMS M&O, 1995c); maintained by Lynx Geosystems, Inc.

Table I-1 Analytical Techniques (continued)

Name	Process	YMP Applications	Status
MACCS Vs. 1.5.11.1 Oct 93	Radiation doses to humans	Calculations of radiation doses to workers and the general public	Theory (Jow et al., 1990), user's manual (Chanin et al., 1990), programmer's manual (Rollstin et al., 1990), maintenance release (Chanin et al., 1993); maintained by U.S. Nuclear Regulatory Commission
MAFIC* Vs. 1.53 1995	Three-dimensional isothermal fluid flow and particle transport in discrete fracture networks with matrix interaction; finite-element method	Analysis of discrete fracture flow and mass transport in Yucca Mountain hydrogeologic units	User documentation (Miller et al., 1995), verification (Busse, 1995c); maintained by Golder Associates, Inc.; see also FRACMAN
MCNP* Vs. 4.2* Mar 94 Vs. 4A* May 96	Three-dimensional criticality and shielding analysis for nuclear/radioactive systems Monte Carlo technique	Criticality and shielding analyses in support of waste package, surface facility, and repository development and design	Theory (Briesmeister, 1993, 1995), primer (Harmon et al., 1994), vs. 4.2 qualification (CRWMS M&O, 1994f), vs. 4A qualification (CRWMS M&O, 1996nn); maintained at Los Alamos National Laboratory
MLAEM Vs. 4.0 1995	Two-dimensional and quasi-three-dimensional saturated ground water flow; analytical element method	Regional saturated ground-water flow analysis to establish boundary conditions for site-scale saturated zone modeling in support of site characterization	Basic theory (Strack, 1989; Haitjema, 1995), user's manual (Strack, 1992a); maintained by Strack Engineering; see also SLAEM
MODFLOW Vs. 1.6.38 1988	Two- and quasi-three-dimensional saturated ground-water flow, finite difference method	Regional and site-scale saturated ground water flow analysis in support of site characterization	Documentation (McDonald and Harbaugh, 1988); maintained by U.S. Geological Survey; see also MODPATH
MODFLOWP Vs. 2.3 1992	Two- and quasi-three-dimensional saturated ground-water flow, finite difference method, parameter estimation using non-linear regression	Regional and site-scale saturated ground-water flow analysis in support of site characterization	Documentation (Hill, 1992); maintained by U.S. Geological Survey; see also BEALEP, MODPATH, RESANP and YCINT
MODPATH MODPATH-PLOT Vs. 3.0 1994	Calculates position and travel time of particles for saturated ground-water flow, using output from MODFLOW or MODFLOWP	Regional ground-water flow analysis in support of site characterization	Documentation (Pollock, 1994), maintained by U.S. Geological Survey, see also MODFLOW and MODFLOWP

Table I-1 Analytical Techniques (continued)

Name	Process	YMP Applications	Status
MPSalsa working version in preparation	Two-dimensional two-phase (gas/liquid) flow in heterogeneous porous media, finite element method	Thermal-hydrological modeling of unsaturated zone air and water flow	Theory (Shadid and Moffat, in prep.); user's manual (Shadid et al., in prep.), maintained at Sandia National Laboratories
NETPATH* Vs. 2.0 1994	Geochemical mass balance	Hydrochemical characterization of unsaturated zone; correction of carbon-14 age dates of perched water	Documentation (Plummer et al., 1994)
NUFT Vs. 1.0 1995	Three-dimensional multiph[illegible]w and transport of water, water [illegible], gas, dissolved solids, radionuclides, and heat; integrated finite difference method	Thermal-hydrologic modeling of unsaturated and saturated zone in support of site characterization, engineered barrier system design studies, and performance assessments	Reference manual (Nitao, 1995); maintained at Lawrence Livermore National Laboratory
ORIGEN ORIGEN2 Vs. 2.1 1980	Build-up and decay of radioisotopes in nuclear fission reactor and in spent fuel after removal from reactor, including associated heat generation	Generation of list, weight, and radioactivity of radionuclides and of heat generated in support of MGDS development and design and performance assessments	Theory (Bell, 1973), user's manual (Croff, 198[illegible]); maintained at Oak Ridge National Laboratory
OS3D/GIMRT Vs. 1.0 Dec 95	Multi-dimensional multicomponent reactive mass transport	Reactive mass transpo[illegible] modeling (water chemistry, porosity/pe[illegible]ability, and mineralogy) of the alt[illegible] zone and repository near field	User's and programmer's manual (Steefel and Yabusaki, 1995); maint[illegible]ed at University of South Florida, modified at Lawrence Livermore National Laboratory
PATH Vs. 88A 1988	Gamma shielding analysis for three-dimensional source-shield configuration; point-kernel integration technique	Calculation of gamma dose rates from waste packages and support of MGDS shielding development and design	Theory and user's manual (Su et al., 1987), validation (Boshoven, 1991); qualification (Su, in prep.); maintained by General Atomics
PEST* Vs. 2.01 1994	Parameter-estimation for saturated ground-water flow models	Site-scale saturated ground-water flow analysis in support of site characterization	User's manual (Watermark Computing, 1994); maintained by Watermark Computing
PIGS working version in preparation	Pitting corrosion of waste package containers	Interpretation of pitting corrosion experiments, potential component of waste package and total system performance assessment models	Theory (Henshall, in prep.); being developed at Lawrence Livermore National Laboratory

Table I-1. Analytical Techniques (continued)

Name	Process	YMP Applications	Status
RegCM2* Vs N/A 1995	Regional climate model	Provides boundary conditions for modeling future net infiltration at Yucca Mountain	Validation (Thompson et al., 1995); component of GENESIS; maintained by National Center for Atmospheric Research
RESANP* Vs 1.3 1994	Calculates linear confidence intervals on estimated saturated ground-water flow parameters output from MODFLOWP	Regional and site-scale saturated ground-water flow analysis in support of site characterization	Documentation (Cooley and Naff, 1990; Hill, 1994); maintained by U.S. Geological Survey; see also MODFLOWP
RIP Vs 4.05 1996	Total system postclosure performance assessment for radionuclide releases to accessible environment and radiation doses to the public	Total system postclosure performance assessments	Theory and user's manual (Golder, 1996), verification (Golder, 1995); maintained by Golder Associates, Inc.
SATTRAK working version 1996	Three-dimensional saturated ground-water particle tracking, random walk dispersion, finite element method	Saturated zone ground-water travel time analyses	Development aspects (Altman et al., 1996a); maintained at Sandia National Laboratories
SCALE System* Vs 4.2* Jan 96 Vs 4.3* Dec 96	Criticality safety, shielding, heat transfer, and nuclear decay/fuel depletion analysis for nuclear facilities and waste package designs	Criticality, shielding, source term, and decay heat analysis in support of waste package development and design	Theory and user's manual (NRC, 1993; ORNL, 1995b), vs. 4.2 qualification (CRWMS M&O, 1996oo), vs. 4.3 qualification (CRWMS M&O, 1996pp), maintained at Oak Ridge National Laboratory
SLAEM Vs 3.0 1995	Two-dimensional single-layer saturated ground-water flow; analytical element method	Regional saturated ground-water flow analysis to establish boundary conditions for site-scale saturated zone modeling in support of site characterization	Basic theory (Strack, 1989; Haitjema, 1995), user's manual (Strack, 1992b); maintained by Strack Engineering; see also MLAEM
STAADIII/ ISDS* Vs 4.8MB, Rev 16.0* Jun 93	Structural analysis and design, including columns, beams, and bracings for plane/ space frame structures	Structural engineering analysis and design applications for plane trusses, plane frames, and space frames in the ESF	User's manual (Research Engineers, 1992), qualification (CRWMS M&O, 1993f); maintained by Research Engineers, Inc.
STAFF3D Vs 2.0 1992	Multi-dimensional isothermal flow and radionuclide transport in anisotropic saturated porous and fractured media; finite element method	Hydrothermal analyses in support of site characterization	Theory (Huyakorn et al., 1992); maintained by HydroGeoLogic, Inc.

Table I-1. Analytical Techniques (continued)

Name	Process	YMP Applications	Status
TOSPAC Vs 1.10 1992	Radionuclide release from waste packages and one-dimensional, unsaturated isothermal water flow and radionuclide transport in fractured media; finite-difference method	Input to total system postclosure performance assessments	Theory (Dudley et al., 1988), user's manual (Gauthier et al., 1992); maintained at Sandia National Laboratories
TOUGH TOUGH2* Vs 1.11* Feb 96	Multi-dimensional multiphase flow and transport of water, water vapor, non-condensible gases, dissolved solids, radio-nuclides, and heat in porous and fractured media, integrated finite difference method	Thermal-hydrological modeling of unsaturated and saturated zone; ground-water travel time calculations; design of laboratory and in-situ thermohydrologic experiments	Theory and user's guide (Pruess, 1987; Pruess et al., 1991), conjugate gradient solvers (Moridis and Pruess, 1995), TOUGH2 vs. 1.11 qualification (Pruess et al., 1996), qualification of TOUGH2 modules (Wu et al., 1996); maintained at Lawrence Berkeley National Laboratory; see also A-TOUGH, ITOUGH2, and V-TOUGH
TRACRN TRACR3D Vs. N/A 1991	Multi-dimensional isothermal liquid and gas flow and multi-component tracer/ radionuclide transport in porous and fractured media; finite difference method	Radionuclide transport modeling in support of site characterization; design of laboratory and in situ tracer experiments	Theory and user's manual (Travis, 1984; Travis and Birdsell, 1988; Birdsell and Travis, 1991); maintained at Los Alamos National Laboratory
TSA working version 1994	Collection of programs for total-system postclosure performance assessment for radionuclide releases to accessible environment	Total system postclosure performance assessments	Development aspects (Barnard et al., 1992; Wilson et al., 1994); maintained at Sandia National Laboratories
UDEC* Vs. 2.0* Mar 94	Two-dimensional response of discontinuous media (such as jointed rock mass) represented as an assemblage of discrete blocks; distinct element method	Analysis of underground openings (in jointed medium) subjected to in situ and seismic loadings in support of ESF and repository development and design	User's manual (Itasca, 1993h), vs. 2.0 qualification (CRWMS M&O, 1994g); maintained by Itasca Consulting Group, Inc.
UNWEDGE* Vs. 2.2* Jan 95	Three-dimensional analysis of geometry and stability of wedges defined by inter-secting structural discontinuities in under-ground excavations, including rock bolts and shotcrete	ESF and repository excavation stability analyses	User's manual (Carvalho et al., 1992), vs. 2.2 qualification (CRWMS M&O, 1995k); maintained at University of Toronto

Table I-1. Analytical Techniques (continued)

Name	Process	YMP Applications	Status
VNETPC* Vs. 3.1* Oct 93	Analysis of subsurface facility ventilation for mine networks, considering gaseous emissions, and design and cost analysis of ventilation equipment	Analysis and design of ESF and repository ventilation systems, including dust and diesel locomotive hydrocarbon exhausts	User's manual (Mine Ventilation Services, 1993), qualification (CRWMS M&O, 1993g); maintained by Mine Ventilation Services, Inc.
V-TOUGH* Vs. 7.8* Sep 95	Vectorized multi-dimensional multiphase flow and transport of water, water vapor, and heat in porous and fractured media; integrated finite difference method	Thermal-hydrologic modeling of unsaturated and saturated zone in support of thermal loading and engineered barrier system development and design	Theory and user's manual (Nitao, 1990); maintained at Lawrence Livermore National Laboratory; see also A-TOUGH, ITOUGH2, and TOUGH/TOUGH2
WAPDEG Vs. 1.0 Sep 96	Waste package degradation	Input to total system postclosure performance assessments	User's manual (Atkins and Lee, 1996)
WEEPTSA working version 1994	Probabilistic analysis of interaction of water flowing in discrete fractures with waste containers, radionuclide release, and transport to the water table	Input to total system postclosure performance assessments	In development; documentation (Barnard et al., 1992; Wilson et al., 1994); maintained at Sandia National Laboratories
X1t working version	One-dimensional multicomponent reactive mass transport	Reactive mass transport modeling (water chemistry, porosity/permeability, and mineralogy) of the altered zone and repository near field	Unpublished; obtained by Lawrence Livermore National Laboratory at 1996 University of Illinois short course "Reactive Transport and Basin Modeling"
YCINT Vs. 1.2 1994	Calculates linear confidence intervals on estimated saturated ground-water flow parameters output from MODFLOWP	Regional and site-scale saturated ground-water flow analysis in support of site characterization	Documentation (Hill, 1994); maintained by U.S. Geological Survey; see also MODFLOWP
YMIM Vs. 2.1 Apr 95	Radionuclide release from waste form and waste packages	Input to total system postclosure performance assessments; development and design of waste form and waste package experiments	User's manual (Gansemer and Lamont, 1995); maintained at Lawrence Livermore National Laboratories

Abbreviations and acronyms:
CD-ROM = compact disc - read-only memory
CRWMS M&O = Civilian Radioactive Waste Management System Management and Operating Contractor
ESF = Exploratory Studies Facility
MGDS = mined geologic disposal system
N/A = not applicable or not available
SNL = Sandia National Laboratories
Vs. = version
YMP = Yucca Mountain Site Characterization Project

Table I-2. Cross-Reference between Modeling Descriptions and Progress Report Sections

Names added since Progress Report #15 are in bold type. No computer codes were deleted.

Name	Description	Development and Improvement	Testing and Verification	Model Validation	Application
3DEC	Excavation rock mechanics				
ABAQUS	Soil and rock mechanics				5.2.4
ANSYS	Thermal-mechanics		5.1.2		5.1.3 5.2.3
AREST AREST-CT	Waste package degradation and radionuclide release				
A-TOUGH	V-TOUGH with atmospheric interaction				
BEALEP	Measure of MODFLOWP model linearity				
CLIMATE	Drift ventilation analysis and design				
CLIMSIM	Drift climatic conditions				
COYOTE	Heat conduction and diffusion in solids				
DIPS	Geologic structure analysis and graphics				
DORT-2D TORT-3D	Neutron and photon transport		5.1.2		
Earthvision	Geologic modeling				
ELFPOINT	Rock deformation from shear and tensile faulting				
EQ3/6	Geochemical speciation, solubility, and reactions		3.2.4	5.2.2	5.2.2 6.10.5
FEHM FEHMN	Multiphase fluid and heat flow with radionuclide transport	3.2.14			3.1.6 3.1.16 3.2.2 3.2.5
FLAC FLAC 3D	Soil and rock mechanics				5.2.4
FRACMAN	Fracture network geometry and parameter analysis				5.2.4
GCM	Global climate modeling				3.1.4 3.1.5

Table I-2. Cross-Reference between Modeling Descriptions and Progress Report Sections (continued)

Name	Description	Development and Improvement	Testing and Verification	Model Validation	Application
GENESIS	Global climate modeling				
GENII GENII-S	Biosphere radionuclide transport and radiation doses				
GIMRT - see OS3D/GIMRT					
GWRAND	Unsaturated zone ground-water particle tracking				
ITOUGH2	Calculation of TOUGH2 parameter values				3.1.13
JAC JAC2D JAC3D	Large deformation mechanics				
LYNX	Modeling of geology and under-ground facility design				4.1.3 4.1.7
MACCS	Radiation doses to humans				
MAFIC	Fluid flow in discrete fracture networks				5.2.4
MCNP	Criticality and shielding		5.1.2		
MLAEM	Saturated ground-water flow				
MODFLOW	Saturated ground-water flow				
MODFLOWP	Saturated ground-water flow				3.1.4
MODPATH MODPATH-PLOT	Saturated ground-water particle transport				
MPSalsa	Twophase fluid and heat flow				
NETPATH	Geochemical mass balance				3.1.11
NUFT	Multiphase fluid and heat flow with radionuclide transport		3.14		3.1.4 5.2.3
ORIGEN ORIGEN2	Nuclear fuel decay and heat generation				
OS3D/GIMRT	Multicomponent reactive mass transport		3.14		3.14 6.10.5 6.10.12

Table I-2. Cross-Reference between Modeling Descriptions and Progress Report Sections (continued)

Name	Description	Development and Improvement	Testing and Verification	Model Validation	Application
PATH	Gamma shielding analysis				
PEST	Saturated ground-water flow model parameter estimation				3.1.16
PIGS	Pitting corrosion	6.9.9			
RegCM2	Regional climate model				
RESANP	Linear confidence intervals for MODFLOWP output				
RIP	Total system postclosure performance			6.10.12	
SATTRAK	Saturated zone ground-water particle tracking				
SCALE	Criticality, shielding, heat transfer, nuclear decay		5.1.2 5.1.3		
SLAEM	Saturated ground-water flow				
STAADIII/ ISDS	Structural analysis of columns, beams, frames				
STAFF3D	Saturated ground-water flow and radionuclide transport				
TOSPAC	Unsaturated zone flow, waste package radionuclide release, and radionuclide transport				
TOUGH TOUGH2	Multiphase fluid and heat flow with radionuclide transport	3.1.13	3.1.13		3.1.13 3.2.2
TRACRN TRACR3D	Liquid and gas flow with radionuclide transport				
TSA	Total system postclosure performance				
UDEC	Jointed-rock mechanics				
UNWEDGE	Jointed-rock mechanics				
VNETPC	Ventilation of underground excavations				
V-TOUGH	Multiphase fluid and heat flow				

Table I-2. Cross-Reference between Modeling Descriptions and Progress Report Sections (continued)

Name	Description	Development and Improvement	Testing and Verification	Model Validation	Application
WAPDEG	Waste package barrier degradation and corrosion				
WEEPSTA	Probabilistic discrete fracture ground-water flow				
X1t	Multicomponent reactive mass transport				6.10.12
YCINT	Linear confidence intervals for MODFLOWP output				
YMIM	Waste package radionuclide release				

APPENDIX J

Glossary

APPENDIX J

Glossary

Accessible environment means the atmosphere, the land surface, surface water oceans, and the portion of the lithosphere that is outside the controlled area.

Advanced conceptual design (ACD) means the design phase that will be used to explore selected design alternatives and will firmly fix and refine the design criteria and concepts to be made final in later design efforts. The project feasibility will be demonstrated, life-cycle costs estimated, preliminary drawings prepared, and a construction schedule developed as required by U.S. Department of Energy Order 6410.1.

Advection means transport that results from macroscopic fluid flow.

Aquifer means a formation, a group of formations, or a part of a formation that contains sufficient saturated permeable material to yield sufficient quantities of water to wells and springs.

Areal mass loading means the amount of heavy metal (usually expressed in metric tons of uranium or equivalent) emplaced per unit area in the proposed repository.

Backfill means (1) The general fill that is placed in the excavated areas of the underground facility. Backfill materials may be either excavated tuff or other earthen materials. (2) The material or process used to refill an excavation.

Barrier means any material or structure that prevents or substantially delays the movement of water or radionuclides.

Borehole means a hole made with a drill, auger, or other tools for exploring strata in search of minerals, supplying water for blasting, emplacing waste, proving the position of old workings or faults, or releasing accumulations of gas or water. Boreholes include core holes, dry-well-monitoring holes, waste-emplacement boreholes, and test holes for geophysical or ground-water characterization.

Bulk permeability means volume-averaged permeability. See "permeability."

Burnup means a measure of nuclear-reactor fuel consumption expressed either as the percentage of fuel atoms that have undergone fission or as the amount of energy produced per unit weight of fuel.

Canister is a metal receptacle with the following purpose: (1) for solidified high-level radioactive waste, its purpose is a pour mold, and (2) for spent fuel, it may provide structural support for loose rods, nonfuel components, or confinement of radionuclides during preclosure operations.

Cladding means the metallic outer sheath of a fuel element, generally made of stainless steel or a zirconium alloy.

Closure means final backfilling of the remaining open operational areas of the underground facility after the termination of waste emplacement, culminating in the sealing of shafts.

Confinement as it pertains to radioactivity, means the retention of radioactive material within some specified bounds. Confinement differs from containment in that there is no absolute physical barrier in the former.

Contact (geology) means a plane or irregular surface between two different types or ages of rocks.

Containment means the confinement of radioactive waste within a designated boundary.

Controlled area means a surface location, to be marked by suitable monuments, extending horizontally no more than 10 kilometers in any direction from the outer boundary of the underground facility, and the underlying subsurface, which area has been committed to use as a geologic repository and from which incompatible activities would be prohibited before and after permanent closure.

Core science means those disciplines capable of providing information and data needed to address the major unresolved technical questions regarding the conceptual design of the repository and/or its expected performance in the geologic setting.

Criticality means the condition of supporting a nuclear chain reaction. It occurs when the number of neutrons present in one generation cycle equals the number generated in the previous cycle.

Defense high-level nuclear waste means the high-level waste generated in the course of national defense activities.

Diffusion means transport that results from random thermal motion of molecules.

Dispersion means the solute-spreading or dilution phenomena caused by mechanical mixing during ground-water movement and molecular diffusion.

Disposal means the emplacement in a repository of high-level radioactive waste, spent nuclear fuel, or other highly radioactive material with no foreseeable intent of recovery, whether or not such emplacement permits the recovery of such waste, and the isolation of such waste from the accessible environment.

Disposal container is a vessel consisting of the barrier materials and internal components designed to meet disposal requirements, into which the uncanistered or canistered waste form will be placed.

Drawdown means the lowering of the water table or potentiometric surface caused by pumping.

Drift means a horizontal or nearly horizontal, [illegible] passageway.

Emplacement means the act of placing waste containers in prepared positions.

Engineered barrier system means the waste packages and the underground facility.

Environmental impact statement means the document required by Section 102(2)(C) of the National Environmental Policy Act of 1969. Sections 114(a) and 114(f) of the Nuclear Waste Policy Act of 1982 include certain limitations on the National Environmental Policy Act requirements as they apply to the preparation of an environmental impact statement for the development of a repository at a characterized site.

Exploratory studies facility means a facility constructed for the purpose of performing underground studies during site characterization.

Fault means a fracture or a zone of fractures along which there has been displacement of the sides relative to one another parallel to the fracture or zone of fractures.

Finite-element computer code means a computer code that uses the finite-element method. The finite-element method is a method of numerical analysis that divides a region of interest into discrete elements and represents the behavior of the elements with a set of simultaneous equations. Solution of the set of equations yields the behavior at discrete points within the region of interest.

Flow path means the theoretical line that ground water follows in moving from a recharge area to a discharge area.

Flux means the volume of fluid per unit area per unit time. Also known as specific discharge.

Fracture is a general term for any break in a rock, whether or not it causes displacement, due to mechanical failure by stress. Fractures include cracks, joints, and faults.

Geochemistry means the study of the distribution and amounts of the chemical elements in minerals, ores, rocks, soils, water, and the atmosphere and the chemical interactions between these phases.

Geologic repository means a system, requiring licensing by the U.S. Nuclear Regulatory Commission, that is intended to be used, or may be used, for the permanent disposal of radioactive waste (including spent nuclear fuel) in excavated geologic media. A geologic repository includes (1) the geologic repository operations area and (2) the portion of the geologic setting that provides isolation of the radioactive waste and is located within the controlled area.

Geomechanics means the branch of geology that deals with the response of earth materials to deformational forces and embraces the fundamentals of structural geology.

Ground-water flux means the rate of ground-water flow per unit area of porous or fractured media measured perpendicular to the direction of flow.

Ground-water travel time means the time required for a unit volume of ground water to travel between two locations. The travel time is the length of the flow path divided by the velocity, where velocity is the average ground-water flux passing through the cross-sectional area of the geologic medium through which flow occurs, perpendicular to the flow direction, divided by the effective porosity along the flow path. If discrete segments of the flow path have different hydrologic properties, the total travel time will be the sum of the travel times for each discrete segment.

Guidelines means Part 960 of Title 10 of the Code of Federal Regulations–General Guidelines for the Recommendation of Sites for Nuclear Waste Repositories.

High-level radioactive waste means (1) the highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations; and (2) other highly radioactive material that the U.S. Nuclear Regulatory Commission, consistent with existing law, determines by rule requires permanent isolation.

Hundred-year storm means a storm whose intensity is such, on a statistical basis, that it is expected to recur only once every 100 years.

Hydrogeologic properties means the properties of a rock that govern the entrance of water and the capacity to hold, transmit, and deliver water, such as porosity, effective porosity, specific retention, permeability, and the directions of maximum and minimum permeabilities.

Hydrologic unit means any soil or rock unit or subsurface zone that affects the storage or movement of ground water by its porosity or permeability.

In situ means in its natural or original position. The phrase distinguishes in-place experiments, conducted in an underground facility from those conducted in the laboratory.

Infiltration means the flow of a fluid into a substance through pores or small openings. It connotates flow into a substance as opposed to the word percolation, which connotates flow through a substance.

Invert has two meanings on the Project. Its general meaning is the low point of something such as a tunnel, drift or drainage channel. However, as mostly used herein, invert means an engineered structure or material placed on excavated drift floors (the low points) to serve as structural support for drift transportation or emplacement systems. (For precast concrete, the proper name is invert segments, but they are commonly referred to simply as inverts.) Typical invert (segments) convert rounded excavated floors to flat level surfaces for transportation system use. Emplacement drift inverts may be specially designed to enhance the waste isolation and criticality prevention capabilities of the proposed repository through choice of invert materials or invert shape. Inverts may also be used to help channel water to improve repository drainage.

Issue means a question relating to the performance of the mined geologic disposal system that must be resolved to demonstrate compliance with the applicable Federal regulations (including 10 CFR Part 60, 10 CFR Part 960, applicable Environmental Protection Agency standards, and 10 CFR Part 20).

Isolation means inhibiting the transport of radioactive material so that the amounts and concentrations of this material entering the accessible environment will be kept within prescribed limits.

License application means an application for a license from the U.S. Nuclear Regulatory Commission to construct a repository.

Lithophysae means voids in rocks composed of concentric shells of finely crystalline alkali feldspar, quartz, and other materials that were formed due to entrapped gas that later escaped.

Maximally exposed individual means a hypothetical person who is exposed to a release of radioactivity in such a way that he receives the maximum possible individual radiation dose or dose commitment. For instance, if the release is a puff of contaminated air, the maximally exposed individual is a person at the point of the largest ground-level concentration and stays there during the whole time the contaminated-air cloud remains above. This term is not meant to imply that there really is such a person; it is used only to indicate the maximum exposure a person could receive.

Metric tons heavy metal means metals with high atomic numbers which are loaded into nuclear reactors to take part in chain reactions. Examples of heavy metals include thorium, uranium, plutonium, and neptunium. When used in the Civilian Radioactive Waste Management Program, the term usually refers to the mass of heavy metal in spent fuel which was present when the fuel was initially loaded into a reactor. (A metric ton is a unit of mass equal to 1000 kg.)

Mined geologic disposal system means a system, requiring licensing by the U.S. Nuclear Regulatory Commission, that is used for the disposal of high-level radioactive waste in excavated geologic media. It is synonymous with "geologic repository."

Multibarrier system means a system of natural and engineered barriers, operating independently or relatively independently, that acts to contain and isolate the waste.

Multi-purpose canister means a sealed, metallic canister holding multiple spent nuclear fuel assemblies in a dry, inert environment and overpacked separately and uniquely for the various system elements of storage, transportation, and disposal.

National Environmental Policy Act means the Federal statute that is the national charter for protection of the environment. The Act is implemented by procedures issued by the Council on Environmental Quality and the DOE. The National Environmental Policy Act of 1969 appears at 42 U.S.C. 4321 et seq.

Natural barrier means the physical, mechanical, chemical, and hydrologic characteristics of the geologic environment that individually and collectively act to minimize or preclude radionuclide transport.

Natural system means a host rock suitable for repository construction and waste emplacement and the surrounding rock formations. It includes natural barriers that provide containment and isolation by limiting radionuclide transport through the geohydrologic environment to the biosphere and provide conditions that will minimize the potential for human interference in the future.

Near field means the region where the natural geohydrologic system has been significantly perturbed by the excavation of the repository and the emplacement of the waste.

Net infiltration means infiltration minus water lost to evapotranspiration and other processes such as circulation of air within the rock mass.

Notice of intent means a notice published in the Federal Register that an environmental impact statement will be prepared and considered by a Federal agency. The notice is required by the National Environmental Policy Act implementing procedures. The notice must describe the proposed action and possible alternatives; describe the agency's proposed scoping process including whether, when, and where any scoping meeting will be held; and state the name of an agency official who can answer questions about the proposed action and the environmental impact statement.

Nuclear Waste Policy Act (42 USC 10101 et seq.) means the Federal statute enacted in 1982 that established the Office of Civilian Radioactive Waste Management and defined its mission to develop a Federal system for the management and geologic disposal of commercial spent nuclear fuel and other high-level radioactive wastes, as appropriate. The Act also specified other Federal responsibilities for nuclear waste management, established the Nuclear Waste Fund to cover the cost of geologic disposal, authorized interim storage under certain circumstances, and defined interactions between Federal agencies and the states, local governments, and Indian tribes. The act was amended in 1987 and 1992

Perched ground water means unconfined ground water separated from an underlying body of ground water by an unsaturated zone. Its water table is a perched water table. Perched ground water is held up by a perching bed whose permeability is so low that water percolating downward through it is not able to bring water in the underlying unsaturated zone above atmospheric pressure.

Percolation means the passage of a liquid through a porous substance (e.g., the movement of water, under hydrostatic pressure developed naturally underground, through the interstices and pores of the rock or soils.)

Percolation flux means volume of water moving downward and/or laterally through the unsaturated zone in a given time period.

Performance assessment means any analysis that predicts the behavior of a system or system component under a given set of constant and/or transient conditions. Performance assessments will include estimates of the effects of uncertainties in data and modeling.

Performance confirmation means the program of tests, experiments, and analyses that is conducted to evaluate the accuracy and adequacy of the information used to determine with reasonable assurance that the performance objectives for the period after permanent closure can be met.

Permeability means the capacity of a medium like rock, sediment, or soil to transmit ground water. Permeability depends on the size and shape of the pores, joints, and fractures in the medium and the manner in which they are interconnected.

Postclosure means the period of time after the closure of the geologic repository.

Preclosure means the period of time before and during the closure of the geologic repository.

Primary area means the surface location, as indicated on a map, of the principal area that may be suitable for waste emplacement. When projected downward along the location of faults and other geologic features, the boundaries of the primary area encompass the principal region within the target emplacement horizon that is considered potentially suitable for waste emplacement.

Radioactive waste or "waste" means high-level radioactive waste and other radioactive materials, including spent nuclear fuel, that are received for emplacement in a geologic repository

Repository construction means all excavation and mining activities associated with the construction of shafts, shaft stations, rooms, and necessary openings in the underground facility, preparatory to radioactive-waste emplacement, as well as the construction of necessary surface facilities, but excluding site characterization activities.

Repository horizon means the horizontal plane within the host rock where the location of the proposed repository is planned.

Rock bolt means a bar, usually constructed of steel, that is anchored into predrilled holes in rock as a support device.

Saturated zone means that part of the Earth's crust beneath the water table in which all voids, large and small, are ideally filled with water under pressure greater than atmospheric.

Seal means an engineered barrier to prevent radionuclide migration or the intrusion of undesirable substances.

Seepage means portion of percolation flux entering the emplacement drifts in a given time period.

Seismic means pertaining to, characteristic of, or produced by earthquakes or earth vibrations.

Shallow infiltration means water that has percolated to a depth of at least 2 meters into the bedrock closest to the surface. Two meters is usually assumed to be below the zone of substantial evapotranspiration.

Site means a potentially acceptable site or a candidate site, as appropriate, until such time as the controlled area has been established, at which time the site and the controlled area are the same.

Site characterization means activities, whether in the laboratory or in the field, undertaken to establish the geologic conditions and the ranges of the parameters of a candidate site relevant to the location of a repository, including borings, surface excavations, excavations of exploratory shafts, limited subsurface lateral excavations and borings, and in situ testing needed to evaluate the suitability of a candidate site for the location of a repository, but not including preliminary borings and geophysical testing needed to assess whether site characterization should be undertaken.

Sorption is a term including both adsorption and absorption, and means the binding, on a microscopic scale, of one substance to another, such as by adsorption or ion exchange. In this document, the word is especially used for the sorption of dissolved radionuclides onto aquifer solids or waste-package materials by means of close-range chemical or physical forces.

Spent nuclear fuel means fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated by reprocessing.

Stakeholders means individuals or organizations who have an important, ongoing interest in the service and service quality of the Office of Civilian Radioactive Waste Management.

Stoichiometry means (1) the application of the laws of definite proportions and of the conservation of matter and energy to chemical activity; (2) the quantitative relationship between constituents in a chemical reaction.

Storativity means the volume of water released from storage in a vertical column of unit area when the water table or other piezometric surface declines 1 unit of height. In an undefined aquifer, it is approximately equal to the specific yield.

Stratigraphy is the branch of geology that deals with the definition and interpretation of the rock strata, the conditions of their formation, character, arrangement, sequence, age, distribution, and especially their correlation by the use of fossils and other means of identification.

Substantially complete containment means that containment of the radionuclides enclosed within the waste packages is substantially complete for 1000 years (with less than 1 percent of the waste packages failing within 1000 years after permanent closure of the geologic repository) and with a mean waste package lifetime well in excess of 1000 years.

Surface facilities means repository support facilities within the restricted area.

Systems engineering systemically applies science and engineering principles to control a complex total system development effort for the purpose of achieving an optimum balance of all system elements. It is a process that transforms and integrates operational needs and requirements into a description of system requirements to maintain the overall system effectiveness.

Thermal loading means the application of heat to a system, and is usually measured in terms of watt density. The thermal loading for a repository is the watts per acre produced by the radioactive waste in the active disposal area.

Thermogravimetric analysis means a method of analysis that measures the loss or gain of weight by a substance as the temperature of the substance is raised or lowered at a constant rate.

Tracer testing means a procedure in which a soluble substance (tracer) is added to ground water at one location and its movement to another location is observed. Tracer testing is a technique by which ground-water flow directions and velocities and other hydrologic properties of rocks can be estimated.

Transmissivity means the rate at which water of the prevailing kinematic viscosity is transmitted through a unit hydraulic gradient. It equals the hydraulic conductivity multiplied by the thickness of the aquifer.

Tuff means a rock formed of compacted volcanic ash and dust.

Unsaturated zone means the zone between the land surface and the water table. Generally, water in this zone is under less than atmospheric pressure, and some of the voids may contain air or other gases at atmospheric pressure. Beneath flooded areas or in perched water bodies, the water pressure locally may be greater than atmospheric.

Viability assessment means an Office of Civilian Radioactive Waste Management Program judgment about the prospects for geologic disposal at the Yucca Mountain site, based on repository and waste package designs, a total system performance assessment, a licensing completion plan, and repository cost and schedule estimates.

Waste package means the waste form and any containers, shielding, packing, and other absorbent materials immediately surrounding an individual waste container.

10 CFR Part 60 means the Nuclear Regulatory Commission regulation, titled "Disposal of High-Level Radioactive Wastes in Geologic Repositories," that sets forth technical requirements governing development of a permanent geologic repository for spent nuclear fuel and high-level radioactive waste sited, constructed, and operated in accordance with the Nuclear Waste Policy Act of 1982.

10 CFR Part 960 means the Department of Energy regulation, titled "General Guidelines for the Recommendation of Sites for Nuclear Waste Repositories," that establishes guidelines for use by the Secretary of Energy in evaluating the suitability of sites for the development of nuclear waste repositories.

APPENDIX K

Acronyms, Abbreviations, and Symbols

APPENDIX K

ACRONYMS, ABBREVIATIONS, AND SYMBOLS

CRWMS	Civilian Radioactive Waste Management System
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
ESF	Exploratory Studies Facility
FY	fiscal year
MGDS	Mined Geologic Disposal System
M&O	Civilian Radioactive Waste Management System Management and Operating Contractor
NRC	U.S. Nuclear Regulatory Commission
OCRWM	Office of Civilian Radioactive Waste Management
Program	Civilian Radioactive Waste Management Site Characterization Program
Project	Yucca Mountain Site Characterization Project
QA	quality assurance
SCP	Site Characterization Plan
USGS	U.S. Geological Survey
YMSCO	Yucca Mountain Site Characterization Office

Miscellaneous Terms, Units, and Designators

atm	atmosphere (pressure)
AISI	American Iron and Steel Institute
ASTM	American Society for Testing and Materials
ATM	approved testing material
darcy	a measure of the permeability of a porous medium; 1 darcy = 9.87×10^{-13} m^2
Eh	oxidation potential, also called redox potential, of a chemical element, expressed in volts or millivolts
gpm	gallons per minute
ka	kiloannum (thousand years ago)
ky	thousand years
Ma	mega-annum (million years ago)
pH	the negative common logarithm of the hydrogen ion concentration of a solution; a measure of the acidity or alkalinity of the solution
pmc	percent modern carbon
ppb	parts per billion
ppm	parts per million
TU	tritium unit
UNS	Unified Numbering System for Metals and Alloys

Borehole Letter Designators

c	Hydrologic test hole
G	Geologic
GA	Geologic Angle "exploratory hole"
GU	Geologic Unsaturated zone
h	Horizontal drilled hole
H	Hydrologic Research Facility holes
HPF	Hydrologic Properties of Faults
J	Jackass Flats (water wells)
N	Neutron hole
NRG	North Ramp Geologic hole
ONC	Oversight Nye County
p	Paleozoic or pre-Tertiary hole
RBT	Radial Borehole Tests
RF	Repository Surface Facility hole
SD	Systematic Drilling hole
SRG	South Ramp Geologic hole
UE	Underground Exploratory
USW	Underground Southern (Nevada) Waste hole
UZ	Unsaturated Zone hole
UZN	Unsaturated Zone Neutron hole
V	Volcanic hole
VH	Volcanic/Hydrologic hole
WT	Water Table hole

Hydrogeologic Unit Names

CFu	Crater Flat unit
CHn	Calico Hills nonwelded unit
PTn	Paintbrush nonwelded unit
TCw	Tiva Canyon welded unit
TSw	Topopah Spring welded unit

SI and Metric Units

°C	degree Celsius
cm^3	cubic centimeter
cm	centimeter (= 10^{-2} m or 0.3937 inch)
d	day
g	gram (= 0.03527 ounce)
GWd	gigawatt-day
h	hour
ha	hectare (= 2.48 acres)

Hz	hertz (cycles per second)
J	joule (newton-meter)
K	degree kelvin
kg	kilogram (= 10 grams or 2.2046 pounds)
kWh	kilowatt-hour
km	kilometer (= 10^{3} m or 0.6214 mile)
L	liter (= 0.2642 gallon)
MTU	metric tons of uranium equivalent
MTIHM	metric tons of initial heavy metal
m	meter (= 3.2808 feet)
mg	milligram (= 10^{-3} g)
mgal	milligalileo
mL	milliliter (= 10^{-3} L)
mm	millimeter (= 10^{-3} m)
μm	micrometer (= 10^{-6} m)
MWd	megawatt-day
MWh	megawatt-hour
nm	nanometer (= 10^{-9} m)
nT	nanotesla (= 10^{-9} tesla)
Pa	pascal (also, MPa = megapascal, kPa = kilopascal)
S	siemens
s	second
V	volt
W	watt

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APPENDIX L

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PROGRESS REPORT #16

Note to Readers

To meet the requirements of Federal Executive Order 12906, the following information is provided:

> "Map number YMP-96-152.3 was compiled on June 30, 1997 by the M&O/TRW Technical Data Management GIS Section. Source documentation for the data sets included in this map are available upon request."

> "Map number YMP-96-153.1 was compiled on May 9, 1997 by the M&O/TRW Technical Data Management GIS Section. Source documentation for the data sets included in this map are available upon request."