Project geologists conducted lithologic logging and made graphical lithologic logs during Phase I of this activity. Bit cuttings from Boreholes UE-25 NRG#4, UE-25 NRG#5, and UE-25 WT#18 were examined to determine depths to lithostratigraphic contacts in the intervals that were not cored.

Project geologists completed lithologic logging of Borehole USW SD-9 which was drilled to a total depth of 675.8 m (2,223.1 ft). Lithologic contacts were selected from the base of the Paintbrush Group to total depth and presented in a table of contacts that was transmitted to project personnel for review. In addition, detailed descriptions of rocks from 1,487 to about 2,000 ft were made, and a graphical lithologic log of this interval of the borehole was prepared. Lithologic logging of this borehole was completed. The lithologic log was reviewed, revised, and submitted for release.

Graphical lithologic logs for Boreholes USW UZ-N31 and UZ-N32 were prepared, reviewed, revised, and submitted for release. Detailed lithologic data were collected for borehole USW UZN-31 from surface to total depth and were compiled for the graphical lithologic log.

Three reports summarizing results to date were completed and approved and are currently in preparation: (1) Geslin and Moyer, in prep.; (2) Moyer and Geslin, in prep.; and (3) Geslin et al., in prep. Geslin and Moyer (in prep.), and Geslin et al., (in prep.), include descriptions of lithologies and stratigraphic contacts based on studies of cores from 20 boreholes at Yucca Mountain. The volcanic units penetrated are in the Miocene Paintbrush Group and Calico Hills Formation. As discussed in Moyer and Geslin (in prep.), an analysis of core samples, combined with outcrop studies, has resulted in the informal subdivision of the Calico Hills Formation and the Prow Pass Tuff (Crater Flat Group) into several lithostratigraphic units and subunits that can be traced throughout the Yucca Mountain area. Stratigraphic thicknesses indicate deposition in south-trending paleovalleys lying east of Yucca Mountain. This report includes detailed descriptions of all defined units.

To further help define rock properties in core, Project scientists continued to examine devitrification textures and vapor-phase mineralogy from the thin section suites collected from Drillholes USW NRG-2A and USW NRG-3 (in the Tiva Canyon Tuff). They compared subsurface petrographic features in the Tiva Canyon Tuff with those examined from the surface sample suites, including thin sections from samples collected from the vertical transects across Antler Ridge, Whale Back Ridge, and Solitario Canyon.

The collection of borehole lithologic data directly supports the development and updating of the three-dimensional geologic framework model. This work supports the development of the stratigraphic and structural setting at Yucca Mountain.

Lithology and Hydrologic Properties in the PTn

This activity consists of reoccupying and remeasuring previously measured sections where samples for hydrogeologic properties analysis have been collected, and measuring and sampling selected new sections. The results will be used to provide regional and local

stratigraphic framework for lateral continuity of beds and tephrostratigraphic correlations in this important hydrostratigraphic unit.

Project investigators examined variations in depositional features in the PTn in the headwaters of Sever Wash. They began processing hydrologic-properties data received from project scientists for comparison with current stratigraphic studies of the PTn. Project geologists completed new measured sections near Fortymile Wash, in Solitario Canyon, and at Isolation Ridge. Review copies were prepared and sent for field checking and technical review.

Project geologists began characterizing stratigraphic variations in the lower part of PTn hydrogeologic unit by examining the interval from the base of the Pah Canyon Tuff to the top of the crystal-rich vitrophyre of the Topopah Spring Tuff in Yucca Mountain boreholes. These data are being synthesized into generalized descriptions of the subunits and marker horizons. Units can be correlated throughout all boreholes despite variable amounts of alteration and locally poor core recovery.

Stratigraphic relations within units of pre-Tiva Canyon Tuff bedded tuffs and pre-Yucca Mountain Tuff bedded tuffs of the PTn hydrogeologic unit were characterized by examining, sampling, and describing these intervals in Yucca Mountain boreholes. These data were synthesized into generalized descriptions of the subunits and marker horizons. Some units can be correlated throughout all boreholes, while others are laterally discontinuous. Bed thickness and distribution data for stratigraphic units within PTn hydrogeologic unit are being compiled.

Project scientists reviewed thin sections in the Tiva Canyon Tuff from a measured section on the west flank of Yucca Mountain. Changes were noted in the (a) relative amounts of welding, as indicated by variations in porosity and the shapes of shards and pumice, (b) types of crystallization of the dust, shards, and pumice, and (c) possibly the characteristics of fractures.

A draft digital location map for all measured sections was compiled, and a draft digital topographic location map for measured sections on and near Yucca Mountain was prepared.

Synthesis of the stratigraphy of the pre-Pah Canyon Tuff bedded tuffs, the pre-Yucca Mountain Tuff bedded tuffs, and pre-Tiva Canyon Tuff bedded tuffs was begun by preparing unit descriptions, tables of contacts, and unit correlations, and assembling data packages. Descriptions of cores of the Yucca Mountain Tuff were completed, and existing information on lithologic variations observed within cores of the Pah Canyon Tuff was compiled.

Project geologists completed examination of pre-Yucca Mountain Tuff bedded tuffs and pre-Tiva Canyon Tuff bedded tuffs in core and compiled their observations into data packages. The correlation of marker horizons within these units between boreholes continued, as did the examination of the hydrologic properties of these units continued. Comparisons of paleosols within pre-Yucca Mountain Tuff bedded tuffs with the negative gamma ray

signatures found on digital geophysical logs were made and preliminary isochore maps of selected subunits of pre-Yucca Mountain Tuff bedded tuffs were drafted.

Project staff updated the data base and existing surfaces for the three-dimensional geologic framework model. New lithologic data acquired from Boreholes USW SD-9, USW SD-12, UE-25 NRG#4, and UE-25 NRG#5 were incorporated into and used to update the LYNX structure contour maps. Project geologists conducted limited geologic field mapping in the vicinity of Boreholes USW UZ-N31, N32, N53, N54, and N55 and on the west side of Exile Hill. The 11 existing surfaces in the model were updated, based on newly acquired borehole and outcrop data. The Bow Ridge fault surface was updated to reflect new information obtained from boreholes USW NRG-2 and UE-25 NRG#2b. Quaternary alluvium/colluvium data were obtained from the USGS unsaturated-zone investigators and added to the three-dimensional model data base. Project staff prepared and submitted to DOE for approval three administrative reports containing the documentation and reviews of the input data, a structure contour map, and 10 isochore maps for model version YMP.R1.1. Two new isopachs for the Calico Hills Formation and Prow Pass Tuff were incorporated into this model.

Technical reviews of input data were conducted by project scientists and a base map showing the location of measured sections within the study area was constructed. Export isopach maps from LYNX model YMP.R2 were constructed to check the performance of the model. A report on this work (USGS, in prep.) was prepared and submitted for review and approval to publish. The central part of the mountain consists of seven structural blocks composed of six formations and the interstratified bedded tuffaceous deposits. Rocks ranging from the 12.7 Ma Tiva Canyon Tuff to the 13.1 Ma Prow Pass Tuff are modeled with 13 surfaces. The model is based on data from 75 boreholes from which a structure contour map at the base of the Tiva Canyon Tuff and isochore maps for each unit are constructed to serve as primary input. The model is capable of producing structure contour maps on the base of each unit, and provides a useful site-scale lithostratigraphic and structural representation of the central block of Yucca Mountain. Such a representation can be used for (a) storing data from, and planning future, site characterization activities, (b) preliminary geometry of units for design of the ESF and the potential repository, and (c) performance assessment evaluations. Preliminary copies of the three-dimensional model were sent to users of the LYNX modeling system.

Work began on modeling new surfaces in the LYNX model. Various interpretations of the potentiometric surface were digitized and incorporated into the model. A regional water table map was obtained to further explain the high gradient area in the northern part of the modeled area. The vitric/zeolitic contact data in the tuffs beneath Yucca Mountain were prepared for incorporation into the model. New features that were being prepared to add to the model included the bedrock/alluvial contact and surfaces, structural data, and topography east of the Bow Ridge fault in order to obtain accurate offsets and elevations of units adjacent to the fault.

Project scientists began a review and field check of pre-1992 measured sections. Work on this task was started in early October, with the field check of several pre-1992 measured

sections near Yucca Wash and Isolation Ridge, in northern Yucca Mountain and in Solitario Canyon. Project geologists field-checked 19 pre-1992 measured sections (including SC#1 and #2, Tpt-10, Tpt-32, Tpt-32A, Tpt-31, Tpt-35, Tpt-12, H-1 and -2, Tpt-15, Tpt-2, Tpt-14, PTn#1 through PTn#6, PTn#2, and PTn#3), and prepared technical review forms for these measured sections. Mandatory and non-mandatory comments that resulted from the technical reviews were addressed by Project scientists.

Project geologists examined exposures in Yucca Wash, in the vicinity of several pre-1992 measured sections, from the top of the Topopah Spring Tuff to the base of the Yucca Mountain Tuff. This work provided additional control for the new lithostratigraphic units in the pre-1992 measured sections. The upper units of the Topopah Spring Tuff and the pre-Pah Canyon Tuff bedded tuffs were re-measured at SC#1, on the east side of Solitario Canyon. The locations of the measured sections were updated, and a list of the measured sections with their completion status was compiled.

The results of the reviews of the pre-1992 measured sections will provide input data to the three-dimensional geologic framework model. The field reviews will not only provide a technical review of the measured sections, but will also help convert the Scott and Bonk (1984) units to the new lithostratigraphic units (Buesch et al., in prep.).

Activity 8.3.1.4.2.1.2 - Surface-based geophysical surveys. The objective of this activity is to improve confidence in stratigraphic models of Yucca Mountain by incorporating geophysical constraints.

A draft of a Geophysical White Paper, Phase II (Oliver et al., in prep.) was submitted for DOE approval. This document includes ten chapters written by specialists in various fields of geophysics. Besides an introductory chapter, which describes the geologic setting of Yucca Mountain and presents an overview of geophysical methods, and a concluding summary chapter, there are separate chapters on gravity, magnetic, magnetotelluric, seismic refraction, seismic reflection, and teleseismic investigations as well as on heat flow and stress measurements. Each chapter summarizes the results and interpretations derived from the various surveys that have been conducted in the area to date, with suggestions as to the course of future geophysical activities. Because Yucca Mountain is structurally complex, and has other aspects that complicate geophysical exploration, such as high resistivity and low seismic velocity and density contrasts near the surface, the general conclusion is that a combination of methods is required to provide high quality subsurface data.

Project personnel acquired seismic-reflection data in Crater Flat and at Yucca Mountain. Station survey crews began locating source points, shotholes, and geophones in mid October 1994. Drilling of deep shotholes contract) was completed by the end of October. Seismic crews completed noise testing, and production data collection began on Line 2SW south of Highway 95 near Steve's Pass in Crater Flat. By the end of October 1994, data collection had proceeded to the approximate boundary of the Test and Waste Isolation Evaluation Zone southwest of Solitario Canyon. Minihole drilling was completed on Fran Ridge, and additional deep shotholes were loaded.

A total of 23 mi of reflection data were acquired. Multiple energy sources used for the survey include (a) vibrator, (b) Poulter (surface charges of 5 lbs mounted on stakes), (c) minihole (5 lb charges in 10-ft deep holes), and (d) explosive shot-hole (200 lb charges in 200-ft deep holes). The first three energy sources produced 8-second records and the fourth produced 20-second records. Thus, the survey resulted in two simultaneous investigations, one relatively shallow and the other deep. A 480-channel digital recording program was used, with geophone spacing of 25 m (82.5 ft) (group interval). Data collection was completed on November 11, 1994, and magnetic data tapes were delivered to Project staff in late November.

Preliminary data (in the form of a Brut stack that represents essentially unprocessed data) indicate that the rocks traversed provided reflections that promised definitive subsurface interpretations upon further processing. Work on processing the reflection data has begun, and project personnel met with the processing team to discuss the geology of the Yucca Mountain area and the specific objectives to be met in the processing program.

The results of the seismic reflection profile will support the further development of the three-dimensional geologic model. The geometry of faults in the subsurface (planar, listric, etc.) can be evaluated using the results of this activity. Additionally, the results will be used to help locate Borehole USW G-6, a deep corehole that is designed to penetrate the Tertiary/ Paleozoic contact.

Activity 8.3.1.4.2.1.3 - Borehole geophysical surveys. The objectives of this activity are to help define and refine the location and character of lithostratigraphic units and contacts between units and to determine the distribution of rock properties within lithostratigraphic units.

Project scientists assisted with geophysical modeling. The staff also discussed the seismic reflection and refraction lines that are in progress, and focused on a possible detailed study of the USW UZ-7A drill pad. Methods of integrating the quantitative mineralogy data into geophysical logs were considered.

Project scientists reviewed the methods for assembling borehole fracture data. Methods that can be used in the review of video tapes of fractures in pre-1990 boreholes were studied, and experiments were conducted with some of these methods on the borehole video tape of UE-25 UZ#16.

The integration of geology and geophysics will help interpret surface and borehole geophysical data. The results will be used as input data for the three-dimensional geologic model, especially in areas either where no boreholes exist or there is little of no core data.

The responsibility for collecting and interpreting borehole geophysical data has been delegated to SAIC-M&O, who will have the responsibility for reporting work conducted under this activity in the future.

Activity 8.3.1.4.2.1.4 - Petrophysical properties testing. The objective of this activity is to provide geophysical and rock property data to be used in the interpretation of surface-based and borehole geophysical surveys.

No progress was made during reporting period; this was an unfunded activity.

Activity 8.3.1.4.2.1.5 - Magnetic properties and stratigraphic correlations. The objective of this activity is to provide magnetic property data to aid in the interpretation of volcanic stratigraphy and structure of rock units, to use paleomagnetic directions to provide orientations for drill core segments, and to assess the rotation of rock units in relation to the geologic structures of Yucca Mountain from paleomagnetic indications.

Project scientists began the processing and reduction of gravity and magnetic data collected in FY 1994. The task will ultimately provide coordinated modeling and interpretation of the traverses conducted on Yucca Mountain and across the Solitario Canyon fault in the spring of 1994. Initial steps were taken to involve geologic staff in interpretations to guide advanced modeling, including generation of preliminary profiles and model solutions for the geologic staff. Processing, reduction, and modeling of these data were completed, and a report was completed and approved (Oliver and Sikora, in press). Preliminary gravity results show a distinct decrease of 0.1 to 0.2 mgal over a 182.4-m (600-ft)-wide zone to the east of and including the mapped location of the Ghost Dance fault. The gravity decrease probably marks a zone of brecciation. The ground magnetic data show a 60.8-m (200-ft)-wide magnetic low of about 400 nT centered about 30 m (100 ft) east of the fault. This low probably also indicates a zone of brecciation within the normally polarized Topopah Spring Tuff, the top of which is about 1,700 ft below the surface at the locality surveyed.

The results of this activity directly support the interpretation of the subsurface geologic setting at Yucca Mountain. Stratigraphic and structural information obtained from this work will be used as input data to the three-dimensional geologic framework model.

Project scientists began acquiring magnetic data along the seismic reflection line described under Activity 8.3.1.4.2.1.2. This task was initiated early to take advantage of survey flags still in place after reflection data was acquired. Geophone and sourcepoint locations provided stations for the magnetic data collection. Magnetic data were collected in a single 37-km pass along the entire seismic line. Collection of offset data on remaining parts of the line will be completed in later field sessions. Two offset and parallel lines were collected between Steve's Pass and Borehole VH-1 to complete the data acquisition phase of this task. The offset lines now extend from Ashton, the west end of the seismic line, to VH-1. Aeromagnetic data will be used for the offset lines for the remainder of the seismic traverses.

The results of this activity directly support the interpretation of the subsurface geologic setting at Yucca Mountain. The outlying profiles will be used to identify discontinuities oblique to the seismic reflection lines. Stratigraphic and structural information obtained from this work will be used as input data to the three-dimensional geologic framework model.

Project scientists began the initial planning of line locations based on existing data and interpretation of general geological/geophysical setting (some data have been collected at one of the proposed drill sites; other extensive regional data exist). The magnetic/gravity crew collecting the gravity and magnetic data conducted the surveying concurrent with the data collection. Collection of the gravity and magnetic data is 90 percent complete.

Data produced by this activity will be used to locate the volcanic boreholes in the Amargosa Desert.

Forecast: Lithostratigraphic studies of surface exposures in the Calico Hills Formation, and the Bullfrog Tuff and tram Tuff will be conducted in the last half of FY 1995. Field review and geochemical sampling, to define stratigraphy, of pre- and post-1992 measured sections will be completed. Provisional interpretations based on partial processing of the regional seismic-reflection data will be completed, and work will begin on the final report. Magnetic and gravity data collected during the first half of FY 1995 will be processed, analyzed, and interpreted. Collection of additional gravity and magnetic data will continue in the second half of FY 1995. Data collected under this study will be used in the construction of the three-dimensional geologic framework model.

3.3.4 Study 8.3.1.4.2.2 - Characterization of the Structural Features Within the Site Area

The objective of this study is to determine the frequency, distribution, characteristics, and relative chronology of structural features within the Yucca Mountain site area.

Activity 8.3.1.4.2.2.1 - Geologic mapping of zonal features in the Paintbrush Tuff. The objectives of this activity are to map zonal variations within exposed tuffs that will aid in the identification of structural displacement at a scale of 10 m or less; and to detect subtle changes in structural styles.

Project geologists began and completed a preliminary study of linear features on low sun-angle photos and have plotted results on 1:5000 topographic maps. A preliminary rough map showing significant photolineaments observed in the central block on 1:12000 and 1:6000 scale airphotos, including low sun-angle photos was completed. A preliminary map of lineaments has been produced. Lineaments appear to be mostly shadow alignments caused by topography but other causes are present also. Review of the photolineaments is complete. Project geologists completed a narrative description of photolineaments within the central block (essentially the site area). A detailed outline of the introduction and geologic setting sections of the final report was completed, and much of the draft stratigraphy, structural geometry, and fracture character sections were written. A map detailing significant photolineaments and other features of interest is near completion.

Work on the Solitario Canyon strip map was begun, and the staff met with project design engineers to discuss surveying of contacts on the west flank of Yucca Mountain and

what the engineers will need for spacing of locations. The lithologic contacts to be surveyed on the east side of Solitario Canyon (west flank of Yucca Crest) were identified and flagged.

Project geologists began to check the consistency of the Scott and Bonk (1984) map. Digital maps of local structure contours for subunits of the Tiva Canyon Tuff, based on the Scott and Bonk (1984) were prepared. These digital maps can be reproduced at any scale and used to compare subunit contacts with each other and with other structural data. Selected portions of the Scott and Bonk (1984) along the north and south sides of Yucca Wash were field checked. Structure contour coverage of the central block of Yucca Mountain on the Scott and Bonk (1984) map was increased by 100 percent, and expanded coverage north to Yucca Wash, east to Exile Hill, and south to drill hole USW H-3. The local strike line maps for the Tiva Canyon base and the Tiva "upper cliff" base were digitized for the consistency check of the Scott and Bonk (1984) map.

Mapping began of the extension of the Sundance fault to the northwest from Split Wash, and preliminary progress maps showing the major structures located within a 456 m. (1,500-ft) wide strip adjacent to the centerline of the fault have been completed.

Activity 8.3.1.4.2.2.2 - Surface-fracture network studies. The objective of this activity is to provide measurements and analyses of fracture networks to support modeling of hydrologic potential flowpaths, particularly in unsaturated zones. Applications are also expected to aid development of tectonic models and determination of the mechanical response of fractured rock to excavation and thermal loading.

Project geologists examined 1:2400 scale air photos of the west flank of Yucca Mountain to identify potential sections for study of the nonwelded unit of the Paintbrush Tuff (PTn). An existing measured section on the west flank of Yucca Mountain in Solitario Canyon was examined. The stratigraphic relationships within the PTn, Topopah Spring Tuff, and Tiva Canyon Tuff were investigated. Project geologists examined several sections in the PTn along a 2-km traverse on the west flank of Yucca Mountain in Solitario Canyon. Two study areas were selected and partially flagged for surveying. Potential locations for the third study area were noted and were examined in mid November.

The three PTn fracture study areas were selected using the following six criteria:

1. Completeness of exposure of the PTn section

2. Quality of exposure at the contacts with the overlying Tiva Canyon Tuff and underlying Topopah Spring Tuff

3. Inclusion of a variety of stratigraphic settings as the Pah Canyon and Yucca Mountain Tuffs pinch out southward

4. Location of one study area adjacent to a northwest-trending fault to evaluate changes in fracture density with proximity to faults within the PTn

5. Ties to Flint-sample traverses and available matrix porosity/permeability information

6. Overall N-S coverage along the western boundary of the proposed repository.

The three PTn fracture study areas have been flagged and await surveying; the surveying will be combined with the surveying of the geologic strip map along Solitario Canyon. Project geologists began studying and mapping fractures in these localities. Activities included observation of fracture orientations and terminations, photography of the study areas, and preparation of a base map of the northern study area through the surveying of location points by triangulation using tape and compass. Geologic maps have been completed, and the total fracture study in Solitario Canyon is over half done. Fracture attribute data remains to be collected from the three areas, as well as in other areas along Solitario Canyon where individual lithologic contacts are well exposed.

Survey information on the Fran Ridge pavement was obtained in paper and digital form. Brecciated material from three 2- to 3-in-wide fracture fillings in this pavement were collected for thin-section study, with the primary purpose of identifying lithic casts. Photo micrographs were also taken as an aid in the study of mineral parogenesis, fracture movement history, and breccia clast identification. Fracture attribute data (orientation, trace length, height, aperture, roughness, fracture filling, termination, and intersection and offset relationships) were collected from about 275 fractures and cooling joints. These data were tabulated and entered in a computer data base in a format suitable for use in a final report.

Field maps of the Fran Ridge pavement were completed, and comparisons made for consistency with the fracture attribute data. The field maps have been digitized and are being compiled and edited. Future work will include a synthesis of the mapped relationships, examination of fracture offsets, and statistical analysis of the fracture attribute data.

Activity 8.3.1.4.2.2.3 - Borehole evaluation of faults and fractures. The objectives of this activity are to assess the reliability and usefulness of available borehole techniques for identifying and characterizing the subsurface fracture distribution; to determine vertical and lateral variability and characteristics of subsurface fractures; and to identify subsurface characteristics of fault zones.

No progress was made during the reporting period; this was an unfunded activity.

Activity 8.3.1.4.2.2.4 - Geologic mapping of the Exploratory Studies Facility. The objectives of this activity are to determine the vertical and horizontal variability of fracture networks in the ESF ramps, drifts, and boreholes; to characterize major faults and fault zones in the subsurface; to map the lithostratigraphic features of the subunits and the abundance and character of lithophysal zones; and to assist in the evaluation of test locations in the ESF test facility.

Project staff monitored the progress of the tunnel boring machine near the end of October 1994, and prepared equipment for mapping. They also continued setting up an

AutoCAD station at the Field Operations Center and modified base maps to be used in the underground operation.

Initially, mapping in the North Ramp was limited to mapping from the trailing gear of the tunnel boring machine. A detailed line survey (DLS-94-1) was started on the right wall, springline at station 0+60.62 and continued to station 0+69.05, just behind the operator's cab. Locations of steel sets and lagging were placed on the full periphery map and full-periphery mapping was started from station 0+60.62 to 0+69.05. Ground support in this area is circular steel ribs, with lagging covering much of the crown. This has created some difficulty in mapping, as many of the fractures causing block fallout in the crown are not visible behind nearly solid lagging.

Project geologists developed a cross-section comparing stratigraphy and predicted geologic structure developed by Sandia/Agapito in cooperation with the USGS with actual geology encountered in the North Ramp.

Project geologists began mapping of the North Ramp on January 24, 1995. Full periphery mapping was divided into two operations, recording the locations of steel sets and lagging first, followed by mapping of geologic features. Detailed line surveys on the right wall springline began on January 26, 1995. Mapping was accomplished as follows:

- Full peripheral mapping completed to approximately station 1+80
- Detailed line survey completed to station 2+11
- Photogrammetry work completed to station 2+35.57
- Sixty-nine samples collected for submittal to the Sample Management Facility as part of the consolidated sampling program.

Mapping crews began gathering of geotechnical data behind the tunnel boring machine. Field data was entered into computers for use in the geotechnical report. Project geologists met with soil and rock support personnel to discuss rock quality designation, quality, and rock mass rating calculation techniques to standardize methods between the two groups.

Activity 8.3.1.4.2.2.5 - Seismic tomography/vertical seismic profiling. The objectives of this activity are to investigate, and if successful, provide a means for broadly detecting and characterizing the subsurface fracture network in regions between the surface, boreholes, and underground workings; and to calibrate and relate the seismic propagation characteristics of the host rock to the fracture patterns observed in boreholes and underground workings, and extrapolate the observed fracture patterns to the surrounding region.

No progress was made during the reporting period; this was an unfunded activity.

Related International Work

See Sections 3.1.17 (under the heading, Field Tracer Test Development) and 3.3.8 (under the heading, Seismic Tomographic Imaging) for related work performed under the auspices of the OCRWM international program.

Forecast: Mapping structural features at the surface of Yucca Mountain will continue. The field check of "significant" structural features, obtained from low-sun-angle aerial photographs, will be completed. Fracture, pavement, and vertical continuity studies will be completed. The ESF mapping will keep pace with the progress of the tunnel boring machine, producing detailed line surveys and full-periphery maps of the tunnel. Surface mapping will expand outside the "central" block area with verification and enhancement studies in the Jet Ridge and Midway Valley areas. Data collected under this study will be used in the construction of the three-dimensional geologic framework model.

3.3.5 Study 8.3.1.4.2.3 - Three-Dimensional Geologic Model

The objective of this study is to develop a three-dimensional geologic model of the site area. In doing so, much of the study will involve synthesis of the results of other studies in the investigation to develop a model that will be integrated into the three-dimensional rock characteristics model described in Study 8.3.1.4.3.2.

Activity 8.3.1.4.2.3.1 - Development of a Three-dimensional Geologic Model of the Site Area. The objective of the this activity is to develop a three-dimensional geologic model of the Yucca Mountain Site that incorporates stratigraphic, structural, geophysical, and rock properties information pertinent to site characterization, and design and performance activities.

An Extended Site Model is under development, using the lithostratigraphic model of the central block extended over a larger area. Additional inputs to the model include a high-resolution topographic surface, a directed-well data base containing boreholes corrected by deviation surveys and the true vertical depth of each lithostratigraphic markers, an extended three-dimensional fault model, and a model of an aeromagnetic map draped on the topographic surface. Development of the Numerical Model Warehouse continues. Several three-dimensional models are continuing to be configured under the Numerical Model Warehouse and will be used by the prototype system, which is currently under development. A comprehensive compilation of borehole lithostratigraphic information was completed in conjunction with the Draft Stratigraphic Compendium (Mattson et al., 1994). The draft Stratigraphic Compendium lists each borehole with available data sources. These data form the basis for the extended site model.

Forecast: The extended site model baseline is expected to be completed during the fourth quarter of 1995. Revisions will proceed on a controlled basis throughout site characterization. Development of the integrated model will begin as the framework model is reviewed and accepted. A major effort will be required to acquire and synthesize the site attributes developed by principal investigators. The scope of this effort will be difficult to

define until the data and descriptive attribute submodels are thoroughly reviewed. A synthesis report will be completed during the fourth quarter of 1995.

3.3.6 Study 8.3.1.4.3.1 - Systematic Acquisition of Site-Specific Subsurface Information

The objective of this study is to acquire physical rock samples, analytical data, and basic descriptions of the subsurface geology of the repository site on a systematic basis. These samples and information are important for characterizing the three-dimensional distribution of rock characteristics, and hydrologic and geochemical variables, for the unsaturated zone at Yucca Mountain. Only one activity is planned under this study.

Activity 8.3.1.4.3.1.1 - Systematic Drilling Program. The purpose of the Systematic Drilling Program is to acquire physical rock samples and analytical data and to develop basic descriptions of the subsurface geology of the potential repository block for characterizing and evaluating the three-dimensional distribution of rock characteristics, hydrologic and geochemical parameters. Core samples taken from selected drillholes provide information related to the design of the ESF Main Test Level and relevant geologic information required for understanding the deeper portions of the repository block.

Drilling of Borehole USW SD-7 commenced October 3, 1994, following relocation of the drill rig from the USW SD-9 drill pad. Borehole USW SD-7 is a combined ESF main drift/Systematic Drilling Program drillhole located approximately where the main test level drift and South Ramp meet. This drillhole, which is about halfway up the mountain on a ridge crest, will provide information regarding the lateral (re)distribution of moisture within what have been observed previously as high-saturation lithologic intervals (particularly at the base of the Tiva Canyon Tuff and Topopah Spring Tuff).

Laboratory measurement of framework hydrologic bulk properties from Drillhole USW SD-9 and from the completed portion of Drillhole USW SD-12 was completed. Scientists at the Hydrologic Research Facility began taking measurements of hydrologic flow properties (e.g., saturated hydraulic conductivity).

Data collected during surface outcrop studies was evaluated in terms of their implications for down-hole sampling strategy (McKenna and Rautman, in prep.); this evaluation is in review.

Geologic logging of core from the USW SD-9 drillhole was also completed.

Project scientists strived to develop a single geologic log format and procedure that would apply to all holes drilled for the Project. According to preliminary plans, geologic logs would no longer be products of the various participant organizations with primary responsibility for the several drilling programs on the Project. Instead, geologic logs would become formal products of the DOE, based on logging input from the several participants, and they would be issued by YMSCO. Current thinking calls for a graphical log format at a primary scale of 1:120 (1 in.=10 ft), with more detailed logging of selected intervals at larger

scales as indicated by the complexity of the geology. Various attributes of the rocks (i.e., degree of welding, devitrification, vapor-phase alteration, etc.) would be portrayed visually in a semiquantitative to quantitative manner on a ft-by-ft basis, together with measured core recoveries for each core run and rock quality designation values based on a standardized 10-ft. interval. Laboratory measurements of selected framework rock properties would be included as well. A preliminary version of the geologic log is likely to be issued virtually on a monthly basis for recently drilled intervals, and this preliminary version would undergo one or more updates as more information becomes available and quantitative measurements are received from the laboratory.

Forecast: While drilling of Borehole USW SD-12 remained suspended during the entire reporting period, resumption of drilling is currently scheduled for mid 1995, following receipt of new dual-wall drill pipe to replace the original drill string. Other field and laboratory activities associated with Drillholes SD-7 and SD-12 will continue. Geologic logging of these holes, including describing lithology, welding and alteration, and fracturing, will be completed. Laboratory measurement of framework material properties and hydrologic-state variables will be completed and compiled in association with the geologic logs. Data will be made available to the ESF designers and other users, including performance assessment analysts, through submittals to the technical data base. Geological logging support will also be provided in association with drilling of various UZ- and SRG-series drillholes.

3.3.7 Study 8.3.1.4.3.2 - Three-Dimensional Rock Characteristics Models

The objective of this study is to produce spatially variable numerical models of material properties for use in various ESF design evaluation and performance-assessment analyses, principally using geostatistical and other computer modeling methods. The study also will support development of new computer algorithms and computer software required to accomplish the modeling.

Activity 8.3.1.4.3.2.1 - Development of three-dimensional models of rock characteristics at the repository site. The objective of this activity is 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.

Numerical experiments are being conducted to scale selected material properties from a core-like measurement scale to the scale of a reasonable flow-and-transport model. Software to compute advective ground-water flow paths through both the detailed and upscaled material properties models has been developed and tested. These numerical experiments will be incorporated into FY 1995 ground-water travel time calculations using two steps. First, core-scale measurements will be used to produce intermediate-scale values, using information from numerical and physical experimentation to control the scaling relationship. Scaling from this intermediate scale to the flow-model grid-block scale will use adaptive-gridding techniques developed several years ago under this activity. Adaptive gridding works to

minimize within-block heterogeneity of flow properties, which in turn reduces problems associated with orders-of-magnitude volumetric averaging. Work has begun to modify the adaptive-grid approach to minimize heterogeneity within polygons and triangles in addition to the currently used quadrilateral elements. Numerical flow codes, such as TOUGH and FEHM, require the use of these specific geometric forms for the calculational elements. A brief summary of the physical and numerical scaling experiments conducted to date is presented by McKenna and Tidwell (1995).

The geostatistically based, heterogeneous thermal property models developed previously in support of ongoing thermal-loading calculations were documented in Longenbaugh et al., (1994) and Rautman (in prep.). Two abstracts that summarized this work (Rautman, 1995); (Rautman et al., 1995) were accepted for presentation at the 1995 High-Level Waste Conference. Work in FY 1995 focuses on identifying how uncertainty in the spatial variability of thermal conductivity and bulk density propagate through heat-flow calculations to impact the temperature distribution within the mountain. Also being evaluated are some of the assumptions necessary in converting thermal conductivity, a very sparsely measured material property, from a surrogate framework property, porosity. Previous thermal modeling invoked very simplified assumptions regarding the in situ saturation of the rocks, and FY 1995 modeling will investigate more realistic saturation distributions for the models. Differences in temperature distributions that can be attributed to using different geostatistical modeling approaches will also be investigated. This latter impact is related to the fact that heat flow is being modeled in these exercises as a diffusive process, with the consequence that small-scale heterogeneity may not prove to be as important as in advective-type transport modeling. The effects of geologic uncertainty, as captured in the geostatistical modeling process, may be less significant under these conditions, leading to greater confidence in the overall conclusions of the thermal modeling studies.

Geometric and geostatistical modeling of rock-quality data for cross-sectional profiles along the ESF North Ramp and main test level drifts continues. The objective is to make location-specific predictions of rock quality along the ESF drifts and to quantify the uncertainty in those predictions. Preparation of deterministic (kriged) models of rock quality designation is summarized by Zelinski (in prep.). Cromer et al. (in prep.) discuss expanded modeling which emphasizes simulation and uncertainty assessment.

The Lynx-GSLIB integration module (GLINTMOD), which accesses a framework geologic model to provide soft information to constrain geostatistical simulation of rock material properties, was coded and tested successfully using a two-dimensional synthetic data set. The test problem consisted of simulating a 40 x 30 grid, conditioned by soft information representing a four-layer geologic model represented on an independent 20 x 15 grid. Sparse, additional hard conditioning data were present in the form of artificial drillholes. The configuration is identical to that frequently encountered in modeling Yucca Mountain, where some hard data exist, but in which portions of the modeled volume are beyond the range of influence of these data. Geologically unrealistic material properties have been simulated in such ill-constrained regions in previous modeling exercises. GLINTMOD refers to the geologic model whenever no conditioning data are located within the range of spatial correlation of a point being simulated. The prior expected value for the identified geologic

unit is then used to constrain stochastic simulation of the material property at that point. Testing of GLINTMOD continues in anticipation of implementation for FY 1995 ground-water travel time modeling.

A prototype three-dimensional geometric model has been created for the Yucca Mountain site area, extending away from the main repository block to and beyond the limits of the controlled area and the accessible environment, and from the topographic surface to the Paleozoic basement. The principal purpose of this model is to provide the geometric control and prior expectations of material property values necessary for the Lynx-GSLIB integration module (GLINTMOD). Accordingly, emphasis has been placed on the geometry of numerous, potentially distinct hydrogeologic or thermal/mechanical units; the exact modeling of faults has not been attempted. Instead, major faults are represented by abrupt folding of the offset units over approximately the width of several known fault zones at Yucca Mountain. The model honors all known drillhole stratigraphic intercepts. Surface outcrop mapping and published structural interpretations were also incorporated wherever possible. A significant observation from this modeling effort is that there appear to be several older faults or faults with differing amounts of older and younger movement that are largely obscured by the tuffs of the Paintbrush Group. The geometry of these early fault blocks, which are only partially related to the surface structure exhibited by the areally dominant exposures of the Tiva Canyon Tuff, will have greatest impact in studies of the saturated zone hydrologic system. The static water table has been incorporated into the prototype model, and the complete model is being used to support design of the saturated zone ground-water travel time modeling exercises for FY 1995. The modeled distribution of the lower Topopah Spring vitrophyre was provided to investigators working on thermal loading strategies.

Forecast: Geometric and geostatistical modeling of the Yucca Mountain site will continue with particular emphasis on specific ESF design and performance assessment problems. Development of models of thermal properties, probably using widely distributed measurements of porosity as a surrogate for thermal conductivity, will continue. Modeling to support ground-water travel time calculations will begin as part of technical site suitability. Modeling of both unsaturated and saturated zone flow paths will be conducted. Major emphasis will be placed on quantifying the uncertainty associated with ground-water travel time estimates.

Upscaling techniques and their applicability to upscaling hydrologic property measurements will be analyzed for their feasibility in producing accurate values of hydrologic properties at the geostatistical grid-block scale and at the flow/transport model grid-block scale. Ground-water travel time calculations depend on using upscaling algorithms beginning in April 1995.

Efforts will continue into FY 1995 to integrate soft information from geologic models into Gaussian-based geostatistical simulation algorithms. The linked Linx-GSLIB modeling software will be demonstrated through the construction and evaluation of prototype models. Successful implementation of this software will be used in support of ground-water travel time studies.

3.3.8 Related International Rock Characteristics Work

Seismic Tomographic Imaging

The following is work related to Study 8.3.1.4.2.2 (Section 3.3.4) conducted cooperatively with Switzerland under the auspices of the OCRWM international program.

During the previous reporting period, the activity focused on two separate efforts: refining software for improving seismic data processing methodology for application at Yucca Mountain and Swiss National Cooperative Society for the Storage of Radioactive Wastes sites, and evaluating cross-hole hardware for improving distance of penetration. With respect to enhancement of data processing codes, improved tomographic imaging methods for producing more reliable and robust interpretations were emphasized. Evaluations began on the utility of high dynamic range systems for data recording. By accurate predicting the location of geologic features (faults, lithology, structure), this work potentially could provide advance warning of "bad ground" ahead of the tunnel boring machine and reduce the number of required boreholes.

During this reporting period, Swiss National Cooperative Society for the Storage of Radioactive Wastes personnel generated a synthetic data set from a finite element code that will be used to test the waveform inversion codes. The data set was generated, travel times picked, and a tomographic inversion, using times only, was produced. An amplifier, using the integrated gate bipolar transistor technology, was fabricated and tested. The integrated gate bipolar transistor technology is an order of magnitude cheaper and potentially more powerful. For successful application to a multisource application, small, powerful, low-cost amplifiers must be available. The results of the initial tests indicated that the new amplifiers are more powerful than the present versions and produce equivalent waveforms.

Forecast: During the remainder of FY 1995, work will involve development and refinement of high resolution tunnel to surface, surface to tunnel, tunnel to tunnel, and surface to surface seismic imaging. The next step for tomographic inversion is to apply the waveform inversion to compare with the results of the travel time inversion. Testing and developing improved sources and receivers, for use in tunnels and underground boreholes, will continue.

3.4 CLIMATE (SCP SECTION 8.3.1.5)

3.4.1 Study 8.3.1.5.1.1 - Characterization of Modern Regional Climate

The objective of this study is to provide a baseline and a background for the interpretation of climatic variation. These data will be used to develop modern vegetation-climate calibration relationships, to assess lake-climate relationships, and to test global and regional climate circulation model relationships in regard to site performance.

Activity 8.3.1.5.1.1.1 - Synoptic characterization of regional climate. The objectives of this activity are to provide the basis for developing vegetation-climate relationships, lake-climate relationships, and climate-circulation models (meteorological data); to provide an understanding of spatial and temporal variation in climate (synoptic climate); and to determine the climate conditions (i.e., time, temperature, seasonality, and air masses) under which recharge occurs (isotopic data).

Precipitation samples continued to be collected from 7 sites on Yucca Mountain and 12 regional sites within 100 km of Yucca Mountain. Seven of the regional sites had snow collectors installed during the reporting period; these will be monitored in May and June. The unusually high amounts of precipitation during the present winter should provide some data defining the dominant weather patterns that prevail during wetter climate cycles.

To date, the $\delta^{18}O$ values of 55 precipitation samples have been determined, but a large backlog of samples await both δD and $\delta^{18}O$ determinations. Because of the recent unusually high amounts of precipitation, the backlog is increasing rapidly, but steps are being taken to provide analyses on a more timely basis.

Forecast: Rain collectors will be installed at the 7 sites where snow collectors were installed in the fall, and the accumulated water from the snow collectors will be recovered. A data base for precipitation stable-isotopic data is currently being developed. This data base will be the focal point of the preparation of charts and maps for a report due during the latter half of FY 1995. Strontium isotopic compositions will not be determined in FY 1995.

3.4.2 Study 8.3.1.5.1.2 - Paleoclimate Study: Lake, Playa, and Marsh Deposits

The objective of this study is to establish the nature, timing, duration, and amplitude of paleoclimate changes in the Yucca Mountain area, based on paleontologic, geochemical, stratigraphic, sedimentologic, and geochronological data obtained from lacustrine, playa, and marsh sediments in or near southern Nevada.

The studies Lake, Playas, and Marshes, and Terrestrial Paleoecology are closely related. During the last six months, data from these two studies were integrated, resulting in a preliminary interpretation of late Pleistocene climate change. The climate change interpretations and new data from past discharge have been compared and further study is in progress. The climate interpretations and their possible implications for climate induced discharge in the Yucca Mountain flow system are summarized below with specific accomplishments detailed under their activity numbers.

Activity 8.3.1.5.1.2.1 - Paleontologic analyses. The objective of this activity is to assemble and interpret, in paleoclimatic terms, detailed records of ostracodes, diatoms, and pollen, along with other types of fossils as warranted by specific paleoclimatic questions.

Ostracode analyses are nearing completion for sections collected in the Las Vegas Valley. That data likely spans the time from about 30 to 10 ka. Ostracode data also are

being collected from long lacustrine records from lakes in the general region. Those data from the lower Quaternary are now available for interpretation . Additional samples from the Pahranagat Marshes are available for analyses of ostracodes and diatoms.

Activity 8.3.1.5.1.2.2 - Analysis of the stratigraphy-sedimentology of marsh, lacustrine, and playa deposits. The objectives of this activity are to identify and characterize the general physical and chemical properties of sedimentary units from outcrops, shore deposits, and cores (providing a physical and relative temporal framework for various paleoenvironmental studies), and to determine the specific environment of deposition for the sedimentary units using the principles of clastic and chemical sedimentology.

A preliminary description of two sections collected in the Las Vegas Valley paleowetland sediments, which were also collected for paleontological analyses, suggests stratigraphic unit D, the unit associated with the maximum wet period, may be divided into two subunits. Those subunits representing changes in deposition may coincide with the paleontological evidence of climate change summarized above. Cores from the Pahranagat Marshes have been described.

Activity 8.3.1.5.1.2.3 - Geochemical analyses of lake, marsh, and playa deposits. The objective of this activity is to provide a detailed chemical and mineralogic characterization of lacustrine, marsh, and playa deposits to generate information about paleohydrology, sediment provenance, weathering rates, and sediment-water interface environments in ancient lakes.

Stable isotopic studies of biogenic carbonate from the upper part of the Pahranagat core have been completed. Results show changes in the isotopic stratigraphy that appear to coincide with those observed in the ostracode and pollen stratigraphy. These collective changes indicate that climate during the last 2,000 yr has undergone changes from wetter to drier episodes.

Activity 8.3.1.5.1.2.4 - Chronologic analyses of lake, playa, and marsh deposits. The objective of this activity is to obtain an accurate chronologic framework for the paleoclimatic information acquired in this study. All age information should, whenever possible, be tested with other techniques to reduce uncertainties.

Brenner and Quade (in prep.) completed a study to determine how various kinds of mollusks store radiocarbon information. They have discovered significant differences between taxa and have determined which species are likely to provide reliable age information.

Forecast: Ostracode valves counts will be made on an additional suite of sediment samples that were collected during December 1994. Further valve counts will be made on available ostracode material from the Pahranagat Marshes, Owens Lake, California, and the Sevier Basin, Utah. Ostracode and mollusc material will be extracted from some of the samples for stable isotope analyses.

The younger (late Pleistocene) sections will be dated using terrestrial gastropods found in the spring and wetland sediments as was suggested by the study by Brenner and Quade (in prep).

Additional diatom samples from the Owens Lake record will be counted and added to the existing data base. The diatom and ostracode data from the long cores (Owens Lake, California, Death Valley, and Sevier Basin) provide the Quaternary history of climate change in the region. Current data, which includes at least one sample from most 10,000-yr intervals ranging from modern to over 2 million yr, seem to suggest that the modern style climate common to Yucca Mountain is very atypical. It is critical that the Project is able to verify that modern dry periods are indeed very rare or determine if the data is biased in some way toward wet records.

3.4.3 Study 8.3.1.5.1.3 - Climatic Implications of Terrestrial Paleoecology

The objective of this study is to provide quantitative estimates of changes in climatic variables (precipitation, temperature, seasonality, etc.) for late Quaternary time in the southern Great Basin. This study will collect and analyze data on plant macrofossils from pack rat middens; fossil pollen assemblages from lake, marsh, and playa deposits; radiocarbon age determinations on paleovegetational assemblages; vegetation-climate and/or pollen-climate response surfaces; and pollen climate transfer functions.

The DOE has committed grant monies to the Desert Research Institute, University of Nevada, Reno, to support independent research that includes paleoclimatic tasks specified in parts of the SCP. Desert Research Institute has agreed to follow USGS quality-assurance techniques in its studies, enabling USGS to use data collected by Desert Research Institute in its own studies.

Activity 8.3.1.5.1.3.1 - Analysis of pack rat middens. The objective of this activity is to determine nature, timing, duration, and magnitude of past vegetation changes as recorded in plant macrofossil assemblages preserved in pack rat middens.

A large data base that includes data from about 800 fossil pack rat middens has been assembled. Several new collections of middens from the area around Yucca Mountain has been made and that data together with existing data in the midden data base provide the primary structure to our understanding of late Pleistocene climate summarized above.

Activity 8.3.1.5.1.3.2 - Analysis of pollen samples. The objective of this activity is to determine the nature, timing, duration, and magnitude of past vegetation change as recorded in the stratigraphic record of fossil pollen grains.

Pollen studies and sampling of the new cores from the Pahranagat Marshes within the interval from about 2 ka to nearly 6 ka are in progress. Those data, together with the completed analyses for the last 2 ka, are expected to provide the information about middle Holocene to present day climate variability.

Activity 8.3.1.5.1.3.3 - Determination of vegetation-climate relationships. The objective of this activity is to translate vegetational records provided by pack rat midden and palynological activities and available dendroclimatological data into quantitative estimates of past climatic variables.

Initial findings of the activities in Study 8.3.1.5.1.3 (Terrestrial Paleoecology) have been integrated with those of Study 8.3.1.5.1.2 (Lake, Playa, and Marshes) to form preliminary interpretations of Pleistocene climate changes. They are discussed under Study 8.3.1.5.1.2.

Forecast: The pollen data base from the Pahranagat Marshes will be extended back in time. Pollen data presently exist for the last 2,000 radiocarbon yr and core exists to at least 5,600 radiocarbon yr ago. Similarly selected samples from the core will be radiocarbon dated to refine the existing chronology. A detailed tree record of climate exists for the last 9,000 yr. The study of the Pahranagat Marshes provides a way for the climate program to turn climate expressed as tree ring variations into climate expressed as surface- and near-surface-water change during the Holocene.

Wood samples from packrat midden samples collected in southern Nevada will be radiocarbon dated by the accelerator mass spectrometry technique. Presently over 60 samples are ready to be dated.

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

The objectives of this study are to evaluate the paleoenvironmental record at Yucca Mountain and surroundings in light of inferred paleoclimate history of the southern Great Basin; to provide information to distinguish the effects of surficial processes from those of tectonic activity, based on the character and distribution of surficial deposits; and to evaluate the age of tectonic events.

Because of the need for defensible numerical ages for Quaternary deposits, a proposal to provide a comprehensive and integrated geochronological investigation of surficial deposits was submitted to DOE. The lack of calibrated materials and the application of nonstandard dating techniques in the past is a distinct problem in evaluating the existing ages used to estimate erosion rates, faulting kinetics, and climate-influenced sedimentation and soil-forming processes. The proposal was developed as a collaborative effort between USGS and LBL geochronologists, and USGS Quaternary geologists with input from DOE as to the Program needs.

A primary goal of this work is to apply a broader range of geochronological techniques most likely to provide useful data (uranium-series disequilibrium, luminescence, cosmogenic nuclide, tephrochronology, and radiocarbon methods) to several well-characterized Quaternary deposit profiles. The numerical dating results will be evaluated on the basis of both internal consistency checks using stratigraphic and geologic controls, and on external consistency

checks between different independent chronometers applied to the same deposits. Sites will be chosen on the basis of representing important surface deposits and considering the materials available for dating at each site. Data on the physical properties of the soils at each of the sites will also be collected. A longer-term goal of this investigation is to evaluate the reliability of assuming an age for a surficial deposit based solely on its physical morphology.

Activity 8.3.1.5.1.4.1 - Modeling of soil properties in the Yucca Mountain region. The objectives of this activity are (a) to determine the relations among properties of late Holocene soils and climatic parameters; (b) to compare properties of selected soils at Pahute Mesa and near Tonopah that formed under conditions similar to those that may have existed at Yucca Mountain during Pleistocene pluvial conditions; (c) to compare postulated past climates based on properties of early Holocene and Pleistocene soils to paleoclimatic models that are reconstructed from other lines of evidence, such as paleolimnology and terrestrial paleocology, as a check on these models; (d) to postulate past climates based on the depth, distribution, and quantity of pedogenic carbonate and other soil parameters; and (e) to quantify rates of soil development in specific climates for use as a dating tool for Quaternary deposits and ages of fault movements.

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

Activity 8.3.1.5.1.4.2 - Surficial deposits mapping of the Yucca Mountain area. The objectives of this activity are to determine the distribution, age, genesis, soil properties, and physical properties of surficial deposits in the Yucca Mountain area; to evaluate the influences of climate and tectonics on the genesis of surficial deposits; to provide a map of surficial deposits for facility placement planning, geomorphic studies, tectonics studies, engineering property studies, and surface infiltration studies; and to determine the distribution of major concentrations of calcite-silica deposits at or near the ground surface at Yucca Mountain.

Preliminary maps of the surficial deposits of the northwest quarter of the Busted Butte Quadrangle (Lundstrom et al., in prep.[a]) and the southern half of the Topopah Springs NW Quadrangle were approved in February 1995 after response to technical review. After digitization, these maps and an earlier map (Lundstrom et al., in prep.[b]) provided the basis for a 1:24,000 color composite map (Hayes, 1995) of surficial deposits that includes northern and central Yucca Mountain, all of Yucca Wash and Midway Valley, upper areas of Solitario Canyon and Fatigue Wash, and lower Fortymile Canyon. Mapping of southern Yucca Mountain is in progress; a preliminary map of the southern half of the Busted Butte Quadrangle was submitted for technical review in February 1995.

Mapping of surficial deposits is significant to several aspects of the Program Plan. The above composite map (Hayes, 1995) was compiled to be used to answer questions raised by the NRC in their review of the Extreme Erosion Topical Report, as was a report on a debris flow event in 1984 (Coe et al., 1995). Information about the alluvial, colluvial, and eolian deposits depicted on the map is also being used in preparation of the Technical Basis Report for Surface Characteristics, Preclosure Hydrology, and Erosion (DOE, in prep.[a]). The distribution of surficial soils indicated by these maps are being further characterized for hydrologic properties relating to infiltration, and so the surficial deposits mapping is an

important input to the site-scale hydrologic model. Moreover, the surficial deposits of this area provide a record of episodes of alluviation relating to past climate and paleohydrology that provide a basis for considering future climate and hydrology.

A planned three-year accelerated Quaternary dating program to support the Tectonics and Climate programs was started at the beginning of FY 1995 with the objective of building a credible and defensible foundation for applied numerical dating. The dating program entails a comprehensive, multiple-method approach for developing, testing, and applying new analytical and sampling techniques. Specific goals include (a) establishing an age-framework for soil chronosequences, (b) evaluating the reliability of using the dated chronosequences to date surface deposits by correlation, and (c) rigorously assessing the reliability of Quaternary dating techniques. Applied dating at specific trenches and other sites continued as a parallel effort to the developmental studies while recognizing the risk that some of the sampling and analytical approaches might subsequently prove to be inferior as information from the developmental studies accrued.

Techniques used in the developmental studies included mass spectrometric U-series, thermoluminescence, Cl-36, and C-14 methods. The cosmogenic dating studies (Cl-36 and C-14) are being conducted by the Center for Isotope Geochemistry at LBL in collaboration with the USGS. Developmental work during this reporting period emphasized testing and evaluating materials used for dating, including detailed sample examination with a scanning electron microscope, and reduction in sample size to allow higher resolution sampling. The applied geochronology effort was largely conducted by U-series and thermoluminescence methods to (a) constrain the timing of deposit of alluvial units on the east side of Yucca Mountain, (b) establish the rupture history at numerous fault trenches on both the east and west side of Yucca Mountain, and (c) establish the timing of spring activity at paleodischarge sites downgradient from Yucca Mountain. A limited effort was expended on tephro-chronology using both basaltic and rhyolitic ash trapped in fault zones and in alluvial stratigraphy.

Major advances in the developmental phase of the geochronology effort resulted from the transition from alpha-counting to thermal ionization mass spectrometry in the U-series work. This has allowed sample sizes to be reduced by one to two orders of magnitude and sampling at a much finer scale. The second major advance resulted from investigations of high-uranium and/or low-thorium pedogenic opaline silica and calcified plant remains. It was demonstrated that stratigraphically coherent ages could be obtained from opaline silica deposits. The generally high-uranium contents of opal also allows for sample-size reduction and higher resolution sampling. With these materials, an age can be determined from a single analysis in contrast to the previously used technique involving the leach-residue approach.

In thermoluminescence dating, new sampling techniques have been successfully applied to materials that could not be sampled by conventional methods. Anomalous fading and sunlight sensitivity experiments have been refined to assess the reliability of data, and a suite of zero-age samples from both eolian and fluvial depositional environments were collected and analyzed to assess the rate of the natural resetting process. In addition to these zero-age tests, several suites of replicate samples have been collected to test reproducibility of the total

and partial bleach methods. Thermoluminescence dating continues to provide internally consistent data on fine-grained detrital materials and ages that are consistent with U-series ages.

On the east side of Yucca Mountain (Coyote Wash, Midway Valley, and Fortymile Wash), samples for thermoluminescence and U-series dating were collected from surface and buried soils to constrain the timing of deposition of the youngest major alluvial map unit, as well as to constrain the age of alluvium associated with the highest terrace of lower Fortymile Wash, a major geomorphic datum in the region. Soils from these sites have also been sampled for particle size and carbonate content to understand rates and processes of soil development calibrated by geochronologic results. Trenches (CF-1, CF-2, and CF-3) on the west side of Yucca Mountain in Crater Flat were sampled for thermoluminescence, U-series, and cosmogenic dating to establish the timing of rupture events.

Activity 8.3.1.5.1.4.3 - Eolian history of the Yucca Mountain region. The objectives of this activity are to document eolian erosion and deposition in the Yucca Mountain area during the last 750,000 yr; to determine paleoenvironmental conditions during times of eolian deposition and intervening times of surface stability and soil formation; and to determine source areas of sand and silt.

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

Forecast: Mapping will continue in the adjoining central and southern map area, and reports for individual 1:12,000 quadrangles will be submitted for review as mapping is completed. Geochronological and pedological investigations of mapped deposits will continue as necessary to provide critical constraints on geomorphic and tectonic rates and on the responses of the Yucca Mountain landscape to Quaternary climatic changes. A report of a debris flow event in July 1984 will be prepared, and additional age dates obtained, to address NRC questions on the Extreme Erosion Topical Report.

Geochronological work will continue to focus on alluvial and eolian deposits on both the east (Midway Valley and Fortymile Wash) and west (Fatigue Wash fault and Solitario Canyon fault) sides of Yucca Mountain in FY 1995 and explore their hydrologic relation and timing to ground-water discharge sites in the Amargosa Desert to the south. Work planned for the first year will involve experimentation with available materials to establish the most reliable analytical techniques applicable to each of the dating methods. Data collected in this period will be evaluated to determine which of these dating methods provides useful information and whether each method is worth pursuing in the future. Dating results and soil property data for a limited number of sites will be compiled in the year-end report. The second stage of data collection (FY 1996) will broaden the study to additional sites in the southern Yucca Mountain area. This work will focus on testing the reliability of correlating soil morphology and depositional age at different sites influenced by a variety of soil-forming factors.

3.4.5 Study 8.3.1.5.1.5 - Paleoclimate-Paleoenvironmental Synthesis

The objectives of this study are to compare paleoclimatic estimates from the various proxy data sets and to provide data syntheses in the formats required for future climate and paleohydrology investigations.

Activity 8.3.1.5.1.5.1 - Paleoclimate-paleoenvironmental synthesis. The objective of this activity is to provide summaries of the paleoclimatic data in formats that can be used by investigations of future climatic changes and paleohydrology.

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

Forecast: The synthesis will be started and preliminary synthesis is scheduled to be completed in the second half of FY 1995.

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

The objective of this study is to estimate key climate parameters, including precipitation, temperature, and evapotranspiration, for the Yucca Mountain area over the next 100,000 yr with special emphasis on the next 10,000 yr.

Activity 8.3.1.5.1.6.1 - Global climate modeling. The objective of this activity is to provide boundary-condition data for regional climate models for a selected set of climate scenarios that may occur during the next 100,000 yr.

The life cycle plan for the GENESIS Atmospheric General Circulation Model was prepared and approved. Efforts may now begin on establishing a QA software baseline for the code.

Activity 8.3.1.5.1.6.2 - Nested global-regional climate modeling. The objective of this activity is to embed higher-resolution regional climate modeling within global climate modeling and couple with soil-physics-hydrology model to develop capability to predict future climatic-induced conditions and net infiltration in the Yucca Mountain area.

Detailed analysis of the preliminary validation run of the regional climate modeling code, RegCM2, indicated a few problems needing correction before continuing. The software baseline was modified as specified in Software Change Requests. After making modifications and minor enhancements, the model was ported to an SGI Power Challenge work station, enabling the longer runs needed to establish a climatology scenario.

After the new current-climate analysis is completed with the modified RegCM2 code, the software baseline for the GENESIS Atmospheric General Circulation Model will be established. At that point, nested runs of the GENESIS - RegCM2 package can proceed.

Activity 8.3.1.5.1.6.3 - Site-specific model output adjustment. The objective of this activity is to predict climatic parameters such as precipitation, soil moisture, and net-infiltration rates for several possible future-climate scenarios at Yucca Mountain.

A summary of techniques for transforming regional climate model outputs was in YMSCO review (Church et al., in prep.). The results indicate that the technique known as Climatological Projection by Model Statistics appears to be the most promising semi-empirical approach for transforming regional-scale model output to the local scale of Yucca Mountain.

Activity 8.3.1.5.1.6.4 - Future climate synthesis. The objective of this activity is to analyze time-series data of climatic variability based on the paleoclimatic record to identify possible future scenarios of concern that may occur during the next 100,000 yr.

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

Forecast: The follow-up analysis of the current-climate RegCM2 will be completed. Baselining the GENESIS code will be completed, then validated, and nesting runs of the two codes will be performed for current- and paleo-climate conditions in preparation for developing reference local climate scenarios. Documentation reports on these activities and their results and analyses will be produced. Other reports identifying bounding future climate conditions, and detail of approach to synthesizing future climate scenarios are also forthcoming.

3.4.7 Study 8.3.1.5.2.1 - Characterization of the Quaternary Regional Hydrology

The objective of this study is to characterize the distribution of surface water, the unsaturated zone infiltration and percolation rates, and the ground-water potentiometric levels during the Quaternary Period in the vicinity of Yucca Mountain.

Activity 8.3.1.5.2.1.1 - Regional paleoflood evaluation. The objectives of this activity are to identify the locations and investigate the hydraulic characteristics of paleoflood events and compare this evidence with the locations and characteristics of modern flooding and geomorphic processes; and to assess the character and severity of paleoflood and debris hazards and the potential of flood and debris hazards for the repository during the preclosure period.

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

Activity 8.3.1.5.2.1.2 - Quaternary unsaturated zone hydrochemical analysis. The objectives of this activity are to determine the past and infiltration percolation history at Yucca Mountain by analyzing the isotopic and chemical characteristics of water from the unsaturated zone; and to understand the past unsaturated-zone hydrologic system by modeling vadose-water hydrochemistry to help predict the future hydrologic system.

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

Activity 8.3.1.5.2.1.3 - Evaluation of past discharge areas. The objectives of this activity are to determine the location, type, and extent of hydrogeologic units in the ground-water discharge areas of the Amargosa Desert and Death Valley; to understand the past quantity and quality of water in the discharge areas of Franklin Lake, Amargosa Desert River, and Peter's Playa and to determine the paleohydrologic significance of Peter's Playa and Franklin Lake as discharge areas; to determine the location and hydrogeologic characteristics of paleospring deposits in the discharge area; to determine the location and amount of discharge by evapotranspiration that has occurred at past discharge sites; to understand the past and present discharge areas of the regional hydrologic system to predict the future saturated zone hydrologic system at Yucca Mountain; and to determine past ground-water levels in carbonate caverns as evidence of past hydrologic conditions.

Studies of past discharge areas are important to constraining the possible changes in the hydrodynamics of the saturated zone at Yucca Mountain in the future. These studies indicate higher water-table altitudes by over 100 m throughout the late Pleistocene to as recently as 10,000 to 15,000 yr ago. They also play a role in assessing the contribution of local recharge and associated flow through the repository block, and ultimately may provide a means of assessing travel times to the accessible environment under wetter climate conditions.

A reconnaissance investigation of previously unexamined spring deposits in the Amargosa Desert near the terminus of the Fortymile Wash alluvial fan was accomplished. Two-dimensional hydrologic models have predicted this area as the site of ground-water discharge under conditions of increased recharge in the upper portions of Fortymile Wash that are approximately two times that of the present day. Work done in the present reporting period was oriented toward initially understanding the age and source water for the hydrogenic deposits. In addition, new samples were analyzed from spring-discharge sites near the southern end of Crater Flat to further constrain ages and ground-water sources.

Two sample-collection field trips to the Amargosa Desert, near Stateline, Nevada, and to the Crater Flat sites were made in the first quarter of the fiscal year. The Stateline deposits consist of fine-grained eolian sediments (clays, silts, and sands) with interbedded carbonate-rich materials typical of paleodischarge deposits throughout the region. Two areas of interest were examined, including an incised higher terrace north of the present-day Amargosa River capped with dense limestone (informally named Mesquite Arroyo), and a lower terrace near the level of the Amargosa River consisting of gastropod-bearing unconsolidated brown clays and silts. Samples were collected for geochronology (U-series disequilibrium, thermoluminescence, radiocarbon), isotope geochemistry (strontium, oxygen, carbon), and paleontology (ostracods). Stable carbon and oxygen isotopic compositions from green and gray silts are similar to paleo marsh and pond deposits found elsewhere in the region. Oxygen and carbon isotopic compositions from carbonates within these high terrace deposits are intermediate between values observed in paleo marsh and pond deposits and pedogenic calcrete. In contrast, uranium and strontium isotopic compositions of these carbonates are uniquely diagnostic of a discharging ground-water source similar to isotopic compositions measured from present-day ground waters sampled immediately north in the

Amargosa Farms area. Strontium concentrations and isotopic compositions also are distinct from the Tertiary bedded lacustrine limestones cropping out in the immediate vicinity. Uranium-series disequilibrium ages of opaline silica and carbonate deposits in the high terrace indicate that discharge spanned a time-period from at least 100 ka to 30 ka although a detailed history is not currently known. Terrestrial snail shells from the brown silt deposits near the Amargosa River have radiocarbon ages of about 9,100 ka. Uranium-series disequilibrium data from aquatic snail shells from the same deposit yields an analytically identical age and an initial U-234/U-238 indicative of a regional ground-water source. In addition to isotopic data, the abundance of opaline silica in the high terrace deposits suggests that silica-rich waters in the Fortymile Wash ground-water system draining the volcanic rocks to the north were responsible for paleodischarge. Thermoluminescence age-dating from the same deposits is in progress.

Deposits near the southern end of Crater Flat were also sampled and analyzed for stable and radiogenic isotopes. Stable carbon and oxygen isotope compositions are similar to marsh and pond deposits having a ground-water source. Uranium-series isotopes provide additional support of previously reported latest late Pleistocene ages, including the first date from a deposit containing root casts and other fossil plant material (informally referred to as "root cast deposit") of 15 ka. Initial uranium ratios for these young rhizoliths is higher than most values measured from the regional Paleozoic aquifers, and is more consistent with values observed in the shallow parts of the volcanic aquifers. These results may imply that recharge through Yucca Mountain may have provided a component of the discharge. The presence of abundant anthropogenic artifacts associated with the higher, older-appearing mounds, and the lack of artifacts in the lower, younger-appearing mounds may be related to the possibility of wet ground occurring into the early Holocene. These sites are critical to establishing fluctuations in the water-table altitudes throughout the late Pleistocene. They may also help constrain paleo ground-water flow paths which may be very different under wetter conditions than those at present, especially if Yucca Mountain represents a local recharge source.

A carbonate mound located immediately north of Highway 95 in Rock Valley, along with bedded limestone just south of the highway, yield stable carbon and oxygen isotopes that are consistent with ground-water discharge. They are currently mapped as Tertiary lacustrine limestone. Calcite $\delta^{13}C$ and $\delta^{18}O$ values describe a trend of compositions nearly identical to those observed at Nevares Spring in Death Valley. Petrographic textures between the Rock Valley and Nevares deposits are also strikingly similar. The Rock Valley carbonate mound deposits have not yet been dated.

Carbonate deposits from Pahroc Spring also were analyzed for stable carbon and oxygen isotopes. The active spring probably represents discharge from a perched-water zone within the southwestern portion of the Pahroc Range. Lithologies are dominated by volcanic tuffs, and the annual precipitation is about twice that observed at Yucca Mountain. Therefore, this system may serve to approximate an analog for Yucca Mountain hydrology during wetter climate episodes. Measured $\delta^{13}C$ and $\delta^{18}O$ values of carbonate crusts on fractures near the spring are consistent with dissolution of pedogenic carbonate during highland recharge and transport through the tuffs to the spring site.

Activity 8.3.1.5.2.1.4 - Analog recharge studies. The objective of this activity is to estimate the conditions and rates of ground-water recharge (infiltration) during the Quaternary Period in the vicinity of Yucca Mountain.

No progress was made during this reporting period; this was an unfunded activity.

Activity 8.3.1.5.2.1.5 - Studies of calcite and opaline silica vein deposits. The objective of this activity is to determine the ages, distribution, origin, and paleohydrologic significance of calcite and opaline silica deposits along faults and fractures in the vicinity of Yucca Mountain.

Cathodluminescence petrographic capabilities are now in place. Cathodluminescence provides a valuable tool for determining the petrogenesis of secondary minerals and is being heavily used in studies of the growth-banding and depositional history of secondary calcite and opal within the unsaturated zone of Yucca Mountain. Secondary calcite and opal record the $\delta^{13}C$ and $\delta^{18}O$ of unsaturated zone fluids, and as such provide a record of the hydrologic response of the unsaturated zone to climate changes in the past. Cathodluminescence is also being used in studies of past discharge.

About a dozen samples collected from the ESF show some promise for climate reconstruction, although their depositional ages have not been determined. The much larger volumes of secondary opal and calcite obtainable from fracture mineralization exposed in the ESF will facilitate U/Th geochronologic studies and will provide adequate material for detailed stable isotope analysis for climatic/hydrologic reconstructions.

Preliminary studies of silica minerals (opal, quartz, and chalcedony) within Yucca Mountain were presented at the Fall Meeting of the Geological Society of America (Moscati and Whelan, 1994). Several important inferences from this data follow:

1. Pedogenic (soil) opal $\delta^{18}O$ values from Trench 14 indicate that opal precipitated at ambient temperatures, but from soil-zone meteoric waters of somewhat variable $\delta^{18}O$ values, perhaps reflecting ^{18}O-enrichment during evaporation.

2. Calcite and opal $\delta^{18}O$ values from both pedogenic and unsaturated zone settings indicate they formed from similar but not identical fluids. Probably different climate/plant community settings controlled the chemistry of the soil zone fluids, and, as a result, the chemistry of fluids infiltrating into the unsaturated zone.

3. Petrographic evidence suggests that most (but not all) of the calcite and opal precipitated independently of each other (i.e., they did not generally coprecipitate) and are, therefore, not suitable for mineral-mineral O-isotope paleotemperature determinations.

These findings are discussed more fully in Moscati and Whelan (in prep.). The conclusions drawn are that the different fluid chemistries of pedogenic calcite and opal likely reflect different climate states, and consequently, that opal may provide an easily datable (by

the uranium/thorium method) secondary phase in paleosols and in the unsaturated zone that records major climate transitions.

Monitoring of soil gas arrays and collection of soil moisture samples at the Amargosa Desert, Breakbone Ridge, Fortymile Wash, Fran Ridge, Holmes Road, and top of Rainier Mesa sites took place during the months of October, December, January, February, and March. The unusually heavy amounts of precipitation during December and January will provide an important "end-member" for the study (McConnaughey et al., 1994).

Investigation of existing computer codes for the modeling of soil fluid and gas chemistry indicates that the codes provide excellent starting points, but will require modification. This modeling will seek to define the "transfer functions" between climate processes and the resulting responses of soil zone geochemistry/mineralogy and plant ecology that control the chemistry (Eh, pH, salinity, etc.) of waters infiltrating the unsaturated zone of Yucca Mountain. Geochronologic studies tying discrete soil zone and unsaturated zone mineral assemblages to defined climate states should provide the compositional bounds for modeling the relationships between climate and unsaturated zone hydrochemistry.

Secondary calcite and opaline silica in veins and fractures represent a record of past water movement within Yucca Mountain and a proxy record of past climate variations at the mountain. Twenty secondary mineral occurrences sampled from depths of 30 to 122 m (100 to 4,400 ft) in Boreholes UE-25 a#1, UE-25 a#5, UE-25 a#6, and UE-25 a#7, and UE-25 UZ#16, USW G-1, USW G-2, USW G-3/GU-3, and USW G-4 resulted in 35 analyses. Acid leaching experiments were performed to test the suitability of opal as a uranium-series geochronometer. These experiments indicated that the fracture-coating opals have behaved as closed systems for at least the past 500 ka. High uranium concentrations in the opals (ranging from 10 to 350 ppm) permit analysis of opal samples as small as several milligrams. This greatly increases the number of datable occurrences from the boreholes and permits detailed geochronologic study of the thicker occurrences. The ages obtained range from 170 ka to more than 500 ka, with an average value of 300 ±60 ka. Published data from both radiocarbon and uranium-series studies suggest that Yucca Mountain hosts younger secondary mineralization.

Forecast: Reconnaissance investigations prove the relevance of further study of these deposits to issues of site suitability under wetter climate conditions. Higher water-table levels are apparent, but a detailed discharge history that links the timing of discharge to surface-water records is still needed. Ultimately, it will be necessary to understand what specific conditions are required to prompt water table fluctuations, how long these conditions must be maintained, and how rapidly the hydrologic system responds to climate variations. Additional knowledge of present ground-water altitudes and compositions are needed for comparisons with paleo spring data.

To construct a more elaborate discharge history, detailed stratigraphic and sediment data are needed in the form of small-scale maps for the most exposed portions of the deposits near Crater Flat and Stateline, Nevada. These maps will allow the identification of the areas of greatest potential for elaborating the history of discharge so that further concentrated

geochronological, geochemical, and paleontological studies are possible. Mapping activities should commence as soon as possible (late spring, early summer) so that maps, archaeological surveys and surface-disturbing permits can be obtained in FY 1996. These geological surveys will identify a minimum of two surface trenches at each of four sites (Crater Flat, Horse Tooth, Root Cast, and Stateline) required for further detailed studies. In addition, the paucity of hydrochemical data in Crater Flat does not allow accurate modeling of water-table altitudes or flow-path identification.

Reports will be prepared detailing the progress of studies of (a) the responses of soil fluids and gases to varying climate conditions, (b) the hydrologic record of the unsaturated zone from secondary minerals, and (c) uranium/thorium and C-14 dating of unsaturated zone calcite and opaline silica.

Collection of stable carbon and oxygen compositions from unsaturated zone calcite will continue on samples from the drilling program and from the ESF. Comprehensive studies will be undertaken on those occurrences that uranium/thorium disequilibria and/or C-14 dating indicate formed largely within the past 100 ka.

Thirty to fifty samples of silica occurrences have been collected or requested from drill core or the ESF. These samples will be used to better define the hydrogeologic environments of silica formation, from the soil zone to the deep saturated zone, through determination of their oxygen-isotopic compositions. In collaboration with Project mineralogists, the postulated formation of quartz from trydimite during saturated conditions (i.e., below the water table) will be tested. Should this theory be verified, it may provide a further tool for reconstructing past water-table altitudes.

Soil-gas arrays and moisture contents will continue to be monitored, probably through FY 1996. Computer codes for modeling of soil gas/fluid geochemistry will be tested and desired modifications defined. This modeling exercise is not specifically funded for FY 1995; however, efforts will be made to begin this fiscal year, hopefully providing some meaningful results during FY 1996.

Uranium/thorium and C-14 dating of vein calcite and opal will continue on samples from both the consolidated drilling program and from the ESF, and on pedogenic calcite and opal from paleosols and trench materials. The dating will focus on reconnaissance sampling to establish a chronology of secondary mineralization and to provide a space-time framework of fracture flow within the unsaturated zone at Yucca Mountain. Provisional data from dating of mammillary calcite draping open fractures at the Sterling Mine (Bare Mountain) indicates that some of this material is young (~5 to 10 ka). As time permits, this potentially valuable paleoclimate proxy will be pursued by further sampling and analysis.

3.4.8 Study 8.3.1.5.2.2 - Characterization of the Future Regional Hydrology Due to Climate Changes

The objective of this study is to characterize impacts of potential future climate changes on site unsaturated zone hydrology and regional and site surface-water system and saturated-zone hydrology.

Activity 8.3.1.5.2.2.1 - Analysis of future surface-water hydrology due to climate changes. The objectives of this activity are to simulate past changes in runoff and surface-water storage (lakes) resulting from past climatic change; and to use the relationship between paleoclimate and paleosurface-water conditions to predict the impact of future climatic conditions on the surface-water hydrology at the site.

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

Activity 8.3.1.5.2.2.2 - Analysis of future unsaturated zone hydrology due to climate changes. As reported in Site Characterization Program Baseline, Revision 9, this activity has been deleted; the scope of work for this activity will be performed in Activity 8.3.1.2.2.9.5.

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

Activity 8.3.1.5.2.2.3 - Evaluation of possible future changes of the climate and regional geologic framework on the regional saturated zone hydrology. The objectives of this activity are to reconstruct paleohydrologic conditions at Yucca Mountain and use these conditions together with the paleoclimatic conditions reconstructed as a basis to predict the impact of future climatic conditions on the saturated-zone hydrologic system; to synthesize the existing paleohydrologic data through the use of numerical simulation techniques to determine effects that greater recharge would have on water-table altitude, ground-water flow paths, and hydraulic gradients between Yucca Mountain and the accessible environment; and to evaluate possible regional tectonic and thermal events that may produce prolonged or transient effects on the regional water level.

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

Forecast: No activity is planned for FY 1995.

3.5 EROSION (SCP SECTION 8.3.1.6)

The objective of this program is to obtain the site-specific data needed to calculate average Quaternary hillslope erosion rates and accurate average short-term erosion rates associated with episodic erosion; estimate the potential effects of future climate on locations and rates of erosion; estimate the potential effects of future tectonic activity on locations and rates of erosion; and produce a topical report to address the possibility that erosional processes at Yucca Mountain could adversely affect the potential for radionuclide releases to the accessible environment.

This work is completed. As a result of the study plan work scope consolidation effort, no study plans will be developed in this program. A topical report was submitted to NRC for comment; nine comments were received. A plan, involving minimal new work, has been developed to provide supplemental responses to the NRC comments. Any additional work needed to provide the supplemental responses will be performed under Study Plan 8.3.1.5.1.4, "Analysis of the Paleoenvironmental History of the Yucca Mountain Region," under its existing work scope.

Forecast: Supplemental responses to the NRC comments are planned for the second half of FY 1995. The Site Design and Test Requirements Document will be revised to delete this program.

3.6 POSTCLOSURE TECTONICS (SCP SECTION 8.3.1.8)

3.6.1 Study 8.3.1.8.1.1 - Probability of Magmatic Disruption of the Repository

The objective of this study is to assess the probability of future magmatic activity with respect to siting of a potential repository for the storage of high-level radioactive waste at Yucca Mountain.

Activity 8.3.1.8.1.1.1 - Location and timing of volcanic events. The objective of this activity is to synthesize the data collected by other activities on the dating, location, and volume of late Cenozoic volcanic events in the region surrounding the site.

A procedure on locating volcanic features using the Garmin global positioning survey instrument was completed. The instrument is being used to obtain latitude, longitude, and altitude data for volcanic features in the Yucca Mountain Region. These data will be compiled and used in revised probability assessments. This activity is not funded in FY 1995. The procedure was prepared in anticipation of funding of the activity in FY 1996.

Activity 8.3.1.8.1.1.2 - Evaluation of the structural controls of basaltic volcanic activity. The objective of this activity is to investigate the time-space patterns of past volcanic activity in the Yucca Mountain region and the possible structural controls of volcanic centers and potential future centers at and adjacent to Yucca Mountain.

A review of tectonic models and geophysical data for the Yucca Mountain region was published (Crowe et al., 1995). Chapter 7 of Crowe et al. (1995) contains tables of 42 spatial and structural models for the distribution of basaltic volcanic activity in the Yucca Mountain region. These tables provided the basis for a revised probabilistic assessment of magmatic disruption of the potential repository, the controlled area, and the Yucca Mountain region. A contract was established for simulation modeling of "disruption of the potential repository" using multiple sets of spatial and structural models.

Activity 8.3.1.8.1.1.3 - Presence of magma bodies in the vicinity of the site. The objective of this activity is to review geophysical and geochemical data collected in the

vicinity of the site to assess whether there are any indications of the presence of crustal magma bodies that could be the source of future volcanic activity.

Paleomagnetic data were collected for the older basalt of Crater Flat and the basalt dike of Solitario Canyon. Data from these samples will be used to test the detectability of basalt intrusions using magnetic methods. Data collection was completed and results regarding the interpretation of geophysical data with respect to the presence of a low velocity teleseismic zone that could represent partial melt were published (Crowe et al., 1995). The authors concluded that further assessment of the significance of the low-velocity zone will depend on the interpreted results of the deep seismic reflection/refraction experiment and acquired data from the upgraded seismic net.

Activity 8.3.1.8.1.1.4 - Probability calculations and assessment. The objective of this activity is to revise the estimates of the probability of volcanic disruption of a repository site at Yucca Mountain incorporating newly acquired data on the age, location, and volume of volcanic centers in the Nevada Test Site region and the results from activities investigating the possibility of structural controls of sites of volcanic activity and the presence of magma bodies in the Yucca Mountain area. These data may result in modifications of the area ratio and the rate of volcanic activity used in the probability formula.

The first formal revision of probabilistic volcanic hazard assessment using the methodology presented in Study Plan 8.3.1.8.1.1, "Probability of Magmatic Disruption of the Repository," was published (Crowe et al., 1995). Project volcanologists presented several talks at the first meeting of the Expert Judgment Panel on Volcanism in Phoenix, Arizona, February 22-23, 1995. The purpose of this panel is to independently estimate the recurrence and intersection probability of volcanism at the Yucca Mountain site.

Forecast: Alternative structural models for the distribution of past basaltic centers will be developed. These models will be used to constrain probability ranges of E2 and stochastic and simulation modeling of spatial and structural models of E2 will be performed at the Yucca Mountain site. Data from field geologic studies and from aspects of the tectonics programs (seismicity, geophysical studies, studies of Quaternary faulting and fault systems, and the evaluation of tectonic models) will be used. Review of the geophysical data for the Yucca Mountain region will continue, as will evaluation to determine if it is sufficiently comprehensive to allow adequate evaluation of the presence of magma bodies in the region. If there is evidence of the presence of significant subsurface magma in the Yucca Mountain region, detailed plans will be developed for evaluating the existence and location of magma using geophysical data. Modeling of aeromagnetic data will be implemented to assess the issue of detectability of igneous intrusions. Refined methods and calculations of the first two parameters of the three-part probability calculation will be developed. An iterative approach using multiple alternative models for establishing the recurrence rate of volcanic events (El), similar to the approach used for establishing E2 will be used. The first iteration of a data matrix of recurrence calculations has been completed (April 1992) using homogeneous and nonhomogeneous Poisson recurrence models, and refinement of these calculations has continued since then. Data will continue to be gathered for the final report on the probability of magmatic disruption of the repository, which is due in FY 1997. The probability of

magmatic disruption at the repository will be calculated assuming a polygenetic model for volcanism. Work in this study will also be evaluated in the Expert Judgment Report, due in late FY 1996.

3.6.2 Study 8.3.1.8.1.2 - Physical Processes of Magmatism and Effects on the Repository

The objective of this study is to gather data on the potential effects of magmatic activity on the proposed repository. The data will be used to assess the consequences of such an eruption on repository performance.

Activity 8.3.1.8.1.2.1 - Eruptive effects. The objective of this activity is to summarize the effects of hydrovolcanic and Strombolian eruptions of basaltic magma on a repository. The summary will be available for use in consequence analyses of possible radiological releases.

This activity will quantify the abundance and depth of derivation of lithic fragments in basaltic centers that are similar to the centers at Crater Flat. The lithic data serve as a first order approximation of the amount of repository debris that could be ejected if a basaltic eruption were to penetrate the repository. Project scientists made significant progress during this period. Upper-crustal xenoliths erupted from small-volume basaltic volcanoes of the Lucero volcanic field (west-central New Mexico) were studied to assess the relative importance of various wall-rock entrainment mechanisms during a wide range of eruptive processes, including strongly hydrovolcanic, Strombolian, and effusive processes. These results were presented in Valentine and Groves (in prep.). It was found that the volcanoes erupted through a thick, well-characterized sequence of Paleozoic and lower Mesozoic sedimentary rocks, so that erupted xenoliths can be correlated with sedimentary units and hence depth ranges. It was also found that the abundance of xenoliths from a given subvolcanic unit can be divided by the thickness of the unit to obtain an average entrainment rate (xenolith volume fraction derived per unit depth in the conduit). Shallow (< 510 m) entrainment rates were found to be very sensitive to the degree of hydrovolcanic activity, while deeper entrainment rates were not. Deep entrainment is very sensitive to the mechanical properties of the wallrocks, and in the cases studied here appears to depend mainly on brittle failure related to offshoot dikes and thermal stresses. These results have direct implications for the entrainment of waste packages should the potential repository be intersected during a volcanic eruption. Reconnaissance studies were performed in the San Francisco volcanic field, central Arizona, where the next suite of lithic studies will be performed at four or five selected basaltic centers. Detailed field studies there are scheduled to begin in April 1995.

Activity 8.3.1.8.1.2.2 - Subsurface effects of magmatic activity. The objective of this activity is to evaluate the subsurface effects of emplacement of basalt dikes and intrusive bodies through and adjacent to a potential repository. This study will assess mechanisms of incorporation of waste in magma, the geometry of basalt intrusions, and coupled effects on waste isolation of basalt intrusions through or near a repository.

The purpose of this activity is to assess subsurface processes accompanying small basaltic intrusions and their potential effects on a repository. Both theoretical modeling approaches and field studies at analog intrusive sites are being used. Theoretical considerations of subsurface effects during the reporting period have focused on quantifying the spatial and temporal extent of convective processes resulting from intrusion of magma. This information is used directly in determining the probability of a magmatic event affecting the repository, because it defines the maximum distance an intrusion can be from a repository and still significantly perturb its performance.

Because the potential repository resides in a thick vadose zone where the spatial extent of hydrothermal water circulation is limited, Project scientists initially focused work on convection of pore air that can circulate over much larger scales. Preliminary results will be presented in Auer and Rosenberg (in prep.). The authors began the studies by rederiving the basic equations for convection of dry (no water vapor) air in a porous medium, and reexamining the linear stability analysis for the onset of convection in a porous medium heated from below. The results indicate that the definition of the Rayleigh numbers for air and for water are very similar, although not identical, and that the two critical Rayleigh numbers are numerically the same. The values of the quantities that appear in the Rayleigh number, however, dominate the difference in the temperature gradient needed to cause subsurface air convection and not the magnitude of the critical Rayleigh number. For reasonable values of air and water properties, the critical temperature gradient for the onset of convection in air is ~3000 times greater than for water. While it is easy to convect large volumes of air (air viscosity is orders of magnitude lower than that of water), those volumes of air carry very little energy that is rapidly dissipated by the conduction through the matrix, damping the convective motion.

Project scientists are now conducting finite amplitude numerical studies of air convection in porous media using the flow and transport code FEHM. They are simulating air convection in response to dikes and sills intruded into a homogeneous box of material assumed to have the properties of the potential repository horizon at Yucca Mountain. Complexity in the modeled physics will gradually be increased so that eventually modeling can be combined with field studies at analog sites.

One of the analog sites at which Project scientists are conducting field studies is Paiute Ridge, located about 40 km northeast of Yucca Mountain. Paiute Ridge is characterized by dikes, small sills, and conduit plugs, representing the shallow (100 to 200 m depth) intrusive plumbing for a small volume volcanic center. Because of erosion and faulting, only a small part of the eruptive lavas and scoria remain. The intrusions are alkali basalts in composition, about 8.6 Ma old, and were emplaced into country rocks consisting of bedded, variably zeolitized silicic tuffs. Although these tuffs are mapped as belonging to the same formation as the tuffs that may actually host the potential repository, they are most analogous in their characteristics to units such as the Calico Hills Formation, one of the main geochemically retarding units beneath the potential repository horizon at Yucca Mountain. Project scientists are performing geologic, mineralogical, and geochemical investigations to characterize the nature and extent of alteration of tuffs around the basaltic intrusions. Zeolite-rich tuffs are characterized by low-temperature alteration minerals. For example, the upper stability limit

for alteration minerals such as clinoptilolite, smectite, and opal that are common in zeolite-rich altered tuffs is generally about 100°C. The effect of the dike and sill intrusions on the zeolite-rich tuffs will be investigated using petrographic, mineralogical, and geochemical studies.

The second analog site is Grants Ridge, in western New Mexico. Here a basaltic cinder cone erupted through a thick sequence of unaltered rhyolite tuffs and some volcaniclastic sediments. Since formation of the cinder cone, at 2.6 Ma, erosion processes have dissected the cone so that a natural cross section is now exposed in a canyon wall. The exposure not only includes the interior of the cone itself, but the lava plug that formed in the feeder conduit, from the original (pre-basalt) land surface down to about 100 m depth. Scientists are characterizing the rhyolite tuff sequence by sampling at regular distances away from the intrusive plug. Thermal and degassing effects are generally more pronounced along the contact zone. Alteration minerals will be described and identified using petrographic methods and x-ray diffraction. Thermal and degassing effects on the host rock at proximal and distal points will be compared and contrasted to determine the degree of geochemical mobilization during hydrothermal processes related to the basaltic intrusion.

Activity 8.3.1.8.1.2.3 - Magma system dynamics. The objectives of this activity are to evaluate the dynamics of basaltic magmatism including tracing the processes of formation of basalt magma through generation in the mantle, ascent through the mantle and crust, potential storage in the mantle and crust, and eruption at the earth's surface. Physically and mathematically based models of basaltic processes will be developed as a framework for a process-based assessment of the effects of basaltic magmatic activity on a repository.

Project scientists developed conceptual models for the melting process in the magma source region and the migration of melt into deep magma chambers. This has involved literature surveys on such topics as the spatial scale of mineralogical heterogeneities in the mantle.

Forecast: Studies of xenolith entrainment (as an analog for repository waste entrainment) at small basaltic centers will continue. Data will be gathered at the volcanoes of the Crater Flat volcanic field near Yucca Mountain, and scoria cones, maars, and lava flows from selected centers in the San Francisco volcanic field (Arizona). Results will be incorporated into probabilistic risk calculations. Work will continue on the subsurface effects of intrusion of magma at or near a potential repository. Modeling studies will focus on determining the maximum spatial and temporal extent of hydrothermal (including vapor phase) circulation. This will include three-dimensional calculations with Yucca Mountain geometry and hydrologic properties, and a range of intrusion geometries. Modeling studies directed at understanding field data from analog sites will continue. Field studies will concentrate on intrusion-induced variations in mechanical and mineralogical properties of tuff host rocks. Work will continue on tying geochemical, isotopic, petrologic, geophysical, and geochronological data for Pliocene-Quaternary magmatism in the Yucca Mountain region with existing theoretical models of melt segregation, ascent, storage, and eruption.

3.6.3 Study 8.3.1.8.2.1 - Tectonic Effects: Evaluations of Changes in the Natural and Engineered Barrier Systems Resulting from Tectonic Processes and Events

The objective of this study is to assess the probability and effects of tectonic processes and events that could result in adverse effects on waste package lifetime, average percolation flux rate over the repository, elevation of the water table, local fracture permeability, effective porosity, and rock geochemical properties.

The study plan and Site Characterization Program Baseline were revised to combine Investigations 8.3.1.8.2, 8.3.1.8.3, and 8.3.1.8.4 into one investigation (8.3.1.8.2), one study (8.3.1.8.2.1), and five activities (listed below, corresponding to the five studies formerly included in the three investigations). This work was consolidated because much of the work assigned in the SCP to these investigations duplicated work in other studies. The remaining work was sufficiently closely related and limited in scope that the planned work elements and the designated objectives and parameters could logically and appropriately be integrated.

As part of the study plan consolidation effort, work scope associated with Study 8.3.1.8.5.3, "Investigation of Folds in Miocene and Younger Rocks of Region," will be transferred to this study. The work will contribute to assessing the tectonic processes affecting Yucca Mountain.

Activity 8.3.1.8.2.1.1 - Analysis of waste package rupture due to tectonic processes and events. The objective of this activity is to collect and synthesize data that can be used to assess the probability and effects of tectonic processes and events that could result in adverse impacts on waste package lifetime and performance.

No progress was made during the reporting period; this was an unfunded activity.

Activity 8.3.1.8.2.1.2 - Analysis of the effects of tectonic processes and events on average percolation flux rates over the repository. The objective of this activity is to 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 unit.

No progress was made during the reporting period; this was an unfunded activity.

Activity 8.3.1.8.2.1.3 - Analysis of the effect of tectonic processes and events on changes in water-table elevation. The objective of this activity is to produce analyses and assessments of 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.

Technical staff for the computer modeling part of this activity were hired, and scoping studies were initiated to evaluate potential tectonic effects. Preliminary (scoping) computer modeling was started.

Activity 8.3.1.8.2.1.4 - Analysis of the effects of tectonic processes and events on local fracture permeability and effective porosity. The objective of this activity is to address possible changes in fracture permeability and effective porosity caused by tectonic events and processes.

No progress was made during the reporting period; this was an unfunded activity.

Activity 8.3.1.8.2.1.5 - Analysis of the effects of tectonic processes and events on rock geochemical properties. The objective of this activity is to provide assessments of the initiating events related to local changes in distribution coefficients resulting from tectonic processes and events.

No progress was made during the reporting period; this was an unfunded activity.

Forecast: Computer modeling of the effects of tectonic processes on the hydrologic system at Yucca Mountain will be conducted.

3.6.4 Study 8.3.1.8.3.1 - Analysis of the Effects of Tectonic Processes and Events on Average Percolation Flux Rates Over the Repository

This study has been combined with Study 8.3.1.8.2.1.

3.6.5 Study 8.3.1.8.3.2 - Analysis of the Effects of Tectonic Processes and Events on Changes in Water-Table Elevation

This study has been combined with Study 8.3.1.8.2.1.

3.6.6 Study 8.3.1.8.3.3 - Analysis of the Effects of Tectonic Processes and Events on Local Fracture Permeability and Effective Porosity

This study has been combined with Study 8.3.1.8.2.1.

3.6.7 Study 8.3.1.8.4.1 - Analysis of the Effects of Tectonic Processes and Events on Rock Geochemical Properties

This study has been combined with Study 8.3.1.8.2.1.

3.6.8 Study 8.3.1.8.5.1 - Characterization of Volcanic Features

The objective of this study is to provide refined data on the age, location, eruptive models, and volume of young volcanic rocks in the vicinity of the site. These data will be

used to refine the calculations on the probability of igneous or volcanic events occurring in the controlled area and penetrating the repository.

Activity 8.3.1.8.5.1.1 - Volcanism drillholes. The objective of this activity is to investigate the origin of four or five aeromagnetic anomalies found in Crater Flat and the Amargosa Valley. Data from this work will be used to refine probability calculations, to evaluate the tectonic setting of volcanic centers, and to test concepts of the temporal and geochemical patterns of basalts in the Nevada Test Site region.

No progress was made during the reporting period; this was an unfunded activity.

Activity 8.3.1.8.5.1.2 - Geochronology studies. The objective of this activity is to establish the chronology of basaltic volcanism and the youngest silicic volcanic activity in the Yucca Mountain region. These data will be used to revise the recurrence rate of the volcanic probability calculations and to determine the age of cessation of silicic volcanic activity. Further studies are required for three topics: the age of the Quaternary volcanic events in the Yucca Mountain region; the age and eruption chronology of the youngest (<0.5 ma) volcanic event in the Yucca Mountain area; and the age of the youngest silicic volcanic activity in the region with emphasis on the Black Mountain caldera or young silicic rocks that may be encountered in shallow volcanic drillholes.

Data collection on the geochronology of all post-Miocene eruptive centers continued. These data will be compiled into a final geochronology milestone, "Geochronology of Basaltic Volcanic Centers of the Yucca Mountain Region," due in FY 1996, which will form the geochronology framework for final volcanism probability calculations.

Six samples were collected from the Little Black Peak and Hidden Cone centers at Sleeping Butte for Ar-40/Ar-39 dating. The Ar-40/Ar-39 dates were determined for two whole-rock samples at Buckboard Mesa, three samples at Red Cone, two samples at Little Cones, two samples at Makani Cone, one sample at Black Cone, one sample from Little Black Peak, and one sample from the Pliocene episode in southeast Crater Flat.

Uranium-thorium disequilibria mineral isochrons were finalized for one sample from Little Black Peak and three samples from Lathrop Wells. The uranium-thorium data from Lathrop Wells support the conclusion of significant age differences between eruptive units. The uranium-thorium results are reported in Murrell et al. (in prep.). Results presented in the abstract indicate that lava flows at Lathrop Wells have ages ranging from approximately 130 to 50 ka.

The Ar-40/Ar-39 ages were completed for 6 samples from flow Ql_2 at Lathrop Wells. These results suggest that the flow erupted between ~100 and 60 ka, with the younger age range being the preferred interpretation. Samples were collected from three sites at Lathrop Wells for thermoluminescence dating. These dates will be integrated with thermoluminescence dating in trenched fault exposures near Yucca Mountain.

Geochronology data gathered before May 1994 were published (Crowe et al., 1995).

Activity 8.3.1.8.5.1.3 - Field geologic studies. The objective of this activity is to establish the field geologic relations and the eruptive history of basaltic volcanic centers in the Yucca Mountain region.

Geologic mapping and map compilation continued for the 3.7-million-yr-old basalts of Crater Flat and the 1-million-yr-old basalts of Little Cones and Makani Cone. These data will be combined with geochemical data to constrain the number of magma pulses involved in the formation of each volcanic center. A geologic map of the Lathrop Wells Volcanic Center, showing the distribution of eruptive units from four main eruptive episodes, was published (Figure 2.33 in Crowe et al. 1995).

Activity 8.3.1.8.5.1.4 - Geochemistry of scoria sequences. The objective of this activity is to determine the geochemistry of scoria sequences of different ages at the Lathrop Wells center and older centers in the Crater Flat area. The models will be used to test geologic assumptions made for the probability calculations and the time-space tectonic model for the distribution of basaltic volcanism. In addition, the data on the geochemistry of the scoria sequences will also be used to correlate basaltic ash interbedded in trenches with their correct eruptive source.

Project scientists completed 15 instrumental neutron activation analyses of basaltic ash from Solitario Canyon Fault Trench 8 and Lathrop Wells. These analyses will be used to constrain the identity of basaltic ash found in numerous trenched fault exposures near Yucca Mountain. Identification of the ashes will place constraints on their age and the timing of coupled seismic/volcanism episodes near Yucca Mountain. Sixty three x-ray fluorescence analyses of basalt samples from Sleeping Butte, Black Cone, Red Cone, Little Cones, southeast Crater Flat, Thirsty Mesa, Buckboard Mesa and the Cima volcanic field were completed. These data will be used to model the evolution of basaltic volcanism in the Yucca Mountain region during the last 5 Ma to determine whether volcanism is waxing or waning. A discussion of geochemical data from the Lathrop Wells volcanic center was published in Chapter 4 of Crowe et al. (1995). These data indicate that multiple magma batches were involved in the formation of the Lathrop Wells center (polygenetic volcanism), each representing a discrete episode of dike intrusion into the upper crust.

Activity 8.3.1.8.5.1.5 - Geochemical cycles of basaltic volcanic fields. The objective of this activity is to determine the time-space geochemical variations of the volcanic fields of the southern Great Basin.

Strontium, neodymium, and lead isotopic analyses continued to be gathered for post-Miocene eruptive centers in the Yucca Mountain region. These data, along with major and trace-element data, will be used to constrain the magmatic evolution of the Crater Flat Volcanic Zone, with particular emphasis on determining whether magmatic processes are waxing or waning in the Yucca Mountain region.

Forecast: Ar-40/Ar-39 dating of basalt will be completed for all post-Miocene volcanic centers. Paleomagnetic, geomorphic, and soils analysis will be completed at selected volcanic centers. Trenching of volcanic units will be completed at the Sleeping Butte Centers

and selected volcanic centers in Crater Flat. Maps of all post-Miocene (<5 million yr) centers will be finalized.

Geochemical studies will focus on petrological and isotopic studies of the basalt of Sleeping Butte and the 1 Ma and 3.7 Ma basalt of Crater Flat. Isotopic analyses of strontium, neodymium, and lead will be obtained for these units. Instrumental neutron activation analysis data for a selected suite of trace elements will also be obtained. Major element data will be obtained by x-ray fluorescence. Petrological modeling of the isotopic and geochemical data will be conducted to examine alternative models of basalt petrogenesis. The results of the modeling will be used to test assumptions used in probability calculations. Basaltic ash exposed in fault trenches east and west of Yucca Mountain will be sampled and analyzed for major and trace-element chemistry to correlate these ashes with eruptive episodes at the Lathrop Wells volcanic center. Correlation of these ashes will constrain the timing of major paleoseismic activity near Yucca Mountain.

Integration of geochemical and isotopic data for all post-Miocene volcanic centers in the Yucca Mountain region will continue. Evaluation of evolution of analog volcanic fields in the southwestern United States will continue to determine whether characteristic time-volume-geochemical patterns can be used to predict patterns of future volcanic activity.

3.6.9 Study 8.3.1.8.5.2 - Characterization of Igneous Intrusive Features

The objective of this study is to 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. The evidence for the presence or absence of thermal anomalies will be used as part of the evaluation of the presence of significant magma bodies in the area and their relation to the probability of future volcanic events.

Activity 8.3.1.8.5.2.1 - Evaluation of depth of curie temperature isotherm. The objective of this activity was intentionally omitted. The most current evaluation of curie temperature data shows that the technique yields results that are too ambiguous and are at a scale of detection too general to be useful for application at Yucca Mountain.

Activity 8.3.1.8.5.2.2 - Chemical and physical changes around dikes. The objective of this activity was intentionally omitted. Data on the nature and extent of physical changes that may occur in the surrounding tuffs as a result of the intrusion of dikes or sills will be collected under Study 8.3.1.8.1.2 (see Section 3.6.2).

Activity 8.3.1.8.5.2.3 - Heat flow at Yucca Mountain and evaluation of regional ambient heat flow anomalies. The objectives of this activity are to compile and evaluate available heat flow data at and near Yucca Mountain, to assess the need for additional heat flow determinations, to collect additional thermal data from existing and planned drillholes, and to identify and evaluate thermal anomalies.

All sondes, meters, balances, and related logging and laboratory equipment were maintained in a ready state pending opportunities to log existing holes. A horizontal temperature log was carried out in drillhole RBT2 in Alcove #1 of the ESF. The primary purpose of this log was to make a final test of the equipment before logging holes in the Bow Ridge Fault alcove, and to familiarize personnel with working in the ESF. A temperature log in the accessible section of the saturated zone of USW G-2 indicated a continued change in the thermal regime with time, indicating that possibly perched water in the area is being drained from one permeable zone into another, but at a rate that is declining with time. Sass et al. (in prep.) review previously published data and discuss additional insights into the hydrologic implications of thermal data. The report is included as Chapter 8 in the Geophysics White Paper Phase II; see description under Activity 8.3.1.4.2.1.2 in Section 3.3.3.

Forecast: Additional continuous high-resolution temperature logs are planned for the unsaturated zone and for the saturated zone below the present bridge in corehole USW-G2 before pumping tests are made. Horizontal temperature logs in the Bow Ridge fault zone in the ESF will test the null hypothesis that water is not flowing vertically at rates of more than a few centimeters per year. High-resolution, continuous-temperature logs in reconfigured WT holes will test the null hypothesis that there is no infiltration of water in the unsaturated zone outside of identified areas having high-angle faults and fractures. Input will be sought to the engineering plans for USW G-5 and/or USW G-6 to ensure that the nature of the hydrologic boundary between the tuffs and the Paleozoic carbonate aquifers can be characterized with sufficient resolution to identify any potential flow paths.

All work on Activity 8.3.1.8.5.2.3 will continue to be funded and performed within the closely-related Activity 8.3.1.15.2.2.1, "Surface-based Evaluation of Ambient Thermal Conditions."

3.6.10 Study 8.3.1.8.5.3 - Investigation of Folds in Miocene and Younger Rocks of Region

The objective of this study is to establish the regional pattern and rate of Neogene folding.

This SCP section contains one activity that relies on available data; no unique data are to be acquired.

Activity 8.3.1.8.5.3.1 - Evaluation of folds in Neogene rocks of the region. The objective of this activity is to establish the pattern, rate, amplitude, and wavelength of post-middle Miocene folding in the region.

No progress was made during the reporting period; this was an unfunded activity.

Forecast: Aspects of this work scope will be transferred to Study Plan 8.3.1.8.2.1.

3.7 HUMAN INTERFERENCE (SCP SECTION 8.3.1.9)

3.7.1 Study 8.3.1.9.1.1 - An Evaluation of Natural Processes that Could Affect the Long-Term Survivability of the Surface Marker System at Yucca Mountain

The objective of this study is to provide information on the currently or potentially active natural processes at Yucca Mountain capable of adversely affecting the long-term survivability of the surface marker system. This study will synthesize data obtained from other activities to be undertaken in support of several investigations. The data will then be evaluated to determine the most suitable locations of the monuments for the surface marker system.

There will be no study plan developed for this SCP section. This study is to identify candidate sites free of tectonic, seismic, volcanic, erosion, or depositional influences that would mitigate against survivability of surface markers. The two activities in this SCP section draw upon data collected from other studies. There are no unique data to be collected. Activity 8.3.1.9.1.1.1 will extract available data from Studies 8.3.1.8.1.2 and 8.3.1.8.2.1 to perform the assessment for marker siting. Activity 8.3.1.9.1.1.2 will use data reported in the Extreme Erosion Topical Report and related work such as surficial mapping and Study 8.3.1.5.1.4 (Paleoenvironmental History).

Activity 8.3.1.9.1.1.1 - Synthesis of tectonic, seismic, and volcanic hazards data from other site characterization activities. The objective of this activity is to identify the potential locations of faulting and volcanic eruption or intrusion that could occur where they could affect the marker system.

A proposal for this study was approved and work was begun. No results or progress have yet been submitted.

Activity 8.3.1.9.1.1.2 - Synthesis evaluation of the effects of future erosion and deposition on the survivability of the marker system at Yucca Mountain. The objective of this activity is to determine the effects of future erosion and deposition on the topographic elements of the controlled area boundary at Yucca Mountain. This information will be evaluated to identify the optimum locations for the markers.

A proposal for this study was approved and work was begun. No results or progress have yet been submitted.

Forecast: A report is being developed to recommend candidate locations for surface markers and other components of the surface marker system; this report should be available in September of 1995.

3.7.2 Study 8.3.1.9.2.1 - Natural Resource Assessment of Yucca Mountain, Nye County, Nevada

The objective of this study is to identify and assess the natural resource potential at the proposed repository site at Yucca Mountain. The information and data obtained in this study will provide the basis for probabilistic calculations for evaluating the potential for inadvertent human interference.

Activity 8.3.1.9.2.1.1 - Geochemical assessment of Yucca Mountain in relation to the potential for mineralization. The objective of this activity is to 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. Specific objectives include (a) selecting a suite of elements for analysis in a geochemical sampling program based upon known commodities that occur in silicic tuffs and/or trace elements indicative of commodities that occur in the tuffs, (b) developing a field program to include a systematic and biased sampling of surface materials, (c) generating a first-order geochemical data base for selected elements obtained from surface and subsurface sampling within the vicinity of Yucca Mountain, (d) evaluating the data base in conjunction with geological and geophysical data obtained from other site characterization activities to determine if additional data are needed for an evaluation of natural resources, and (e) evaluating the potential for the occurrence of natural resources in the vicinity of Yucca Mountain based on an analysis of the geochemical data.

A geotechnical sampling program is being implemented by the Nevada Bureau of Mines & Geology to provide the basis for the analysis described above. This sampling initiative includes surface and subsurface sampling and may use multiple analytical techniques. All sampling, field work, laboratory analyses, and the metallic resource assessment work is the responsibility of the Nevada Bureau of Mines & Geology and is being accomplished in this activity and as a part of Activities 8.3.1.9.2.1.2 and 8.3.1.9.2.1.5.

The Mineral Resources and Isotope Hydrology Team developed and implemented innovative procedures for assessing the potential for mineralization of the Miocene volcanic rock mass and its basement of Paleozoic limestones at Yucca Mountain. These procedures combined stable and radiogenic isotope geochemistry with more traditional trace-element geochemical analyses to search for evidence of mineralizing fluids that may have pervaded the rock mass in the past. The isotopic approaches were based upon principles established by researchers working in the Great Basin since the early 1970s and are much more sensitive to detecting subtle indications of mineralizing fluids than the more conventional or industry standard approaches to prospecting. These numerous studies have shown that epithermal hydrothermal systems in igneous terrains are targeted by bulls-eye zones of $^{18}0$ depletion that formed by interaction between the host rocks and hydrothermal fluids (Criss and Taylor, 1986). Additionally, hydrothermal fluids commonly carry the strontium and lead isotopic signatures of the Precambrian basement rocks through which the fluids ascended (Peterman et al., 1994; Peterman and Aleinikoff, 1994). These isotopic signatures are indelibly imprinted on the mineralized zones of the host rocks and on surrounding haloes.

Two studies using the principles and approaches outlined above were completed during this reporting period by the Mineral Resources and Isotope Hydrology Team. Neither study detected any evidence of the past involvement of the volcanic rocks with mineralizing fluids. The first study entailed a geochemical and oxygen-isotope study of outcrop samples of the Tiva Canyon Tuff collected within the conceptual controlled area (Marshall et al., in prep). The study was designed to detect any subtle indications of past interactions of the Tiva Canyon Tuff with hydrothermal solutions. Such evidence of intermediate- to high-temperature water-rock interaction would indicate the possibility of epithermal mineralization within the volcanic rock mass at and below the stratigraphic level of the Tiva Canyon Tuff. Unaltered volcanic rocks have primary $\delta^{18}O$ values between +5.5 and +11.0 permil (Taylor and Sheppard, 1986). Mineralizing fluids would have had $\delta^{18}O$ values between -14 and -13 permil based on modern meteoric water in the region (Benson and McKinley, 1985); thus, any interaction with hydrothermal fluids would have substantially lowered the $\delta^{18}O$ rock values as shown by O'Neil and Silberman (1974).

For this investigation, 159 samples were systematically collected from the upper cliff and caprock zones of the Tiva Canyon Tuff at spacings of 500 m where possible. For control, 36 samples were collected from a reference section of the Tiva Canyon Tuff in Solitario Canyon. All these samples were analyzed for ^{18}O and for selected major and trace elements including precious metals (gold, silver) and elements considered to be pathfinders for epithermal mineralization (e.g. arsenic, selenium, and mercury). $\delta^{18}O$ in the samples from the upper cliff and caprock zones of the Tiva Canyon ranged from +6.9 to +11.9 permil, with no indications of ^{18}O depletion that would have derived from interaction with hydrothermal fluids. Similarly, none of the trace metals indicative of epithermal mineralization were elevated in the Tiva Canyon samples. Some of the pathfinder elements were below detection limits, and both arsenic and gold are only marginally higher than typical magmatic levels in siliceous volcanic rocks (Connors et al., 1993).

The second study focused on potential fluid pathways in the Tiva Canyon Tuff and the Topopah Spring Tuff (Neymark et al., in press). Strontium, lead, and oxygen isotope analyses, and x-ray fluorescence analyses for selected major and trace elements were conducted on brecciated and altered samples within fault zones at Trench 14 and Busted Butte. Hydrothermal fluids ascending along fault zones would have modified the oxygen isotopic compositions of the rocks as described above and added or exchanged strontium and lead with isotopic compositions reflecting a source in older rocks. Isotopic and geochemical data for the altered rocks in the fault zones were compared with data obtained on unaltered samples of the Tiva Canyon Tuff from Antler Ridge and of the Topopah Spring Tuff from core in bore hole UE-25 a#l. Calcite and opaline silica have been introduced into the breccias resulting in the increase of calcium, strontium, uranium, and barium concentrations and $\delta^{18}O$ to values between +12.1 and +20.4 permil. The data do not indicate any introduction of radiogenic isotopes or oxygen isotope exchange by hydrothermal fluids, and it was concluded that the fault zones have not been pathways for epithermal mineralizing solutions.

Activity 8.3.1.9.2.1.2 - Geophysical/geological appraisal of the site relative to mineral resources. The objective of this activity is to qualitatively evaluate the available geophysical

data base as it relates to Study Plan 8.3.1.9.2.1. Geologic models derived from geophysical data will be evaluated for their impact on mineral resources.

This work is being conducted and will be reported in FY 1996 as part of Activity 8.3.1.9.2.1.5.

Activity 8.3.1.9.2.1.3 - Assessment of the potential for geothermal energy at Yucca Mountain, Nevada. The objective of this activity is to evaluate regional ambient heat flow and local heat flow anomalies. This activity assesses the geothermal regime in terms of its energy resource potential for either hydrothermal or conductive reservoir thermal systems.

A report on the work is due in September of 1995. Temperature, thermal conductivity, and heat flow data were compiled and transmitted to the Technical Data Base on March 15.

Activity 8.3.1.9.2.1.4 - Assessment of hydrocarbon resources at and near the site. The objectives of this activity are to determine the potential for the presence or absence of suitable source rocks, reservoir rocks, and traps and seals at or near the site; to determine the potential for occurrence of conventional hydrocarbon resources (crude oil and natural gas) at and near the site; and to provide necessary data for the overall mineral and energy resource assessment to be performed.

No progress was made during the reporting period; this was an unfunded activity.

Activity 8.3.1.9.2.1.5 - Mineral and energy assessment of the site, comparison to known mineralized areas, and the potential for undiscovered resources and future exploration. The objective of this activity is to integrate the data and information collected from the geochemical assessment, geophysical/geologic assessment, geothermal energy assessment, and hydrocarbon assessment. Integrating these activities and the data acquired from them will allow (a) the identification of mineral resources with current markets, as well as the calculation of gross and net values for identified resources or reserves; (b) the physical description of mineral resources with potential future markets relative to "tonnage, or other amount, grade, and quality," as described in 10 CFR 60.21(c)(13); (c) the physical description of energy resources using appropriate parameters that describe the extent and magnitude of those resources; (d) the evaluation of the resource potential of any identified or undiscovered mineral and energy resources based on a "representative" area of "similar size" and a comparison to the Yucca Mountain site as prescribed in 10 CFR 60.122(c)(17); and (e) an estimation of the potential for undiscovered deposits of those resources described in 10 CFR 60.21(c)(13).

Data are being collected as the result of activity in many studies. These data and information are being integrated and a report is due in FY 1996.

Forecast: Previously collected downhole temperature data and geochemical data including sample locations, sample descriptions, and elemental abundance data will be submitted to the Yucca Mountain Technical Data Base. These data will then be available for the assessment of natural resources within the controlled area of Yucca Mountain.

Reports are expected in early FY 1996 except for the assessment of metallic resources which is expected in mid- to late FY 1996.

3.7.3 Study 8.3.1.9.2.2 - Water Resource Assessment of Yucca Mountain, Nevada

The objective of this study is to use available data to estimate the future supply, demand, and value of the ground-water resource proximal to Yucca Mountain.

Activity 8.3.1.9.2.2.1 - Projected trends in local and regional ground-water development and estimated withdrawal rates in southern Nevada, proximal to Yucca Mountain. The objectives of this activity are to assess the current and projected supply and demand situation in the foreseeable future for ground water in the geohydrologic study area and to estimate the value of the ground-water resource.

No progress was made during the reporting period; this was an unfunded study.

Forecast: A milestone is being established to report on the availability, quality, potential uses, and demand for water resources in the area of the Yucca Mountain site. This work is expected to be completed in FY 1996

3.7.4 Study 8.3.1.9.3.1 - Evaluation of Data Needed to Support an Assessment of the Likelihood of Future Inadvertent Human Intrusion at Yucca Mountain as a Result of Exploration and/or Extraction of Natural Resources

The objective of this study is to compile and analyze data to assess the likelihood of inadvertent human interference in the Yucca Mountain vicinity.

No unique data are to be acquired by this study. As a result, there will be no study plan developed forthis SCP section. The results of Study 8.3.1.9.2.1 will be a major, direct input to this study. Other inputs will be acquired from existing study plans or available data.

Activity 8.3.1.9.3.1.1 - Compilation of data to support the assessment calculation of the potential for inadvertent human intrusion at Yucca Mountain. The objectives of this activity are to determine the maximum drilling density and frequency (drillholes per square kilometer per 10,000 yr) that can be reasonably assumed for a repository at Yucca Mountain; and to determine the extent to which future ground-water withdrawals will modify the expected ground-water flow paths.

Forecast: A DOE working paper will be developed to document and discuss input parameters for inadvertent intrusion performance modeling using direct inputs from Study 8.3.1.9.2.1 and other studies.

3.7.5 Study 8.3.1.9.3.2 - An Evaluation of the Potential Effects of Exploration for, or Extraction of, Natural Resources on the Hydrologic Characteristics at Yucca Mountain

The objective of this study is to assess, in qualitative or quantitative terms, the effects of exploiting natural resources known or believed to be present at Yucca Mountain. Consideration of the effects of resource exploitation or extraction are limited to changes in the hydrologic, geochemical, and rock characteristics.

There will be no study plan developed for this SCP section. No unique data are to be acquired by this study. The inputs to computer modeling for varying water withdrawal assumptions and input bounds for sensitivity analysis of the code will be supplied directly from Study Plan 8.3.1.9.2.2.

Forecast: No activity is planned for FY 1995.

3.8 METEOROLOGY (SCP SECTION 8.3.1.12)

3.8.1 Study 8.3.1.12.1.1 - Characterization of the Regional Meteorological Conditions

The objective of this study is to gather and analyze meteorological data from various locations to characterize the regional meteorology and assimilate that information into a regional summary report. This characterization will provide a regional overview of wind flow patterns and other meteorological parameters (related to atmospheric dispersion) associated with those patterns in and around Yucca Mountain.

There will be no further study plans developed for this SCP program. Three SCP studies and one investigation in the Meteorology Program (8.3.1.12) include work to describe current regional meteorological conditions: Study 8.3.1.12.1.1, "Characterization of the Regional Meteorological Conditions," Study 8.3.1.12.1.2, "Plan for Synthesis of Yucca Mountain Site Characterization Project Meteorological Monitoring," Investigation 8.3.1.12.3, "Studies to Provide Data on the Location of Population Centers Relative to Wind Patterns in the General Region of the Site," and Study 8.3.1.12.4.1, "Characterize the Potential Extreme Weather Phenomena and their Recurrence Intervals." These studies (and the investigation) were identified as suitable for control through means other than study plans. The planning material intended for inclusion in Study Plan 8.3.1.12.1.1 was written as a Scientific Investigation Implementation Package and was completed in January 1995. The next step is the preparation of one or more Work Instructions, initiated this reporting period.

Forecast: The Work Instruction(s) controlling the regional meteorology work will be completed during the next reporting period. The literature and data search portion of the investigation will be initiated. Information collected for this search will probably be applied to a technical basis report to support the Technical Site Suitability determination.

3.8.2 Study 8.3.1.12.1.2 - Plan for Synthesis of Yucca Mountain Site Characterization Project Meteorological Monitoring

The objective of this study is to develop a plan that provides for coordination of meteorological monitoring efforts prepared during site characterization by various Project participants.

The work in this study was combined with other studies into the Scientific Investigation Implementation Package. See Section 3.8.1 of this Progress Report.

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

The objective of this study is to provide data to resolve design and performance issues associated with preclosure radiological safety.

Activity 8.3.1.12.2.1.1 - Site meteorological monitoring program. The objective of this activity is to collect meteorological 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.

The ongoing meteorological monitoring program continued at the nine active sites. This program is currently focused on data collection, though results from the monitoring program are being used in some current site characterization activities. The primary use of the data is for future site suitability and licensing work in preclosure radiological safety issues to estimate potential radiological dosage related to repository operations.

Data from the network were included in two quarterly Ambient Air Monitoring Reports submitted to the State of Nevada during this reporting period. These reports fulfill requirements of State Air Quality Permit No. AP9999-0076 (previously identified by the State as No. 2693), which covers site characterization surface-disturbing activities. No significant increase in the concentrations of inhalable particulate matter has been noted, despite increased surface-disturbing activity at the site.

Data from this program were used to prepare a study report on nocturnal airflow discussed in Section 3.8.4 of this report. Data from this routine monitoring program are also being supplied to other Project participants in support of other characterization activities. These requests are being completed in a timely manner.

Activity 8.3.1.12.2.1.2 - Data summary for input to dose assessments. The objective of this activity is to process the collected meteorological data into a format and content that will be useful in assessing radiological impacts, as required by design and performance issues.

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

Forecast: Data collection will continue at the nine sites during FY 1995 and beyond.

3.8.4 Study 8.3.1.12.3 - Studies to Provide Data on the Location of Population Centers Relative to Wind Patterns in the General Region of the Site

The objective of this study is to provide data on wind flow patterns in the general region of Yucca Mountain. These data will then be used in estimating doses to the public and in doing so ensure that wind flow patterns would not preferentially transport material towards population centers.

The work in this study was combined with other studies in the Scientific Investigation Implementation Package. See Section 3.8.1 of this Progress Report.

A report was issued that describes the special intensive field study program performed during late autumn 1993 with participation by the National Oceanic and Atmospheric Administration, Air Resources Laboratory, Atmospheric Turbulence and Diffusion Division in Oak Ridge, Tennessee, and the National Oceanic and Atmospheric Administration, Air Resources Laboratory, Special Operations and Research Division in Las Vegas and Mercury, Nevada. The purpose of the study was to characterize nighttime downslope airflow related to the west and east sides of the main Yucca Mountain ridge. These conditions may be the "worst-case" atmospheric dispersion relative to possible releases of airborne radioactive material in terms of impacts to the public. The results showed complex airflow patterns occurring, which appear to be influenced by local topography and large scale meteorological patterns.

Forecast: Future work on this study will be controlled and tracked through Study 8.3.1.12.1.1, discussed in Section 3.8.1 of this Progress Report.

3.8.5 Study 8.3.1.12.4.1 - Characterize the Potential Extreme Weather Phenomena and Their Recurrence Intervals

The objective of this study is to evaluate existing historical meteorological and climatological records, technical publications, and other relevant information to quantify the extreme weather phenomena that may be expected at the Yucca Mountain site and determine their recurrence interval.

The work in this study was combined with other studies in the Scientific Investigation Implementation Package. See Section 3.8.1 of this Progress Report.

3.9 OFFSITE INSTALLATIONS AND OPERATIONS (SCP SECTION 8.3.1.13)

The radiological environmental monitoring program is designed to provide, among other things, the data necessary to fulfill the objectives of SCP Section 8.3.1.13. Data from this program will form the basis of all future radiological monitoring programs and will be used to identify any possible future radiological impacts on the environs of Yucca Mountain.

The data generated by this program are reported for each calendar year. Soil and air samples are collected and analyzed for radionuclide concentrations. Ambient gamma exposure and environmental radon concentrations are also measured. The process of validating data continued during the reporting period. Collection and analysis of small mammal and vegetation samples has been suspended.

Data from the previous calendar year is presented in DOE (1994p) and DOE (in prep.).

Forecast: The collection of soil and airborne particulates will continue through FY 1995, as will measurements of ambient gamma exposure rates and environmental radon concentrations. The collection of vegetation samples, suspended in FY 1994, is scheduled to resume in FY 1995. Data validation of backlog data will continue through FY 1995.

3.10 SURFACE CHARACTERISTICS (SCP SECTION 8.3.1.14)

3.10.1 Study 8.3.1.14.2.1 - Exploration Program

The objective of this study is to conduct an exploration program for characterization of the soil and rock conditions that will influence or be influenced by the construction of the surface and subsurface facilities. The exploration program study will consist of site reconnaissance, and preliminary and detailed exploration.

Activity 8.3.1.14.2.1.1 - Site reconnaissance. The objective of this activity is to review existing site information and conduct a field reconnaissance to establish a preliminary exploration program to include further topographic and geologic mapping, subsurface drilling, test pits, trenching, and geophysical methods.

A team was formed to develop a uniform method for geologic and structural core logging and to develop a computer-based core logging process. This effort is supported by activities conducted under SCP Section 8.3.1.4, Rock Characteristics, and the log format was developed to include selected framework rock properties. A preliminary computer-based core logging procedure was developed and was provided to the Lithostratigraphy Working Group during its meeting on March 10, 1995.

Preliminary reconnaissance for locating boreholes to support design of the South Ramp was completed. Preliminary surface mapping of the South Portal area was completed, and a preliminary geologic cross section was developed.

Activity 8.3.1.14.2.1.2 - Preliminary and detailed exploration. The objective of this activity is to obtain sufficient surface and subsurface data to prepare a preliminary design for the ESF surface and subsurface access facilities. Preliminary designs based on these explorations will be suitable for economic and technical feasibility reports and Project planning reports.

A report was issued to present the results of the engineering characterization of the pre-Rainier Mesa and Rainier Mesa tuffs that were encountered by the Exploratory Studies Facility North Ramp (Kessel et al., 1994). This report provided the basis for determining whether these nonlithified tuffs could be mined through by the tunnel boring machine, and provided the geoengineering data for the North Ramp through station 6 +00 m.

Three specific objectives of the investigations were met:

- Develop a detailed cross section showing the extent and continuity of the nonlithified tuffs
- Determine if the nonlithified tuffs had sufficient bearing capacity to allow the TBM to maintain grade and alignment
- Determine if the nonlithified tuffs had sufficient cohesion to prevent material from running in on the tunnel boring machine.

The geotechnical investigation for the North Ramp was completed, and all data were submitted to the technical data base. The report documenting this work is in review (Brechtel, in prep.).

Various geological cross sections along the ESF tunnel alignment continue to evolve:

- The North Ramp cross section was revised to include additional borehole data.
- The Exile Hill cross section was revised to include additional data based on refined lithostratigraphic interpretation and surface mapping.
- A preliminary cross section was developed for the main drift.

Forecast: An administrative procedure will be developed to define the process for geologic core logging and the computer software to support logging and the generation of the uniform core log will be completed. Locations and requirements for South Ramp exploratory boreholes will be submitted.

A final cross section for the main drift will be issued and a geoengineering report on rock properties for the main drift will be issued.

3.10.2 Study 8.3.1.14.2.2 - Laboratory Tests and Material Property Measurements

The objective of this study is to conduct laboratory tests and material property measurements on representative samples of soil and rock. These tests and measurements are intended to determine physical, mechanical, and dynamic properties. Additional tests and measurements will be conducted on soils to determine index properties and moisture-density compaction curves for potential fill material.

Activity 8.3.1.14.2.2.1 - Physical property and index laboratory tests. The objective of this activity is to measure the soil or rock weight and volume components using physical property tests.

The results of laboratory tests on samples from the Rainier Mesa nonlithified tuffs were analyzed. The results were used to assess several factors important for constructing the North Ramp through the nonlithified tuffs. These included the following:

- Groutability of the nonlithified tuffs
- Identification of potential weak zones resulting from possible saturation conditions
- Strength parameters.

Activity 8.3.1.14.2.2.2 - Mechanical and dynamic laboratory property tests. The objective of this activity is to measure in the laboratory the static and dynamic deformation and strength characteristics of soil and rock samples obtained from the exploratory program. The results of this testing will be used to evaluate bearing capacity, earth pressures, shear strength parameters, slope stability, settlement and swelling potentials, and the dynamic characteristics of the soil and rock.

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

Forecast: Laboratory tests on samples from the Rainier Mesa nonlithified tuffs to determine detailed strength parameters will be completed. The results of these tests will support modeling of long-term stability of the North Ramp.

3.10.3 Study 8.3.1.14.2.3 - Field Tests and Characterization Measurements

The objective of this study is to conduct field tests and characterization measurements. These field tests are intended to determine the in situ physical, mechanical, and dynamic properties of the soil and rock.

Activity 8.3.1.14.2.3.1 - Physical property field tests and characterization measurements. The objectives of this activity are to classify and describe the soil and rock conditions in the field and to determine their physical properties. The results of these tests and measurements will be used to develop estimates of the engineering characteristics of the soil and rock. In addition, these properties and measurements will aid in the grouping of soil and rock into stratigraphic units and the extrapolation of results from a restricted number of mechanical and dynamic properties tests to zones of soil and rock with similar material properties.

The geology and rock structure log for NRG-7A was completed. Core rock mass quality indices and rock mass mechanical properties estimates for the NRG holes were revised to include additional borehole data. Geology and rock structure logs for the NRG boreholes

were revised to provide improved estimates of percent lithophysae and incorporate the USGS stratigraphic nomenclature. These data were transmitted to the design team in support of design of the North Ramp.

Activity 8.3.1.14.2.3.2 - Mechanical property field tests. The objective of this activity is to measure the deformation and strength characteristics of in situ soil and rock conditions. The results of this testing will be used to evaluate bearing capacity, earth pressures, settlement and swelling potentials, slope stability, and the dynamic response of soil and rock for the design of foundations, retaining walls, backfills, roads, slopes, ramps, and shafts.

Tests were completed to support the design of the water storage tanks for the ESF and a geotechnical report was transmitted to the design team. Tests were completed to support the design of the Muck Conveyor System and preliminary results were prepared and transmitted to the design team.

Activity 8.3.1.14.2.3.3 - Geophysical field measurements. The objectives of this activity are to obtain measurements of the compressional and shear wave velocities and to determine the velocity structure in the area of the ESF surface facilities and subsurface ramps and shafts. These methods may also be used to profile the alluvium-bedrock contact, locate discontinuities or other structural abnormalities, and to determine the depth, thickness, and lateral extent of soil and rock stratigraphic units.

Preliminary results from surface seismic studies in Daylight Valley indicated that additional intervals of the nonwelded "Tuff X" unit could be encountered in the North Ramp. These data were made available to the design team to support construction of the North Ramp.

Forecast: Geology and rock structure logs will be issued for USW SD-7, SD-9, and SD-12. Rock properties data will be developed from these holes.

A final geotechnical report for the muck conveyor system will be issued.

A report documenting results from the surface seismic studies in Daylight Valley will be issued.

3.11 THERMAL AND MECHANICAL ROCK PROPERTIES (SCP SECTION 8.3.1.15)

3.11.1 Study 8.3.1.15.1.1 - Laboratory Thermal Properties

The objective of this study is to provide laboratory characterization of thermal conductivity and heat capacity and the spatial variability thereof. To accomplish this, porosity, grain density, and the heat capacity and thermal conductivity of zero-porosity material must also be characterized.

Activity 8.3.1.15.1.1.1 - Density and porosity characterization. The objective of this activity is to obtain data on density and porosity and to evaluate its spatial variability. Data will contribute to determination of in situ thermal properties (porosity and grain density), to vertical in situ stress (bulk density), and radiation-shielding properties (bulk density).

Potential correlations between thermal properties and sample characteristics (bulk properties, grain densities, mineralogical and petrologic characterizations, and whole-rock chemistry) are being examined, for samples obtained from USW NRG-6. The existence of correlations have the potential to extrapolate measured thermal properties from specific drillholes to the three dimensional model of the site.

Activity 8.3.1.15.1.1.2 - Volumetric heat capacity characterization. The objective of this activity is to obtain data for volumetric heat capacity and to evaluate its spatial variability. The data will be used in calculations of the thermal response to the presence of heat-producing waste in unit TSw2.

Development of equipment to measure heat capacity of tuff continued.

Activity 8.3.1.15.1.1.3 - Thermal conductivity characterization. The objective of this activity is to obtain data for thermal conductivity and to evaluate its spatial variability. The data will be used in calculations of the thermal response to the presence of heat-producing waste in unit TSw2.

Measurements of thermal conductivity were made on samples of the TSw2 and TSw1 thermomechanical units from Drillholes UE-25 NRG#4, UE-25 NRG#5, and USW NRG-7A, to obtain an indication of the lateral and vertical variability of these units.

Forecast: Measurement of thermal conductivity will continue for samples from NRG, SD, and SRG holes. A data report, summarizing the data from samples from UE-25 NRG#4, UE-25 NRG#5, USW NRG-6, and USW NRG-7A drillholes will be submitted. In addition, this report will report any correlations between thermal conductivity and sample characteristics from samples from USW NRG-6.

3.11.2 Study 8.3.1.15.1.2 - Laboratory Thermal Expansion Testing

The objective of this study is to provide laboratory characterization of thermal-expansion behavior and the spatial variability thereof. Testing frequency at the main test level in the ESF will depend on spatial variability.

The coefficient of thermal expansion is a basic physical parameter that is required to determine the mechanical response of the repository to applied heat. The coefficient is required to predict thermal stresses in underground openings during operation and closure of the potential repository, and to predict thermohydrologic flow.

Project scientists are measuring thermal expansion on samples of tuff from the NRG and SD drillholes. These measurements will produce values for thermal expansion and indicate the lateral and vertical variability of thermal expansion. Testing this year is emphasizing the TSw2 thermomechanical unit.

Activity 8.3.1.15.1.2.1 - Thermal expansion characterization. The objective of this activity is to obtain data for thermal-expansion behavior and to evaluate the spatial variability thereof. The data will be used in calculations of thermal stress and deformation associated with the temperature field produced by the presence of heat-producing waste in unit TSw2.

Measurements of thermal expansion were made on samples of the TSw2 and TSw1 thermomechanical units from drillholes UE-25 NRG#4, UE-25 NRG#5, and USW NRG-7A, to obtain an indication of the lateral and vertical variability of these units.

A study of the effects of confining pressure on thermal expansion is ongoing. Past experiments on unconfined samples have resulted in values for thermal expansion that were higher than expected. These high values have been associated with silica phase transformations. This study is designed to determine if confining pressure will suppress the high values of thermal expansion. Equipment to conduct these experiments was assembled. Laboratory measurements were made of the amount of cristobalite and tridymite (the silica phases thought to be associated with the high values for thermal expansion) in the samples.

Forecast: Measurement of thermal conductivity will continue for samples from NRG, SD, and SRG holes. A data report summarizing the data from samples from UE-25 NRG#4, UE-25 NRG#5, USW NRG-6, and USW NRG-7A drillholes will be submitted. A second report, summarizing the results of the study on the effects of confining pressure on thermal expansion, will be also be submitted.

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

The objective of this study is to provide laboratory characterization of the mechanical properties of intact rock and its spatial variability. Testing frequency at the main test level in the ESF will depend on spatial variability.

Activity 8.3.1.15.1.3.1 - Compressive mechanical properties of intact rock at baseline experiment conditions. The objective of this activity is to obtain data for the comprehensive mechanical properties of intact rock and the spatial variability thereof for baseline experiment conditions. These data will be used in mechanical and thermomechanical calculations of stresses and deformations induced by the presence of underground openings in unit TSw2 and overlying units and by the presence of heat-producing waste in unit TSw2.

During the reporting period, samples have been collected from core taken in drillholes USW SD-12, USW SD-9, and USW SD-7 for intact mechanical properties testing at baseline conditions. Although a lower density of samples will be tested from these holes as was tested

from the NRG holes, the experiments from these samples will help refine the mechanical properties/porosity relationships and indicate the level of north-south variability along the main drift.

The mechanical properties and supporting bulk properties from samples collected from core of USW NRG-6 were documented (Martin et al., 1994).

Activity 8.3.1.15.1.3.2 - Effects of variable environmental conditions on mechanical properties. The objective of this activity is to evaluate the effects of varying sample size, strain rate, temperature, confining pressure, lithophysal content, saturation state, and anisotropy on compressive mechanical properties. In addition, the tensile strength of unit TSw2 will be measured. Data will be used in mechanical and thermomechanical calculations of stresses and deformations induced by the presence of underground openings in unit TSw2 and overlying units and by the presence of heat-producing waste in unit TSw2.

Samples were collected from core taken from the NRG drillholes for intact mechanical properties testing. During the reporting period, Project scientists prepared and tested samples from USW NRG-6 and USW NRG-7A. The samples were characterized and prepared, and then confined compression experiments were performed. The results from 23 confined compression experiments have been reported; 11 samples were tested at 5 MPa confining pressure, and 12 at 10 MPa. In addition, average grain density was determined and reported for 46 samples. The results are being analyzed for a correlation between the mechanical properties and porosity; however, these data are not sufficient to evaluate the entire range of porosities observed in these tuffs (i.e., between about 5 and 60 percent).

Also conducted was a study of time-dependent deformation involving high-temperature experiments at creep and low strain rate conditions. During this time period, one incrementally-stepped constant stress experiment was completed when the sample failed within a few hours of the creep stress being increased from 170 to 180 MPa. The saturated sample was tested at a pore pressure of 4.5 MPa, a confining pressure of 5 MPa, and a temperature of 250°C.

Forecast: Quasi-static experiments will continue on samples from SD drillhole core and the creep experiments will continue to investigate time dependent mechanical properties. The data will be reduced, analyzed, and reported in support of the ESF design and site suitability activities.

3.11.4 Study 8.3.1.15.1.4 - Laboratory Determination of the Mechanical Properties of Fractures

The objective of this study is to provide laboratory characterization of the mechanical properties of fractures and the spatial variability thereof. The discussion applies for each new core hole and for the ESF.

The Fracture Properties Working Group, composed of several Project scientists, met nine times during the reporting period to discuss the testing activities supporting the ESF design and site suitability efforts.

Activity 8.3.1.15.1.4.1 - Mechanical properties of fractures at baseline experiment conditions. The objective of this activity is to obtain data for the mechanical properties of fractures, and the spatial variability thereof, for baseline experiment conditions. The data will be used in mechanical and thermomechanical calculations of the stresses and deformations induced by the presence of underground openings in unit TSw2 and overlying units and by the presence of heat-producing waste in unit TSw2.

During the reporting period, seven natural fractures from UE-25 NRG#4, USW NRG-6, and USW NRG-7A were characterized by gathering topographic information on each sample with a laser profilometer. Eight samples have been tested at room dry and ambient temperature conditions. The mated, rough fractures are subjected to a cycle of normal loading and then, at a constant normal stress (either 5 of 10 MPa), sheared at a constant rate. These samples have, in general, had a rounded peak shear response with a slow decrease in the shear strength to a residual, sliding value. Results from a study of mechanical properties of natural fractures at various normal stresses were documented and reported (Olsson and Brown, 1994). Samples were also collected from USW SD-9 core and are being prepared for testing.

Activity 8.3.1.15.1.4.2 - Effects of variable environmental conditions on mechanical properties of fractures. The objective of this activity is to 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. The data will be used in mechanical and thermomechanical calculations of stresses and deformations induced by the presence of underground openings in unit TSw2 and overlying units and by the presence of heat-producing waste in unit TSw2.

Samples were collected from core taken in the SD drillholes for fracture mechanical properties testing. Some of the samples from USW SD-9 are being prepared to run a series of experiments to investigate the effects of elevated temperature on the mechanical properties and to run two creep experiments. One of the creep (or constant stress) experiments will be performed at ambient temperature and one at elevated temperature.

Work continued on developing a computer program to model the dilation, normal stiffness, and shear stiffness of single fractures in rock. An early version of the code is being used to study the changes in the aperture of a fracture under normal stress.

Forecast: Efforts will continue in the performance of baseline, elevated temperature, and creep experiments on samples from SD drillhole core. The data will be reduced, analyzed, and reported in a timely manner to support the ESF design and site suitability activities.

3.11.5 Study 8.3.1.15.1.5 - Excavation Investigations

The objective of this study is to obtain site-specific information concerning the behavior of underground excavations in the proposed repository horizon and overlying units. Most of the data will be used for testing of computer codes that will be used to predict mechanical behavior of the rock mass. In addition, some of the information will serve as direct demonstration of constructability with reasonably available technology.

Activity 8.3.1.15.1.5.1 - Access convergence experiment. The objective of this activity is to obtain measurements to (a) monitor access convergence and rock mass deformation at several discrete locations, (b) measure the radial stress distribution and in situ state of stress at these locations, and (c) routinely measure the response of the rock mass to the loads imposed by the tunnel boring machine gripper pads. This information is important to demonstrate the stability of, and state of stress around, a full-scale repository opening in rock of varying quality.

A feasibility study was started using the gripper pads of the tunnel boring machine to measure rock-mass modulus of the host rock of the ESF as it is excavated. The mechanical response of underground excavations is governed by rock-mass modulus. This parameter, therefore, is needed to evaluate whether the host rock is capable of accommodating stresses induced by repository construction, operation, and closure.

Activity 8.3.1.15.1.5.2 - Demonstration breakout room. The objective of this activity is to 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. This demonstration will include an evaluation of the deformations that occur around the openings. A secondary objective is to provide facilities for other testing (e.g., heater tests and overcoring). Demonstration of constructability and stability will contribute to empirical evaluations of nonradiological health and safety.

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

Activity 8.3.1.15.1.5.3 - Sequential drift mining. The objectives of this activity are to obtain data on the deformation response of drifts with cross-sectional dimensions equivalent to those of a repository in welded tuff, to use the data in code evaluation activities, and to demonstrate constructability and stability of repository-sized drifts in lithophysae-poor material. Data will contribute to validation of computer codes to be used to calculate mechanical responses, as well as contributing to empirical evaluations related to nonradiological health and safety.

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

Forecast: The feasibility study on using the tunnel boring machine gripper pads to measure rock-mass modulus will be completed by September 1995.

3.11.6 Study 8.3.1.15.1.6 - In Situ Thermomechanical Properties

The objective of this study is to obtain data on in situ thermal and thermomechanical properties for units TSw1 and TSw2. Properties to be obtained include heat capacity, thermal conductivity, and thermal expansion. Additional heater experiments will be conducted to characterize the waste container environment.

The experiments in this study are designed to obtain the experimental data needed to develop computational tools that can be used to predict the response of underground openings at Yucca Mountain to the elevated temperatures and stresses expected in a high-level radioactive waste repository. The addition of thermal loads makes the design of a repository unique among civil construction of underground structures. This study is designed to provide data to validate new predictive techniques, including the ability to predict preclosure stability of underground openings, and to enhance the ability to predict thermal-hydrologic flow. This study will also obtain thermal and mechanical properties at the rock-mass scale.

In December 1994, the DOE directed that a multi-participant team be assembled to review the current in situ thermal testing program and to provide DOE with a new consolidated ESF thermal test strategy that is consistent with the Program Plan. This effort is being conducted in two phases: The first phase focused on the early time period (1995 through 2001) and developed a set of information and data needs that must be met by the thermal test program to support the determination of Technical Site Suitability in 1998 and the initial license application in 2001. These needs were identified through discussions with the future users of this data in repository design, pre- and postclosure performance assessment, waste package design, and licensing. Constraints on in situ testing, and lessons learned from previous in situ thermal tests were also identified. Conceptual designs of laboratory thermal process tests and in situ thermal tests were then proposed. The results of this effort were documented in a draft report submitted to DOE on January 31, 1995 (Costin, in prep.). This report is expected to complete review and be released in early April 1995.

As a DOE report, the second phase of the thermal test definition effort, will extend the work documented in the first phase to present an integrated test strategy for the long-term thermal test effort. This includes a definition of testing required by the Program Plan to be completed by the 2008 license amendment to receive waste and on through the performance confirmation period, that may last as much as 100 yr.

The report on the second phase of the thermal test definition effort is scheduled to be submitted to DOE for review by the end of April 1995.

Activity 8.3.1.15.1.6.1 - Heater experiment in unit TSw1. The objective of this activity is to estimate the in situ thermomechanical properties of lithophysae-rich tuff (unit TSw1) and to evaluate the thermal and mechanical response of this tuff unit to elevated temperatures. The data will be used to evaluate models during this and other experiments.

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

Activity 8.3.1.15.1.6.2 - Canister-scale heater experiment. The objective of this activity is to 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 (unit TSw2). The data will be used to evaluate the thermal and thermomechanical models.

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

Activity 8.3.1.15.1.6.3 - Yucca Mountain heated block. The objective of this activity is to estimate in situ mechanical and thermomechanical properties of unit TSw2 and to test thermomechanical computer models. Data on the properties will be used in mechanical and thermomechanical calculations of stresses and deformations induced by the presence of underground openings in unit TSw2 and overlying units and by the presence of heat-producing waste in unit TSw2.

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

Activity 8.3.1.15.1.6.4 - Thermal stress measurements. The objective of this activity is to monitor thermally induced stress in jointed welded tuffs in an accelerated test. The data will be used to evaluate thermally induced stresses calculated with thermomechanical computer codes.

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

Activity 8.3.1.15.1.6.5 - Heated room experiment. The objectives of this activity are to evaluate the thermomechanical response of welded tuff around repository openings to expected repository conditions during both construction and operation; to develop a data base for evaluating thermal and thermomechanical design analyses and methods applicable for repository considerations; and to use actual site data in predicting drift response and support/rock interactions during construction, operation, retrievability, and postclosure.

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

Forecast: The second phase of the thermal test program definition will be completed (including DOE review) by June 1995. Efforts will then focus on completing the designs of the early tests and the initial phase of detailed design for the later, more complex tests. Design of the facility at the bottom of the north ramp that is required to conduct the thermal tests will also be a priority.

The report will be expanded to consider additional data needs that must be met between 2001 and 2008, and to develop more fully the proposed in situ thermal tests by May 1995.

The study plan revision for in situ thermomechanical properties is being delayed until definition of the consolidated thermal test program is completed. The study plan will then be revised to be consistent with the consolidated thermal test program. Definition of tests and

activities within the study may change considerably based on the consolidation of thermal testing.

3.11.7 Study 8.3.1.15.1.7 - In Situ Mechanical Properties

The objective of this study is to obtain in situ measurements of the mechanical properties of the rock mass for unit TSw2.

Activity 8.3.1.15.1.7.1 - Plate loading tests. The objective of this activity is to measure the deformation modulus of the rock mass and to evaluate the zone of increased fracturing adjacent to underground openings.

No progress was made during the reporting period; this was an unfunded activity.

Activity 8.3.1.15.1.7.2 - Rock-mass strength experiment. The objective of this activity is to evaluate the mechanical behavior of the rock mass or its components by using experiments to obtain information related to the mechanical strength of single joints and to multiply jointed volumes of rock.

No progress was made during the reporting period; this was an unfunded activity.

Forecast: The draft study plan will be submitted for DOE review by August 30, 1995.

3.11.8 Study 8.3.1.15.1.8 - In Situ Design Verification

The objectives of this study are to investigate the effects of the spatial variability of the rock on drift stability, mining activities, and ground supports; to evaluate techniques for underground excavation and ground support, for selecting ground supports to be used in different rock types, and for monitoring drift stability; to quantify the emanation of radon into repository drifts and observe its dispersion with airflow; and to measure parameters needed to design repository ventilation systems.

Geotechnical design verification activities are being conducted in the North Ramp of the ESF to provide dates that can be used to confirm adequate design, construction, and long term performance from the very beginning of ESF construction. The data from these activities will also be used to support repository design and to validate the ESF design.

Activity 8.3.1.15.1.8.1 - Evaluation of mining methods. The objective of this activity is to develop recommendation for mining in the repository by monitoring and evaluating mining activities in the ESF and by conducting mining investigations.

Before the start-up of the tunnel boring machine, six stress gauges were installed in the starter tunnel, past the location of the face. These gauges were used to monitor the stress changes that occurred with the initial tunnel boring machine excavation and with the

application of the tunnel boring machine gripper pads. Data collection from this test was completed and preliminary analysis of the data began.

Rock mass quality evaluations, needed for correlations with other studies and by the ESF constructors for making ground support decisions, have been conducted, keeping pace with ESF excavation.

Activity 8.3.1.15.1.8.2 - Monitoring of ground-support systems. The objective of this activity is to develop recommendations for a ground-support methodology to be used in drifts in the repository, based on evaluations of the ground-support methodology used in the ESF and on experimentation with other ground-support configurations. Recommendations will be made for support systems to be used, as well as for methods of selection of supports that are appropriate for the ground conditions encountered.

Project scientists continued to monitor installed geotechnical instruments, and to install new geotechnical instruments, closely following the excavation of the ESF. The geotechnical instrumentation includes rock-bolt load cells, instrumented rock bolts, and strain gauges on steel sets installed as part of the ground support. Strain gauges were installed on selected steel sets before installation, and measurements made before, during, and after installation, to measure the installation loads. Readings from these instruments have identified no concerns regarding ground support.

Activity 8.3.1.15.1.8.3 - Monitoring drift stability. The objectives of this activity are to provide confidence in predictions of usability of the repository underground facilities over their 100-yr operational life, to contribute to evaluations of the effectiveness of mining methods and ground supports, to calibrate and refine criteria for determining stability of the openings, and to develop techniques for monitoring stability of the repository drifts.

Project scientists continued to monitor installed geotechnical instruments, and to install new geotechnical instruments, closely following the excavation of the ESF. The geotechnical instrumentation includes multi-point and single point extensometers and cross drift convergence pins. Readings from these instruments have identified no tunnel stability concerns.

Activity 8.3.1.15.1.8.4 - Air quality and ventilation experiment. The objectives of this activity are to measure the rate of radon emanation from the repository host rock; and to evaluate parameters and variables needed as input to or for testing of the models to be used for design of the ventilation systems in the repository underground facility.

Project scientists finalized the plans and began the procurements needed to measure of diesel exhaust in the ESF ventilation system. These plans were provided as input for the required test planning package and job package. Diesel emissions are being measured because the unburned compounds may be detrimental to both experiments to be conducted in the ESF and to waste isolation packaging.

Forecast: Efforts will continue to monitor installed geotechnical instruments, to install new geotechnical instruments, and to make rock mass quality evaluations in the ESF as it is excavated. Diesel exhaust in the ESF ventilation system will be measured and documented by August 30, 1995. Monitoring of construction blasting will be conducted as each alcove is excavated.

3.11.9 Study 8.3.1.15.2.1 - Characterization of the Site Ambient Stress Conditions

The objective of this study is to 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.

Related International Work

See Section 3.11.11 for related work (under the heading, In Situ Stress Determination) performed under the auspices of the OCRWM international program.

Activity 8.3.1.15.2.1.1 - Anelastic strain recovery experiments in core holes. The objective of this activity is to determine the horizontal stresses at Yucca Mountain, particularly the spatial variability thereof. In situ stress data will contribute to definition of initial and boundary conditions for mechanical and thermomechanical analyses.

As a result of the study plan work scope consolidation, there will be no study plan developed for this SCP section. The work scope for Activity 8.3.1.15.2.1.1 is being deleted from the program. The proposed technique is not likely to work, would not be cost effective, and would be redundant with other planned approaches.

Activity 8.3.1.15.2.1.2 - Overcore stress experiments in the Exploratory Studies Facility. The objectives of this activity are to determine the in situ state of stress above, within, and below the repository host rock in that portion of the repository block penetrated by the ESF, and to evaluate the extent to which the ambient stress conditions are redistributed adjacent to excavations. In situ stress data will contribute to definition of initial and boundary conditions for mechanical and thermomechanical analyses.

The scope of work for this activity has been transferred to Study 8.3.1.15.1.8.

Forecast: The Site Design and Test Requirements Document will be revised to reflect these changes.

3.11.10 Study 8.3.1.15.2.2 - Characterization of the Site Ambient Thermal Conditions

The objective of this study is to evaluate available thermal data to determine the ambient (pre-repository) temperature and thermal conductivity 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.

Activity 8.3.1.15.2.2.1 - Surface-based evaluation of ambient thermal conditions. The objective of this activity is to evaluate available thermal data to determine the ambient (pre-repository) temperature and thermal conductivity 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.

This activity was not funded in FY 1995. All work is being carried out in the closely related Activity 8.3.1.8.5.2.3 (Heat flow at Yucca Mountain and evaluation of regional ambient heat flow anomalies). Temperatures and thermal conductivities required to achieve the objectives of this activity are also needed to calculate heat flows.

Forecast: Input will be sought to the engineering plans for USW G-5 and/or USW G-6 to ensure that the hydrologic boundary between the tuffs and the Paleozoic carbonate aquifers can be characterized with sufficient resolution to identify any potential flow paths.

3.11.11 Related International Thermal and Mechanical Rock Properties Work

In Situ Stress Determination

The following is work related to Study 8.3.1.15.2.1 (Section 3.11.9) conducted cooperatively with Canada under the auspices of the OCRWM international program.

During the previous reporting period, the task team (United States and Atomic Energy of Canada Limited) gained access to an abandoned silver mine (the Amethyst mine, near Creede, Colorado), with rock characteristics resembling those at Yucca Mountain. Modified instruments were developed by Atomic Energy of Canada Limited and evaluation tests were run in the mine. Significant problems occurred with the purchased equipment and with performance in welded tuff. A German instrument did exhibit some advantages, but did not solve the problems. Further details of the investigations were provided in Austin and Thompson (1994). Petrographers conducted microscopic rock-fabric analyses to obtain detailed three-dimensional data on fracturing and mineral grains. These data are needed to evaluate observed variations in elastic rock parameters required for interpreting stress determination data. Results of the investigation will provide improved techniques and expanded knowledge for performing required in situ stress determinations in rock masses with dense fracture patterns.

During this reporting period, analysis and evaluation of stress relief data obtained at the Amethyst Mine test site during field testing activities in FY 1993-1994, proceeded. The triaxial load cell was assembled and some of the initial calibration tests performed. Petrographic analysis of granite samples from the 420 level of the Underground Research Laboratory continued. Results of the investigation will provide improved techniques and

expanded knowledge for performing required in situ stress determinations in rock masses with dense fracture patterns.

Forecast: The following actions are planned:

- Complete evaluation of stress relief data obtained at Amethyst Mine
- Complete calibration/evaluation of triaxial load cell and begin testing specimens from Underground Research Laboratory and Amethyst
- Complete petrographic analysis of Underground Research Laboratory and Amethyst and prepare report
- Perform bench scale testing evaluation of Atomic Energy of Canada Limited triaxial stress determination cell
- Complete report on technical procedures for borehole TV logging
- Complete status paper covering the work accomplished thus far under this task and defining future directions
- Consider purchasing borehole slotter equipment for bench scale testing
- Finish paper on results of fracture characterization studies at the Amethyst Mine
- Finish technical procedures for borehole TV logging using equipment developed or refined on this study.

3.12 PRECLOSURE HYDROLOGY (SCP SECTION 8.3.1.16)

3.12.1 Study 8.3.1.16.1.1 - Characterization of Flood Potential of the Yucca Mountain Site

The objective of this study is to evaluate the potential for flooding in the many small, dry, desert washes that drain Yucca Mountain. This evaluation will be used for designing the surface facilities for the proposed repository. Proper design for flood potential is necessary to ensure the safety of workers and surface facilities.

Activity 8.3.1.16.1.1.1 - Site flood and debris hazards studies. The objective of this activity is to assess the flood and debris 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.

No progress was made during the reporting period; this was an unfunded activity.

Forecast: No activity is planned for FY 1995.

3.12.2 Study 8.3.1.16.2.1 - Location of Adequate Water Supply for Construction, Operation, Closure, and Decommissioning of a Mined Geologic Disposal System at Yucca Mountain, Nevada

The purpose of this study is to identify water supply sources for a potential repository. Four activities were identified in the SCP (1) assess the cost, feasibility, and adequacy of using Wells UE-25 J#12 and J#13 as an alternative water supply; (2) identify a primary water source; (3) identify another alternative water source (other than Wells UE-25 J#12 and J#13); and (4) identify and evaluate the potential effects of repository-related withdrawals on the ground-water flow system.

There will be no study plan developed for this SCP section. For the first activity, a DOE working paper or participant report will be developed compiling known production histories of UE-25 J#12 and J#13 from an extensive record. A second activity will identify a primary water supply for repository operations that is closer to, and topographically higher than, facilities important to safety; and a third activity will identify an alternative water source. This work concerns repository construction and is suited for a standard engineering trade study in support of a future design package for repository facilities important to safety. The fourth activity will provide for a sensitivity analysis with the flow models developed for Study 8.3.1.2.1.3 (Regional Ground Water Flow System) and Study 8.3.1.2.3.1 (Site Saturated Zone Ground Water Flow System).

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

Forecast: No activity is planned for FY 1995.

3.12.3 Study 8.3.1.16.3.1 - Determination of the Preclosure Hydrologic Conditions of the Unsaturated Zone at Yucca Mountain, Nevada

The objective of this study is to compile the data collected under Geohydrology Investigation 8.3.1.2.2 (Exploratory Studies Facility Investigations) for input to Design Issue 4.4.

No progress was made during the reporting period; this was an unfunded activity.

Forecast: No activity is planned for FY 1995.

3.13 PRECLOSURE TECTONICS (SCP SECTION 8.3.1.17)

3.13.1 Study 8.3.1.17.1.1 - Potential for Ash Fall at the Site

The objective of this study is to provide required information on volcanic activity that could affect repository design performance.

Activity 8.3.1.17.1.1.1 - Survey literature regarding Quaternary silicic volcanic centers in the western Great Basin. The objective of this activity is to compile information on Quaternary silicic volcanism in the western Great Basin, the reoccurrence of which might produce an ash fall at the site.

Activity 8.3.1.17.1.1.2 - Assess potential ash-fall thickness at the site. The objective of this activity is to produce an approximate probability-vs.-thickness function for potential ash falls at the site and to estimate a particular ash-fall thickness that has less than one chance in ten of occurring in 100 yr. These hazard estimates will be considered in the design of filters in the mining and surface-facility ventilation systems.

As a result of the study plan work scope consolidation effort, there will be no study plan developed for this SCP section. All these activities rely on data from other SCP studies, or available data. The work identified in this section has been completed and was documented in Perry and Crowe (1987). Additional discussion is included in Crowe et al. (1995).

3.13.2 Study 8.3.1.17.2.1 - Faulting Potential at the Repository

The objective of this study is to provide required information on fault displacement that could affect repository design or performance.

Activity 8.3.1.17.2.1.1 - Assess the potential for surface faulting at prospective sites of surface facilities important to safety. The objective of this activity is to assess the stability of the site surface with respect to fault displacement, at locations proposed for facilities important to safety.

Activity 8.3.1.17.2.1.2 - Assess the potential for displacement on faults that intersect underground facilities. The objective of this activity is to assess the potential for displacement on faults intersecting underground facilities.

Faulting potential at the site will be assessed in a manner similar to that used to assess vibratory ground motion. This probabilistic approach will allow the significance of faults with respect to design and performance assessment to be determined. Given the similarity in these approaches, there will be no study plan developed for this SCP section. The work scope for this study is being combined with that of Study 8.3.1.17.3.6 (Probabilistic Seismic Hazard Analysis). The study plan for Study 8.3.1.17.3.6, revised during this reporting period, addresses this assessment of faulting potential at and near Yucca Mountain.

Forecast: The work scope is to be transferred to Study Plan 8.3.1.17.3.6. The Site Design and Test Requirements Document will be revised to reflect this change.

3.13.3 Study 8.3.1.17.3.1 - Relevant Earthquake Sources

The objective of this study is to identify and characterize those earthquake sources relevant to seismic hazard analysis of the site (i.e., those sources that could cause significant surface fault displacement or ground shaking at the site).

Activity 8.3.1.17.3.1.1 - Identify relevant earthquake sources. The objective of this activity is to identify earthquake sources that could generate significant surface fault displacements or severe ground motions at the site.

Project scientists continued to compile geologic, geophysical, and seismic data to support seismic source evaluation and characterization for the Probabilistic Seismic Hazard Analysis. This task is nearing completion with a study to identify relevant seismic sources in the Yucca Mountain region. Maximum fault lengths and evidence of Quaternary displacement for 88 known and suspected Quaternary faults in the area are used with empirical relationships to calculate expected maximum moment magnitudes on the faults and average peak acceleration at the Yucca Mountain site. Using the Quaternary activities and the 84th-percentile level of peak acceleration as a basis, 21 Quaternary faults are confidently identified as relevant. There are 26 additional relevant sources if faults with unknown or suspected Quaternary activity are included. All but two of these 47 relevant and potentially relevant sources are located within 60 km of Yucca Mountain. The 47 faults are the most important sources of vibratory ground motion to the potential repository. A report has been prepared for inclusion in a USGS circular and was in technical review (Pezzapane, in prep.).

Project scientists began preparing a report on seismic source evaluations by compiling the necessary data. Short summaries of the available data for some of the more important data compilations were written. Copies of published data were assembled and the data summaries have been evaluated by the seismic source characterization methodology team in a meeting held March 3, 1995, in San Francisco, California. Work continues to compile and summarize published data sets, as well as expected data from site characterization activities.

Activity 8.3.1.17.3.1.2 - Characterize relevant earthquake sources. The objective of this activity is to characterize each relevant earthquake source identified in the previous activity with a spatial description (including an expected depth or depth range), an assessment of activity, evaluations of maximum earthquake magnitude, the size and location of expected coseismic displacements (for sources in or near the controlled area), and the recurrence rate for earthquakes associated with the source. The source characterization includes an evaluation of variability in and dependency of input parameters.

Literature searches and library research were performed to compile information about historical surface-rupturing earthquakes in the Basin and Range Province and normal-faulting earthquakes in analogous regions, theoretical rupture models, and different deformational

aspects of Earth's crust; data that will be useful in the characterization of fault-displacement models and seismic sources at Yucca Mountain.

Faults in the Yucca Mountain region were examined, assessing their paleoseismic data and uncertainties. Project geologists examined the geomorphology of faulting along the southwestern Rock Valley, central Mine Mountain, and northern Cane Springs faults, and evaluated the regional tectonic implications of these structures.

Forecast: Geological, geophysical, and seismic data to support seismic-source evaluations will be compiled. A report that describes the available data to be used for seismic-source evaluations will be written.

3.13.4 Study 8.3.1.17.3.2 - Underground Nuclear Explosion Sources

The objective of this study is 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.

Activities 8.3.1.17.3.2.1 and 8.3.1.17.3.2.2. These activities rely on available data. No additional data are to be acquired.

There will be no study plan developed for this SCP section. This work is substantially complete, and the results will be reported in a participant technical report or a DOE working paper.

Forecast: No activity is planned in FY 1995.

3.13.5 Study 8.3.1.17.3.3 - Ground Motion From Regional Earthquakes and Underground Nuclear Explosions

The objective of this study is to select or develop ground-motion models that are appropriate for estimating ground motion at the site from earthquakes and underground nuclear explosions. These models will be used to determine the relevancy of seismic sources to a deterministic seismic hazard analysis, identify controlling seismic events, constrain simulated ground motions from controlling seismic events, and estimate the probabilities of exceeding given ground-motion levels at the site.

Activity 8.3.1.17.3.3.1 - Select or develop empirical models for earthquake ground motions. The objective of this activity is to select or develop empirical ground-motion models that are appropriate for estimating earthquake ground motion at the site. The models will predict ground motion as a function of earthquake magnitude and distance between the earthquake source and the site.

Project scientists have assembled seismograms from available data bases and have begun to analyze the variation of ground-motion amplitudes as a function of earthquake magnitude, source-site distance, and frequency spectra. Various regression methods and different functional forms of the attenuation equations are being applied to the ground-motion datasets and the results and uncertainties are being examined. They have chosen appropriate data processing schemes and have continued to collect earthquake-source parameters. Details of various published attenuation relations are being compared and reconciled to facilitate intercomparison of the relations.

Project scientists planned and conducted a Yucca Mountain Earthquake Scenario Workshop February 28-March 1, 1995. The workshop brought together a broad group of approximately 35 earth scientists (25 participants and 10 observers) from various government and academic institutions to discuss earthquake scenarios for Yucca Mountain and vicinity. The objectives of the workshop were to select approximately five scenario earthquakes and to specify geologic constraints and associated uncertainties for input to a set of ground-motion modeling exercises pertinent to the potential nuclear waste repository at Yucca Mountain. Observable fault characteristics such as fault length, displacement and geometry were expressed and used to constrain earthquake parameters such as magnitude, distance and focal mechanism.

Activity 8.3.1.17.3.3.2 - Select or develop empirical models for ground motion from underground nuclear explosions. The objective of this activity is to select or develop empirical ground-motion models that are appropriate for estimating ground motion at the site from underground nuclear explosions at the Nevada Test Site. The models will predict ground motion as a function of the yield and distance of the underground nuclear explosion.

During the reporting period, work commenced on two tasks: assessment of existing ground-motion models for applicability to Yucca Flat underground nuclear explosion data, and one-dimensional uphole/downhole modeling of underground nuclear explosion data. Data bases of ground motion records for both tasks were completed. The uphole/downhole modeling task was completed for vertical records and results were presented at the Fall 1994 Meeting of the American Geophysical Union (Durrani and Walck, 1994). An initial two-dimensional model to be used for purposes of subsurface motion prediction was developed using the one-dimensional models.

Forecast: Analysis of available earthquake data will continue. A report describing the ground-motion data, the analyses, and the results, including peak and frequency-dependent relationships and their uncertainties will be prepared, reviewed, and revised. Earthquake-scenario modeling results will be presented at a ground-motion modeling workshop. A report that describes the different ground-motion models will be written. In addition, the geologic constraints on the scenario earthquakes will be combined with seismological constraints and parameters to develop formal ground motion modeling exercises. Modeling work is scheduled to begin about May 1, 1995, once contracts are in place and modeling exercises are established

Appropriate ground motion models for Yucca Flat underground nuclear explosion data will be determined. The reporting for the one-dimensional uphole/downhole modeling of underground nuclear explosion data will be finalized. The results of the first two tasks and previous work will be synthesized to provide an empirical model for ground motion at Yucca Mountain from underground nuclear explosions. Data tapes containing underground nuclear explosion data will be copied and submitted to the data records management system.

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

The objective of this study is to document systematic effects on surface and subsurface ground motions resulting from the local site geology.

Activity 8.3.1.17.3.4.1 - Determine site effects from ground-motion recordings. The objective of this activity is to determine, from ground-motion recordings, the systematic effects of local site geology on surface and subsurface motions and to identify any significant site-wide bias in ground-motion levels, as compared with average levels for the Southern Great Basin.

Activity 8.3.1.17.3.4.2 - Model site effects using the wave properties of the local geology. The objective of this activity is to develop a calibrated theoretical site-effects model for use in extrapolating the observations documented in Activity 8.3.1.17.3.4.1 to locations and depths where ground-motion predictions are needed, but where instrumental recordings are not available.

The site effects study was completed at the end of FY 1994 (Su et al., in prep). Site amplification factors were determined for 12 3-M_L=5.6 Little Skull Mountain earthquake of June 29, 1992. The 12 stations were located at a variety of sites, including hard rock, alluvial fill, ridge crest, and underground tunnel. The results of the study show that the site amplification factors are well related to the underlying geology and nearby topography at these stations.

3.13.7 Study 8.3.1.17.3.5 - Ground Motion at the Site From Controlling Seismic Events

The objective of this study is to identify the controlling seismic events and to characterize the resulting controlling ground motions. Controlling seismic events are those underground nuclear explosions or 10,000-yr cumulative-slip earthquakes that would generate the most severe ground motions at the site at frequencies of engineering significance.

Activity 8.3.1.17.3.5.1 - Identify controlling seismic events. The objective of this activity is to identify underground nuclear explosions or 10,000-yr cumulative-slip earthquakes that would produce the most severe ground motions at the site at frequencies of engineering significance. There may be more than one controlling seismic event because different events may generate the most severe ground motions in different frequency bands.

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

Activity 8.3.1.17.3.5.2 - Characterize ground motion from the controlling seismic events. The objective of this activity is to generate suites of strong-motion time histories and corresponding response spectra representative in amplitude, frequency content, and duration of site ground motions that could be generated by the controlling seismic events.

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

Forecast: Identification of controlling seismic events and development of seismic design inputs from them will take place in FY 1996 following completion of the probabilistic seismic hazard analysis (Study 8.3.1.17.3.6). The study plan for this study will be revised to address fault displacement in addition to ground motion.

3.13.8 Study 8.3.1.17.3.6 - Probabilistic Seismic Hazards Analyses

The objectives of this study are to quantify (a) the probability of experiencing ground motions of varying degrees of severity that might result from earthquakes of varying magnitudes and distances from the potential repository site, and (b) the potential for fault displacements of varying degrees of severity to disrupt the surface facilities or the underground repository. (Note: This study combines the objectives originally designated for Studies 8.3.1.17.3.6 and 8.3.1.17.2.1).

Activity 8.3.1.17.3.6.1 - Evaluate Ground Motion Probabilities. The objectives of this activity are to (a) quantify the probabilistic vibratory ground motion values appropriate for seismic design of the potential repository structures, systems, and components, and (b) provide documentation of the bases for these determinations sufficient for regulatory review and licensing.

The study plan for Probabilistic Analyses of Vibratory Ground Motion and Fault Displacement at Yucca Mountain was transmitted to DOE for technical review and was returned by DOE to USGS for comment resolution. Project staff met in Menlo Park, California, to discuss appropriate criteria for selection of expert panels and methodology teams. A preliminary list of experts in the geology and seismology of the Great Basin was drawn up and the first invitations were sent to prospective panelists. At the suggestion of the oversight committee, the size of the panel was increased from 6 to 7 members. Documentation of the selection process was done by the management team.

Project scientists assembled a first draft of the bibliography and data available for the Probabilistic Analyses of Vibratory Ground Motion and Fault Displacement at Yucca Mountain. The data management team completed writing the 3 to 5 page summaries of the data and interpretations available for each topic pertinent to seismic hazards. The summaries are intended to be a road map for the experts to help them select data sets. The overall seismic hazards bibliography was revised by including citations into separate topics.

Activity 8.3.1.17.3.6.2 - Assessment of fault displacement hazard. The objective of this activity is to assess the fault displacement hazard for repository design.

Assembly of data bases and selection of expert panels as discussed for Activity 8.3.1.17.3.6.1 above, also applies to this activity. Project scientists conceptualized and documented a methodology for assessing fault displacement that can be applied to Yucca Mountain. The first meeting of the Fault Displacement Working Group was convened to discuss different methodologies for the assessment and to identify essential data sets. A preliminary approach for fault displacement methodology was developed to create logic trees for Probabilistic Analyses of Vibratory Ground Motion and Fault Displacement at Yucca Mountain.

Forecast: The study plan will be completed and forwarded to the NRC. The first two workshops implementing the probabalistic analyses methodology will be carried out in mid April 1995. Results of these workshops will guide additional data analysis during the remainder of the fiscal year. Alternative methods of characterizing fault displacement for probabilistic analyses will be documented in a report. Future workshops will be planned.

3.13.9 Study 8.3.1.17.4.1 - Historical and Current Seismicity

The objective of this study is to compile information on reported and instrumentally recorded earthquakes that characterize the earthquake potential near Yucca Mountain. This information will be used to help identify and characterize potentially relevant earthquake sources for the deterministic hazard analysis and potentially contributing earthquake sources for the probabilistic hazard analysis; to develop regional earthquake ground-motion models; and to determine local-geologic and depth-of-burial effects on ground motion at the site.

Activity 8.3.1.17.4.1.1 - Compile historical earthquake record. The objective of this activity is to compile a record of historical seismic events in the southern Great Basin or within 100 km of Yucca Mountain that will indicate whether each cataloged seismic event is thought to be a natural earthquake, induced earthquake, underground nuclear explosion, cavity collapse, or blast. For potentially damaging earthquakes ($M \geq 5.5$) in the study region, available information will be compiled on ground-motion intensity, availability of strong-motion records, and extent and style of faulting.

During the reporting period, the catalog of historical earthquakes for the Yucca Mountain region underwent technical review and comment resolution.

The methodology for using the distribution of precariously balanced rocks as an indicator of past ground-motion levels is being documented in a report. Further constraints are being placed on the method as a result of (a) field experiments to determine the force needed to topple precariously balanced rocks, (b) laboratory experiments with models of rocks, and (c) computer modeling.

Activity 8.3.1.17.4.1.2 - Monitor current seismicity. The objective of this activity is to provide empirical information on how often earthquakes are currently occurring in the southern Great Basin; what the orientation, depth, and style of faulting are; 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.

Seismic monitoring of the southern Great Basin continued. The CalTech-USGS Seismic Processor (CUSP) system operated satisfactorily with very little downtime, most of which was caused by the installation of an uninterruptible power supply. The computer backup system that continuously records network data was put on-line on October 27, 1994. This system replaces the outdated Develocorder system. The new backup system operated satisfactorily with the exception of the period January 1-4, 1995, when software problems resulted in the loss of about 50 percent of incoming data. A paging system was subsequently implemented to alert personnel of problems with the continuously recording backup system. An alarm system was also implemented to indicate the loss of transmission of analog and digital data from microwave telemetry sites.

Calibration of analog seismic stations continued during the reporting period. The calendar year 1994 cycle of calibrations was completed. An experiment was conducted to evaluate the calibration of CUSP waveforms. It was discovered that apparent amplitudes were too low by a factor of two. Corrections to Richter Magnitude determinations for calendar year 1994 data were being implemented.

The catalog of events and waveform data for calendar year 1994 was completed. The catalog includes 2,034 earthquakes and 249 explosions. Work was continuing on determining focal methanisms for 1994 data. Richter Magnitude determinations were compared with duration magnitudes for about 220 earthquakes. At small magnitudes, Richter Magnitude is significantly smaller than the corresponding duration magnitude. A report discussing the 1994 seismicity was being prepared.

Project seismologists deployed portable seismic instruments in Rock Valley and at locations along the Crater Flat seismic reflection line. Data were collected for most of the seismic shots associated with the seismic reflection line. Preliminary data analysis was completed. Analysis continued on the Little Skull Mountain data set. Over 500 aftershocks were analyzed to determine seismic moment and stress-drop estimates. Upgrade of the seismic network to digital recording continued. The permitting process was initiated for five additional sites bringing to sixteen the number in various stages of approval. Eight sites were selected for the installation of strong-motion instrumentation. Preparation of permit requests was initiated.

Activity 8.3.1.17.4.1.3 - Evaluate potential for induced seismicity at the site. The objective of this activity is to evaluate the potential for human activity to significantly perturb natural seismic hazard at the site by inducing seismicity at or near the site. To date, the human activities that have been identified as having a potential to induce seismicity in the site region are the impoundment of Lake Mead, the testing of nuclear devices at the Nevada Test Site, and mining of the repository itself.

Project seismologists met with tunnel engineers at Yucca Mountain and consulted with other project personnel concerning the strategy for seismic instrumentation of the ESF to monitor for excavation induced seismicity.

Forecast: Review of the catalog of historical earthquakes for the Yucca Mountain will be completed and a report issued. The report on precariously balanced rocks in the vicinity of Yucca Mountain and their implications for levels of past ground motion will be completed.

Seismic monitoring of the southern Great Basin will continue with periodic maintenance and calibration of equipment. The report on 1994 seismicity will be completed. Hardware and software upgrades will continue to integrate digital stations into the network. A technical procedure on the deployment, calibration, and operation of the portable seismic instruments will be written. Strong motion instrumentation will be installed in the vicinity of Yucca Mountain and technical procedures for its installation and operation will be prepared. Portable seismometers will be installed in the ESF to monitor for excavation-induced seismicity.

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

The objective of this study is to identify a site in Midway Valley sufficiently large for surface facilities in which significant Quaternary faults are absent.

Activity 8.3.1.17.4.2.1 - Identify appropriate trench locations in Midway Valley. The objective of this activity is to identify appropriate trench locations at proposed locations for repository surface facilities that are important to safety through detailed geologic mapping and remote sensing studies. The recommended locations will be used in trenching investigations in Activity 8.3.1.17.4.2.2.

This activity was completed and the trench locations are documented in the report identified in Activity 8.3.1.17.4.2.2 below.

Activity 8.3.1.17.4.2.2 - Conduct exploratory trenching in Midway Valley. The objectives of this activity are to investigate the possible occurrence 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. This activity will provide input into the location and design of surface facilities important to safety, particularly those associated with waste handling.

No progress was made during the reporting period; report to be completed in the third quarter of FY 1995.

Forecast: This activity and the resulting report is planned to be completed in FY 1995.

3.13.11 Study 8.3.1.17.4.3 Quaternary Faulting Within 100 km of Yucca Mountain, Including the Walker Lane

The objective of this study is to identify Quaternary faults within 100 km of Yucca Mountain; and to characterize faults capable of future earthquakes with magnitude such that associated ground shaking could impact design or affect performance of the waste facility.

Activity 8.3.1.17.4.3.1 - Conduct and evaluate deep geophysical surveys in an east-west transect crossing the Furnace Creek fault zone, Yucca Mountain, and the Walker Lane. The objectives of this activity are:

- To identify and locate potential seismic source zones, including possible through-going extensions of the Walker Lane, beneath the Oligocene-Miocene cover of the Yucca Mountain area

- To determine width and subsurface geometry of such extensions and of the Furnace Creek fault zone and the relation of these features to detachment faults and to Quaternary faults

- To evaluate the postulated incipient rift zone at Crater Flat

- To characterize the crustal velocity structure and define lateral inhomogeneities in that structure in the Yucca Mountain area

- To trace the 5- and 10-s events found on Death Valley COCORP profiles through the Yucca Mountain region and, if possible, to trace reflections from the upper and lower carbonate aquifers, the Precambrian-Cambrian Pahrump Group and Noonday Dolomite, and the Proterozoic basement across the Furnace Creek fault and through the area of the projected northwest continuation in the subsurface of the Las Vegas Valley shear zone

- To identify differences in mass caused by variation in source lithology in the upper few kilometers of the crust, and correlate those sources with reflections obtained in the seismic reflection survey, or with conductivity features obtained in the magnetotelluric survey

- To identify differences in magnetic field caused by sources in the upper few kilometers of the crust and correlate those sources with reflections obtained in the seismic reflection survey, or with conductivity features obtained in the magnetotelluric survey

- To characterize conductivity structures of crust in the Yucca Mountain region, focusing in particular on the conductivity signature of the Walker Lane and Walker Belt, and if possible, trace the signature into the subsurface of conductive units such as the Eleana Formation or nonconductive units such as the lineated and

mylonitized gneisses (lower plate?) of the northern Amargosa Desert, and to correlate these features at their offsets with Quaternary faults

- To provide data for analysis to determine if buried magma bodies are present in the vicinity of Yucca Mountain.

No progress was made during the reporting period; this was an out-year activity; however, note that intermediate and deep reflection data were obtained along a 23-mi traverse across Crater Flat and Yucca Mountain in November 1994 as part of Activity 8.3.1.4.2.1.2.

Activity 8.3.1.17.4.3.2 - Evaluate Quaternary faults within 100 km of Yucca Mountain. The objectives of this activity are:

- To establish the abundance, distribution, and geographic orientation of known and suspected Quaternary faults within 100 km of the site
- To characterize Quaternary and Holocene fault and fracture pattern within 100 km of the site and, if feasible, to relate that pattern to regionally important wrench fault systems, including the Walker Lane, the Death Valley-Furnace Creek fault zone, and the Mine Mountain-Pahranagat shear zone
- To characterize Quaternary faults within 100 km of the site whose apparent length or recurrence rate indicate potential for future earthquakes of magnitude sufficient to affect design or performance of the waste facility
- To evaluate the recurrence history of that part of the Death Valley-Furnace Creek fault zone within 100 km of the site
- To identify fault scarps within 100 km of the site that may have been overlooked during conventional geologic field surveys and that may not have been apparent on conventional vertical aerial photography
- To verify the existence and age of scarps in the Nevada Test Site area that were detected by low-sun-angle photogeologic interpretation
- To determine whether the Beatty scarp originated through tectonic or fluvial processes, or both, the nature of the movement along the scarp, if tectonic, and the age of the scarp.

Regional reconnaissance studies, through evaluation of air photos and field observations, were conducted to identify Quaternary faults that may be capable of generating ground motions >0.1 g peak ground acceleration at the potential repository site. More detailed, follow-up investigations of faults in the Amargosa Desert, Belted Range, Oasis Valley, and Cawich Range areas, and along the Bare Mountain and Death Valley-Furnace Creek fault zones included field mapping, air photo interpretations, and scarp studies to determine fault lengths, slip rates, displacements per faulting event, age of faulting, and

recurrence intervals. The resulting data are being compiled on maps and in tables designed to provide the kinds of data required to characterize those faults that are potentially capable of generating peak ground acceleration >0.1 g.

A report and map, at a scale of 1:250,000, shows known or suspected Quaternary faults that are characterized for purposes of identifying sources of future seismic events (Piety, in prep.). Klinger and Piety (1994) report that studies along the Death Valley fault indicate that three and possibly four faulting events occurred during the late Quaternary, with vertical displacements of about 2.6 to 3.5 m per event; the calculated slip rate is 3 to 5 mm/yr. Along the Furnace Creek fault zone, also during the late Quaternary, three and possibly four events occurred with lateral displacements of about 2.5 to 3.5 m per event and slip rates of 5 to 12 mm/yr.

Activity 8.3.1.17.4.3.3 - Evaluate the Cedar Mountain earthquake of 1932 and its bearing on wrench tectonics of the Walker Lane within 100 km of the site. The objective of this activity is to evaluate the relevance of the 1932 Cedar Mountain earthquake to potential sources of ground shaking and rupture in that part of Walker Lane within 100 km of Yucca Mountain.

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

Activity 8.3.1.17.4.3.4 - Evaluate the Bare Mountain fault zone. The objectives of this activity are to evaluate the potential for ground shaking associated with future movement along the Bare Mountain fault zone; to estimate the age of the most recent faulting on the Bare Mountain frontal fault; to estimate the recurrence intervals of faulting; to determine the nature and age of faulting within the fault complex east of the frontal zone, and to determine the nature of tectonic control of the location and orientation of the main wash in Crater Flat; and to determine the subsurface configuration of fault zones.

Project geologists conducted analysis of previously collected data on the Bare Mountain fault. Anderson and Klinger (in prep.) concluded, based on detailed mapping, studies of fault scarps, and trench-wall mapping, that the Quaternary rate of faulting along this feature is very low, and that the age of the most recent faulting event may be no younger than late Pleistocene. The Project Principal Investigator led a field trip to Bare Mountain for members of the USGS on November 16, 1994. Included in the field trip were stops at BMT-1 and BMT-2. Discussions at the two trenches centered around evidence for or against multiple surface faulting events. The earliest estimated start date for additional trenching and soil pits at Bare Mountain is in April. The Principal Investigator attended a USGS-sponsored workshop on probabilistic seismic hazards held in Salt Lake City February 15-16, 1995, and discussed new slip-rate data for the Death Valley, Furnace Creek, and Bare Mountain faults.

Activity 8.3.1.17.4.3.5 - Evaluate structural domains and characterize the Yucca Mountain region with respect to regional patterns of faults and fractures. The objectives of this activity are to map faults and lineaments within 100 km of the site and identify those with geomorphic expression indicative of Quaternary faulting, to classify the area into

subareas (domains) containing relatively homogeneous fault and lineament, to map the areal extent of desert varnish coating, and to identify areas of suspected hydrothermal alteration.

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

Activity 8.3.1.17.4.3.6 - Analyze rotation (drag) of bedrock along or over suspected wrench faults based on rotation of paleomagnetic declinations. The objective of this activity is to determine the spatial and temporal patterns of oroflexure bending based on rotation of paleomagnetic declinations.

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

Forecast: The draft and final reports with accompanying tables and maps that will characterize the seismic characteristics of suspected Quaternary faults in the Amargosa Desert will be written and submitted. The report on Quaternary faulting within 100 km of Yucca Mountain also will be written and submitted. Trenches will be excavated and logged at Bare Mountain. Final reports on the Bare Mountain and Death Valley-Furnace Creek fault zones, characterizing the Quaternary history and seismic characteristics, will be written.

3.13.12 Study 8.3.1.17.4.4 - Quaternary Faulting Proximal to the Site Within Northeast-Trending Fault Zones

The objective of this study is to evaluate the potential for ground motion resulting from future movement of Quaternary strike-slip faults east and south of the site area.

Activity 8.3.1.17.4.4.1 - Evaluate the Rock Valley fault system. The objective of this activity is to determine the location, spatial orientation, length, width, Quaternary recurrence rate, and the location, amount, and nature of Quaternary movement of the Rock Valley fault system. Estimate the total displacement, including strike-slip and dip-slip components, of Quaternary datums.

Two 3-m (10-ft) deep trenches and six 1.5 m (5-ft) deep trenches were excavated on the south and north strands of the Rock Valley fault system in December 1994. Subsequently, trench logs were prepared on three of the trenches, and samples for radiometric dating (six for thermoluminescence and eight for uranium series) were collected. Initial findings include (a) on the south strand, the top soil unit is broken over fault traces in the youngest faulting event, which resulted in less than 10 cm of vertical displacement (horizontal displacement is also indicated, but amount could not be determined); and (b) on the north strand, perhaps three faulting events with 50 to 100 cm of apparent vertical displacements and with unknown but significant horizontal displacement took place. Probable mid-to-late Holocene sediments are not faulted at the east end of the trenched area on the north strand.

Activity 8.3.1.17.4.4.2 - Evaluate the Mine Mountain fault system. The objective of this activity is to determine the location, spatial orientation, length, width, Quaternary

recurrence rate, and the location, amount, and nature of Quaternary movement of the Mine Mountain fault system.

Project scientists conferred with colleagues on interpretive and structural problems along flank of Shoshone Mountain, and Mid Valley. No trenching is planned along the Mine Mountain fault system.

Activity 8.3.1.17.4.4.3 - Evaluate the Stagecoach Road fault zone. The Stagecoach Road fault evaluation has been transferred to Study Plan 8.3.1.17.4.6 (Quaternary Faulting in the Site Area). (See Section 3.13.14.)

Activity 8.3.1.17.4.4.4 - Evaluate the Cane Spring fault system. The object of this activity is to determine the location, spatial orientation, length, width, Quaternary recurrence rate, and the location, amount, and nature of Quaternary movement of the Cane Spring fault system.

Project geologists reviewed published data and aerial photographs. Five days were spent in the field to obtain measurements and other data on Cane Spring fault system. Field work was curtailed because of the inaccessibility of Area 27. Project geologists must be escorted by someone with proper clearance and must coordinate with such a person at a convenient time. This is important because the Cane Spring fault zone extends through Area 27.

Project geologists reviewed accessible field exposures with colleagues and discussed interpretations.

Forecast: Project geologists will draft, edit, and prepare trench logs for inclusion in data packages. They will conduct a review and analysis of structural interpretations based on trench exposures, geomorphology, and detailed mapping. A final report providing characterization of the Rock Valley fault zone as a seismic source will be prepared. A report will be prepared that provides the final characterization of the Mine Mountain fault zone as a seismic source. Field work, such as mapping and sampling, will continue on the Cane Spring fault provided that access can be gained to Area 27. Data will be compiled and analyzed for the preparation of a report on the seismic characterization of the Cane Spring fault zone.

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

The objectives of this study are to supply information pertaining to distribution, displacement rate, and age of detachment faults proximal to Yucca Mountain. Key questions regarding detachment faults are whether they represent a significant earthquake source, and whether they conceal a significant earthquake source at depth. To resolve both questions, activities are focused on resolving the Quaternary behavior of postulated detachment faults.

A field review of all five activities in the detachment faulting study plan was conducted. The review team visited the Calico Hills, Red Mountain, Point of Rocks, southern

Crater Flat, northern Bare Mountain, Bullfrog Hills, Daylight Pass, Birdtrack Hills, and Yucca Mountain. Postulated detachment faults at each of these areas were examined. Simonds et al. (in prep.) summarize all available data resulting from each of the activities in this study.

Activity 8.3.1.17.4.5.1 - Evaluate the significance of the Miocene-Paleozoic contact in the Calico Hills area to detachment faulting within the site area. The objectives of this activity are to determine whether the contact of Miocene volcanic rocks on Paleozoic strata is tectonic or depositional; if tectonic, to determine Quaternary activity, if any, of the possible detachment fault; and, if Quaternary, to determine the direction and age of movement, attitude of fault plane, and nature of deformation of the Miocene (upper plate?) sequence.

Simonds (in prep.[a]) shows that although low-angle faults are present locally along the Miocene/Paleozoic contact, they represent small gravity slide blocks or slabs that formed in response to down-to-the-west offset on adjacent high-angle normal faults. Elsewhere, the Miocene/Paleozoic contact is mostly a depositional contact, and there is no evidence of detachment fault movement parallel to that surface. Peer review continued on Simonds (in prep.[b])

Activity 8.3.1.17.4.5.2 - Evaluate postulated detachment faults in the Beatty-Bare Mountain area. The objective of this activity is to determine if postulated detachment faults in the Beatty Bare Mountain have been active in the Quaternary.

Geologic mapping of key areas within the Beatty Mountain quadrangle continued. The geologic map of the Big Dune quadrangle was compiled on four 1:12,000 scale orthophoto base maps, map unit descriptions were completed, and the map was in technical review.

Activity 8.3.1.17.4.5.3 - Evaluate the potential relationship of breccia within and south of Crater Flat to detachment faulting. The objective of this activity is to determine whether breccias tectonically emplaced on low-angle surfaces beveled across the Paleozoic and younger strata are slide masses or near-surface parts of a detached upper plate; and, if either, how they relate to postulated Quaternary detachment faulting.

No progress was made during the reporting period; this was an unfunded activity.

Activity 8.3.1.17.4.5.4 - Evaluate postulated detachment faults in the Specter Range and Camp Desert Rock areas. The objective of this activity is to determine whether the basal contact of the Horse Spring Formation is depositional or tectonic; and, if tectonic, to determine whether movement was Quaternary or older, and if Quaternary, to determine the direction and amount of offset, the amount of extension, and the style of intentional deformation of the upper plate.

Field work was conducted to evaluate geologic mapping in the Point of Rocks area and a previously prepared report was revised for inclusion in the final detachment fault report.

A field review of all five activities in the detachment faulting study plan was conducted. The review team visited the Calico Hills, Red Mountain, Point of Rocks, southern

Crater Flat, northern Bare Mountain, Bullfrog Hills, Daylight Pass, Birdtrack Hills, and Yucca Mountain. Postulated detachment faults at each of these areas were examined.

Activity 8.3.1.17.4.5.5 - Evaluate the age of detachment faults using radiometric ages. The objectives of this activity are to determine if the subdetachment basement and the Bare Mountain massif cooled through the blocking temperatures of zircon and apatite during the Quaternary period; and to determine if the Northern Amargosa core complex cooled through the blocking temperatures of muscovite and biotite during the Quaternary period.

Seven preliminary ages determined by fission track methodology on metamorphic minerals from Bare Mountain and the Bullfrog Hills were completed, and the results are being analyzed.

A mineral separate of hornblende was prepared and sent to the New Mexico Bureau of Mines for analysis. Preliminary fission track age determinations were obtained and work continued to refine Ar-40/Ar-39 age determinations at the New Mexico Bureau of Mines.

Forecast: Mapping is nearly complete for most of the study areas; mapping will be completed for the Beatty Mountain quadrangle. The review draft of the manuscript on detachment faulting will receive technical review. Other reports will be prepared, presenting data and interpretations resulting from several of the activities.

3.13.14 Study 8.3.1.17.4.6 - Quaternary Faulting Within the Site Area

The objectives of this study are to identify and characterize Quaternary faults that intersect or project toward the surface facility, repository, or controlled area; and to identify and characterize Quaternary faults at the site whose length or recurrence rate suggest a potential for future earthquakes with magnitudes such that associated ground shaking could affect design or performance of the waste facility.

Activity 8.3.1.17.4.6.1 - Evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain. The objectives of this activity are to synthesize and evaluate data pertaining to location, orientation, length, width, Quaternary recurrence rate, and location, amount, and nature of Quaternary movement of faults within the site area; and to identify unrecognized faults in the site area.

The Quaternary faults being studied in detail are Crater Flat, Solitario Canyon, Windy Wash, Bow Ridge, Paintbrush Canyon, Fatigue Wash, and Stagecoach Road. Although Quaternary movement has not been demonstrated, the Ghost Dance fault is also included. Discussions concerning the investigations now being conducted are given as part of Activity 8.3.1.17.4.6.2 (see below), inasmuch as most of the current work is directed toward mapping and related studies of trenches that transect these features. Analysis and evaluation of the collected fault data are continuing, and reports are being prepared on various topics as the data become available. A field trip was conducted for personnel involved in the probabilistic

analysis of fault displacement, to evaluate preliminary results of the fault investigations (primarily from the trench studies described below).

Work continued on preparation of a digital file containing fault data for USGS Miscellaneous Investigations Map I-2520 and it was submitted for printing. On this 1:224,000-scale map, all mapped faults within a 400-sq. km area, centered approximately on Yucca Mountain, are plotted in detail, with dips of fault planes shown as well as notations describing relationships that can be observed at various points along the fault traces (including any evidence of Quaternary movement). Locations of trenches are also shown.

Activity 8.3.1.17.4.6.2 - Evaluate age and recurrence of movement on suspected and known Quaternary faults. The objectives of this activity are to determine through trenching and trench wall mapping the location, spatial orientation, length, width, Quaternary recurrence rate, interconnections at the surface, and the location, amount, and nature of Quaternary movement of the Windy Wash, Solitario Canyon, Ghost Dance, and Paintbrush Canyon faults and other suspected or possible Quaternary faults within the site area; and to determine through trenching and dating the age, amount, and nature of offset and the recurrence history of the Bow Ridge fault system and to evaluate that information in context with data contributed by other studies on the age, nature, and origin of fracture coatings and fissure fillings deposited within that zone.

Crater Flat fault

Four trenches were excavated across Crater Flat fault, but studies have not started.

Solitario Canyon fault

Logging activities began at Trench SCF-T2. Contacts and structural features were mapped, a preliminary log was compiled, and soil and lithostratigraphic units are currently being described. Additional sections of a natural exposure, labeled SCF-E1, were cleaned and flagged, exposing an additional strand of the fault. Soil profiles were completed in Trench SCF-Tf. Field reviews were conducted for all of the completed logs.

Windy Wash fault

Preliminary logs were examined and revised in the field at Trenches CF2 and CF3 on the Windy Wash fault. Selected contacts and structural features were remapped, and soil and lithostratigraphic unit descriptions were reviewed and revised. Project geologists began field revisions of preliminary trench logs, and internal technical reviews of Trenches CF2, CF2.5, and CF3 were conducted. Samples were collected for cosmogenic dating of surficial deposits exposed in Trenches CF-2 and CF-3.

Bow Ridge fault

The collection of field data from Trench 14D on the Bow Ridge fault was completed. Field reviews of the logs from both Trench 14D and 14C were also completed. The final report for the fault is being revised to incorporate results of the field reviews.

Paintbrush Canyon fault

Project geologists completed logs for walls #1, #2, and #4 at the exposures of the Paintbrush Canyon fault on Busted Butte. Descriptions of stratigraphic units and measurements of unit thicknesses and amounts of fault displacements were obtained. The top of wall #4 was reexamined and critically evaluated for faulting relations and unit boundaries, resulting in revisions of previous interpretations of stratigraphy and paleoseismicity. Exposures of the fault were prepared for the required technical field reviews.

Preliminary logs of the south wall and parts of the north wall and inner slot of Trench A1 on the northern segment of the Paintbrush Canyon fault were completed, bringing to near completion the preparation of the log for the entire trench. Samples of deposits exposed along the trench walls were collected for geochronological dating, and samples of basaltic ash were submitted for geochemical analysis and comparison with possible source tephra from the Lathrop Wells volcanic center.

Fatigue Wash fault

Samples for dating surficial deposits exposed in Trench CF-1 were collected.

Stagecoach Road fault

Stratigraphic logs of Boreholes SR-1, SR-2, and SR-3, drilled near Trench SCR-T1 on the Stagecoach Road fault were completed. Bedrock (8.5 Ma tuff) was encountered at depths of about 300 ft in the hanging wall.

Ghost Dance fault

Project geologists examined bedrock sections exposed in Trenches GDF-T1 and GDF-T3 with geologists involved in Study 8.3.1.4.2.1 (Characterization of the Vertical and Lateral Distribution of Stratigraphic Units Within the Site Area) to evaluate the structural and bedrock stratigraphic features that can be observed along the trench walls. Trench GDF-T1 was subsequently deepened, and key sections cleaned. Flagged pins in Trenches T2, T4, GDF-T1, and GDF-T3 were surveyed and coordinates established as preliminary steps in the preparation of field trench logs for each trench. Photographs were taken of the vertical walls of Trench GDF-T1 and of the vertical wall on the south side of the pad for Borehole USW UZ-7a where the Ghost Dance fault is exposed. Samples were collected for laboratory analyses from Trenches T2 and T4, and samples for U-series dating were obtained from Trench GDF-T1.

Forecast: Final reports will be written on the Crater Flat, Solitario Canyon, Windy Wash, Paintbrush Canyon, Bow Ridge, Stagecoach Road, and Ghost Dance faults, as well as on northwest-trending faults (such as the Sundance fault).

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

The objectives of this study are to provide data on the distribution of mass, magnetic gradients, geoelectric features, and seismic velocities and reflections that will aid in evaluating the continuity of Quaternary faults where concealed by Holocene and late Pleistocene surficial deposits; to evaluate the data and its limitations; to evaluate the possibility that Quaternary faults exposed as high-angle faults at the site continue to depth as planar, high-angle faults, or alternatively, flatten at depth and merge with one or more long-angle faults; and to provide information on continuity of rock units within the repository and controlled area to assist the investigation of site geology.

There will be no study plan developed for this SCP section. There are eight activities in this SCP section. Field geophysical surveys critical to, and analysis and assessment of, the subsurface geometry and concealed extensions of Quaternary faults are to be performed under Study Plan 8.3.1.4.2.1, "Characterization of the Vertical and Lateral Distribution of Stratigraphic Units Within the Site Area." Geophysical surveys conducted for Study 8.3.1.4.2.1 will be examined as inputs for assessing concealed faults and subsurface geometries. The implications of subsurface geometry and concealed extensions of Quaternary faults will be addressed as part of the sensitivity studies associated with Study 8.3.1.17.3.6.

Forecast: Study Plan 8.3.1.4.2.1 will be revised to incorporate this scope of work. The Site Design and Test Requirements Document will be revised to reflect this change.

3.13.16 Study 8.3.1.17.4.8 - Stress Field Within and Proximal to the Site Area

The objective of this study is to provide data on ambient stress at the site and its immediate vicinity that will aid in evaluating most favored orientation and nature of future movement on faults within the site area, stability of potential pathways for radionuclide travel controlled by or related to fracture aperture, the stability of mined excavations, response of rock mass to thermal loading, and applicability of tectonic models. A secondary objective is to evaluate the potential relevance of paleostress data to prediction of future stress orientations.

As originally described in the SCP, four activities were included in Study 8.3.1.17.4.8. Because (a) the objectives and parameters assigned to two of the activities are very similar, and (b) tasks assigned to the other two activities are adequately covered by Study 8.3.1.17.4.12 (Tectonic Models and Synthesis), the scope of this study is limited to one activity as indicated below.

Activity 8.3.1.17.4.8.1 - Evaluate Present Stress Field Within and Proximal to the Site Area. The objective of this activity is to measure the vertical and lateral variation of in situ stress at and proximal to the potential repository by conducting hydraulic fracturing stress measurements and observations of stress-induced borehole breakouts in boreholes that are scheduled to be drilled adjacent to the site. The magnitudes and orientations of the horizontal and vertical in situ stresses are the principal parameters to be determined.

The study plan was prepared and reviewed by the USGS, and transmitted to DOE-YMSCO for review. The scope of the study involves in situ stress measurements in new boreholes adjacent to Yucca Mountain using the hydraulic fracturing method combined with observations of stress-induced borehole breakouts as recorded on geophysical logs.

Forecast: Work will continue on a revised study plan. Conduct of the study depends upon the drilling of proposed boreholes at localities adjacent to Yucca Mountain.

3.13.17 Study 8.3.1.17.4.9 - Tectonic Geomorphology of the Yucca Mountain Region

The objective of this study is to document Quaternary uplift and subsidence within the Yucca Mountain region and to evaluate regional variation in the nature and intensity of Quaternary faulting.

Activities 8.3.1.17.4.9.1 through 8.3.1.17.4.9.3. Activities 8.3.1.17.4.9.1 and 8.3.1.17.4.9.2 define a work scope documented in the Extreme Erosion Topical Report (DOE, 1993b), and that is still in progress through the surface mapping performed under Study 8.3.1.5.1.4. The work scope for Activity 8.3.1.17.4.9.3 is to be transferred to Study Plans 8.3.1.17.4.3 and 8.3.1.17.4.12.

There will be no study plan developed for this SCP section. The work scope already has been, or will be, transferred to, and performed under, Studies 8.3.1.5.1.4, 8.3.1.17.4.3, and 8.3.1.17.4.12.

Forecast: The study plans and Site Design and Test Requirements Document will be revised to reflect this change.

3.13.18 Study 8.3.1.17.4.10 - Geodetic Leveling

The objective of this study is to evaluate possible historical and contemporary vertical displacements across potentially significant Quaternary faults within 100 km of Yucca Mountain. A secondary objective is to characterize the historical rate of uplift and subsidence in the Yucca Mountain region and evaluate the possible existence of tectonic boundaries, coinciding perhaps with the Walker Lane or with the Furnace Creek fault zone, that may separate domains with differing rates of uplift and subsidence.

Three activities are assigned to Study 8.3.1.17.4.10: Activity 8.3.1.17.4.10.1, Relevel base-station network, Yucca Mountain and vicinity; Activity 8.3.1.17.4.10.2, Survey selected base stations, Yucca Mountain and vicinity, using global positioning satellite; and Activity 8.3.1.17.4.10.3, Analyze existing releveling data, Yucca Mountain and vicinity. Because the tasks involved in conducting these activities are closely allied, the progress and descriptions of the work being performed are combined in the following paragraphs.

To date, 90 km of leveling have been accomplished out of a total of 200 km of level-lines involved in the releveling program. In addition, quadrilaterials spanning five of the faults suspected of Quaternary movement within and near the site area are included in the periodic resurveys. Results to date indicate that no significant movements have taken place within these quadrilateral areas since measurements were begun in the early 1980s. Periodic resurveys of a trilateration network centered on Yucca Mountain, were reported in Savage et al. (1994), and also show that no significant deformation took place during the reporting period, except in the vicinity of Little Skull Mountain where measured rates of change in line lengths between stations is considered to reflect coseismic activity associated with the magnitude 5.4 earthquake that occurred there in 1992.

Twenty new global positioning system stations were identified and surveyed across Death Valley, and were tied into the Yucca Mountain global positioning system network on the east and to the Navy's Coso network on the west. This 140-km-long profile spans several major structural features including the Furnace Creek fault zone, Death Valley, Panamint Mountains, Panamint fault zone, and prominent faults near Coso Junction, California.

Forecast: The resurveying of the level-line will be continued and the data will be submitted to the Local Records Center. A progress report on the global positioning system profile from Beatty, Nevada, to Coso Junction, California will be prepared and submitted.

3.13.19 Study 8.3.1.17.4.11 - Characterization of Regional Lateral Crustal Movement

The objective of this study is to evaluate rates and orientation of historical and current crustal strain based on analysis of existing data on seismicity, historical fault, offset, and creep in the Basin Range and at Yucca Mountain.

There will be no study plan developed for this SCP section. The activity in this SCP section will receive and evaluate information from Study 8.3.1.17.4.10. No unique data are to be acquired by this study. This scope of work is to be transferred to Study 8.3.1.17.4.10.

Forecast: Study Plan 8.3.1.17.4.10 and the Site Design and Test Requirements Document will be revised to reflect this change.

3.13.20 Study 8.3.1.17.4.12 - Tectonic Models and Synthesis

The objectives of this study are to synthesize data relevant to tectonics; to develop a model or range of models that establishes the causal relation between application of tectonic forces and formation of structures observed at Yucca Mountain and vicinity, to link observed rates of formation of structures with regional rates of crustal strain; to forecast changes in tectonic setting and the manner in which changes will affect both regional crustal strain rate and tectonic stability in the Yucca Mountain region, to estimate effect of changes on rate and nature of crustal strain at Yucca Mountain and vicinity, and to estimate future rate of tectonic processes at Yucca Mountain.

Activity 8.3.1.17.4.12.1 - Evaluate tectonic processes and tectonic stability at the site. The objectives of this activity are:

- To synthesize gravity studies at Yucca Mountain and vicinity and define regional variations in mass, and attribute them, as appropriate, to variations in crustal thickness, degree of melting, shallow intrusions, distribution of specific stratigraphic units, and faults

- To synthesize magnetic studies at Yucca Mountain and vicinity and define areal variations in magnetic field and relate them, as appropriate, to distribution of specific stratigraphic units, shallow intrusions, and subsurface configuration of faults

- To evaluate regional extent of detachment faults, wrench faults, volcanic rocks belonging to the Death Valley-Pancake Range belt, regional pattern of oroclinal bending (oroflexing), regional extent of Miocene ash-flow tuffs and associated pyroclastic and epiclastic rocks, and regional extent of Paleozoic rocks known to be aquifers, aquitards, or to provide favored surfaces of detachment or thrusting

- To synthesize and evaluate information pertaining to Quaternary wrench faulting in the Walker Lane (Las Vegas to Cedar Mountain), constrain, if possible, the rate of offset and recurrence interval of potentially significant faults (including the Bare Mountain fault and faults analogous to those near Cedar Mountain), and evaluate the applicability of this information to geologic hazards at the site

- To synthesize and evaluate information pertaining to detachment faults at Yucca Mountain and vicinity and constrain the rate of displacement, subsurface configuration, and risk posed by this class of faults

- To synthesize and evaluate information pertaining to normal (and north-trending oblique and strike-slip faults) at the site and vicinity, and possibly constrain aggregate strain rate, subsurface configuration, recurrence interval, and risk posed by this class of faults

- To synthesize and evaluate information pertaining to the northeast-trending left-lateral strike-slip faults at the Nevada Test Site and vicinity, and constrain slip rate, recurrence interval, and risk posed by this class of fault.

Project geologists conducted a field review of evidence for detachment faults and strike-slip faulting relevant to tectonic models and tectonic domains that constitute the tectonic setting of Yucca Mountain. Technical data bearing on faulting in the Pahute Mesa area and volcanism in Crater Flat were reviewed.

Activity 8.3.1.17.4.12.2 - Evaluate tectonic models. The objectives of this activity are to formulate a range of tectonic models that relate the nature and estimated rates (including bounding values) of Quaternary processes (volcanism, faulting, uplift, and subsidence, lateral strain, and possibly folding) of potential significance to design and performance of the repository at Yucca Mountain; to evaluate temporal changes in tectonic activity and resulting changes in fractures and other structural features of potential hydrologic significance at and in the vicinity of Yucca Mountain (relate tectonic cycle, if it exists, to tectonic model(s)); to ensure that assumptions, inferences, and conclusions concerning tectonic processes that are important to design and performance of the repository are consistent with tectonic models applicable to the site; and to ensure that uncertainty in the data, assumptions, and inferences concerning rates and nature of those tectonic processes that are important to design or performance of the repository is adequately reflected in conclusions about those processes.

Work continued on the development of the boundary element modeling technique and code to meet QA standards. The boundary element modeling technique is a mathematical method of simulating crustal conditions for purposes of analyzing fault behavior.

Activity 8.3.1.17.4.12.3 - Evaluate tectonic disruption sequences. The objective of this activity is to evaluate disruption sequences involving faulting, folding, uplift and subsidence, and volcanism that are of potential significance to design or performance of the repository.

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

Forecast: A summary evaluation of tectonic models, boundary-element modeling results, and tectonic processes at Yucca Mountain and its geologic setting will be submitted. Models will be refined, and data will continue to be synthesized during the remainder of FY 1995, so that a revised model can be reported in FY 1996. The report "Current Evaluation of Tectonic Models for the Yucca Mountain Region" will be revised in light of new data from relevant activities and conceptual evaluations.

3.14 STUDY 8.3.1.20.1.1 - ALTERED ZONE CHARACTERIZATION

The objective of this study is to characterize the effects on the region around the potential repository that is altered by hydrothermal processes that develop in response to heating of the repository block due to radioactive decay of the emplaced nuclear waste.

Activity 8.3.1.20.1.1.1 - Field and laboratory studies of the effects of mineralogical and mechanical changes on transport processes. The impact of chemical, mineralogical and mechanical change on hydrological properties, particularly on porosity and permeability, and the kinetics of these processes, will be evaluated as a function of several environmental variables, including temperature, fluid composition, fluid flow rate, stress, and water volume to surface area ratio. Also considered in these studies will be the relationship between pore geometry and permeability as recrystallization occurs within crushed, fractured and intact materials.

Experiments were started to evaluate the effect on water composition and secondary mineral development of water-rock interaction in vitric and vitrophyric rocks that occur in the near-vicinity of the repository. The experiments will determine the rates of reactions, the controls on the solid phases that form that could influence radionuclide transport, and the effect of reactions on water chemistry. These experiments are still under way. In support of the experimental studies, efforts are under way to update available data on precipitation and dissolution kinetics, from literature sources.

Experiments are being developed to measure the impact of water-rock interaction effects (such as recrystallization, precipitation and dissolution) on porosity and permeability. These experiments support efforts to establish the capability to evaluate the impact of coupled hydrological-geochemical processes on thermal response of the repository block, and on water flux and composition entering the Engineered Barrier System/Near-Field Environment. The experimental apparatus to be used in these studies is a plug flow reactor, with flow controllers and temperature control. The system is undergoing testing. Experiments in support of these studies, which are being conducted under static fully saturated conditions at 90°, 150°, and 250°C, are continuing. These experiments focus on a range of lithologies, as a means of describing the magnitude of variation among lithologic units that may be expected for the limiting case of slow flow under saturated conditions.

Experimental measurements of precipitation rates will be conducted to evaluate the kinetics of changes in the altered zone regions where refluxing or mineral precipitation may occur. Some of these experiments will focus on the effects of solutes on precipitation rates, which is an area that has received very little attention, and yet is of major importance in establishing reaction kinetics. The experimental system to accomplish these measurements is being renovated and updated to allow appropriate measurements to be made.

Activity 8.3.1.20.1.1.2 - Evaluating existing and developing future capabilities to simulate coupled hydrothermal and reactive transport processes. The objectives of this activity are to compare codes and to evaluate their suitability for application to altered zone efforts in two steps. The first step will be to review the capabilities of the codes as they currently exist. Comparisons will be made of how the codes simulate well-documented processes. Once several codes are selected, they will be used to simulate the results of the ongoing experimental studies, and to predict the outcome of those studies. They will also be used to simulate field properties of sites selected for field study. These forecasts will be used to refine modeling strategies, as discrepancies between measurement, observation, and field data become evident.

Codes to conduct the coupled simulations, and to aid in the design of experiments evaluating coupled processes, have been obtained and installed, and test cases designed. These codes will be used to identify experimental conditions, to ensure that processes of interest will be observed and adequately monitored.

Activity 8.3.1.20.1.1.3 - Performing bounding calculations of the effect of coupled processes in the altered zone on near-field properties. The parameter values, limits and/or ranges that must be obtained to define the waste package environment are described in the SCP. To generate these values from models of specific characteristics of the near-field, initial conditions must be defined in a manner compatible with the respective near-field models. This activity will generate bounding values for those inputs.

Initial reconnaissance computations to bound the effects of coupled hydro-geochemical processes were completed and reported (Glassley, 1994). These computations demonstrate that simulating mass transport of large quantities can be accomplished. The conditions and chemical system used in the simulations were selected to determine if significant changes might occur, and whether there might be unforeseen problems in conducting the simulations. No problems were encountered, and the results demonstrated that, for the selected conditions, large masses could be redistributed around the repository.

Activity 8.3.1.20.1.1.4 - Performing bounding calculations of the effect of coupled hydrological and reactive transport processes on thermal evolution. Within the SCP, the parameter values, limits and/or ranges are described that must be obtained to satisfy the resolution strategy dealing with thermal loading decisions. To generate this information, the potential designs and operation of the repository must be used as initial conditions for simulations that determine the response, over time, of the altered zone to waste emplacement. This activity will generate bounding values for the range of scenarios considered for repository design and operation

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

Forecast: Experiments and code activities will continue. New simulations will be conducted to refine bounding conditions and expected processes.

CHAPTER 4 - REPOSITORY DESIGN

This chapter reports progress in designing the potential repository, which consists of surface facilities, underground facilities, and shafts and ramps connecting the surface and underground facilities. When the repository is prepared for permanent closure, seals will be constructed for the shafts, ramps, and exploratory boreholes. Thus, this section discusses progress in evaluating seals. The repository facilities will be designed to meet various functional and regulatory requirements, including those of the NRC.

4.1 CONFIGURATION OF UNDERGROUND FACILITIES (POSTCLOSURE) (SCP SECTION 8.3.2.2)

Development of repository layout concepts continued during the current reporting period. The modifications to the baselined ESF/Repository interface layout that were described in Progress Report #11 also continued. Revision of both the baselined ESF/Repository interface drawings and the Advanced Conceptual Design Summary Report (CRWMS M&O, 1994b) is planned for the latter part of FY 1995.

4.1.1 Design Activity 1.11.1.1 - Compile a Comprehensive List of All the Information Required From Site Characterization to Resolve This Issue

The objective of this design activity is to summarize, in one place, all the information required from site characterization for design.

Work begun last period continued. The main work has involved determining the data (information) needed from site characterization by the repository surface and subsurface design groups, and developing the format in which to transmit the data request. The following types of data needs have been identified:

- Geographic Data (topography and natural features, boundaries and cultural features, borehole location)
- Geologic Data (stratigraphy, structure, ground-water hydrology)
- Geoengineering Data (in situ rock mass conditions, rock index properties, joint parameters, rock mass quality indices, rock mechanical properties, rock thermal and thermomechanical parameters, rock dynamic properties, rock mass performance parameters, soil parameters)
- Natural Phenomena (air temperature/humidity, rainfall/snowfall, floods, wind and tornadoes, earthquakes)
- Baseline Environmental Conditions (air/noise, water quality/quantity).

Repository structures, systems, and components for which the data are needed have been identified. These structures, systems, and components are being related to the needed data by means of a matrix.

Most data needs are required only in sufficient time to support the draft Environmental Impact Statement, the Technical Site Suitability determination, and the License Application. These relatively longer-term data needs will be tabulated and formally requested in a comprehensive Repository Data Needs Document (CRWMS M&O, in prep.[d]). The Data Needs Document will identify both the intended use and the preferred source of the data (either surface-based testing or ESF construction and testing). It will also state the accuracy required from the data. SCP Table 8.3.2.2-5 will be consulted as the starting point for the evaluation of accuracy required.

Some data, however, are needed from now through the end of FY 1996 to better define the stratigraphy and to establish better stratigraphic control for repository and ESF design and current ESF construction. These near-term needs include surface mapping of the top and bottom of the TSw1 unit in Solitario Canyon and where possible, geophysical logging in some of the older boreholes in the general repository area. These near-term needs have been communicated through meetings and letters.

Forecast: The comprehensive Data Needs Document is scheduled to be completed in June 1995. The YMSCO is expected to direct that study plans be revised to include identified data needs and to eliminate unneeded data.

4.1.2 Design Activity 1.11.1.2 - Determine Adequacy of Existing Site Data

The objective of this design activity is to determine whether the available site data are sufficient for licensing. If they are not, then it must be determined whether additional data must be gathered or whether the design must be changed to accommodate the existing data. This is an ongoing determination up to License Application.

This activity is related to Design Activity 1.11.1.1. It involves evaluating the quantity and quality of currently available data, and subsequent reevaluating new or additional data as received. The proposed geophysical logging of old boreholes mentioned in Section 4.1.1 relates to this activity because it is an attempt to use boreholes previously drilled under a non-QA program to now obtain qualified site characterization data that can be used. This is a more cost effective and timely way to obtain additional data; the alternative would be to drill additional holes.

Forecast: Efforts in this activity will become an ongoing activity through most of License Application Design. The effort will end when all data necessary for License Application are available.

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

The objective of this design activity is to produce topical reports that describe the three-dimensional thermal and mechanical stratigraphy of Yucca Mountain. The description will rely on information gathered from the site and will be entered into the Reference Information Base.

During this reporting period, work on a related design activity, 1.11.3.2, also resulted in progress towards the completion of this activity. An analysis was begun during the previous reporting period (CRWMS M&O, 1994c) to further define zones acceptable for waste emplacement within the limits established by the key assumptions. This analysis included the evaluation of lithostratigraphic and thermal/mechanical stratigraphic nomenclature and unit characteristics needed to identify the available, three-dimensional waste emplacement volume. A three-dimensional computer model of the Topopah Spring welded thermal/mechanical units was developed using the LYNX geology and engineering modeling system.

At the close of this reporting period, work was continuing on this task, but at that time, significant changes and unit definitions had been developed and applied to the three-dimensional computer model. Some of these significant items are discussed in more detail under the description of design activity 1.11.3.2. A report summarizing the results of the current efforts on the thermal/mechanical stratigraphy is scheduled for completion in April 1995 (CRWMS M&O, in prep.[e]).

Forecast: Work on the thermal/mechanical stratigraphy of Yucca Mountain will continue into the next reporting period and through FY 1996. The current report describing the work in FY 1995 will be issued in April 1995.

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

The objective of this design activity is to produce topical reports giving properties and describing how they were determined from field and lab measurements. These reports will be compared with the requirements of this issue to ensure that the Reference Information Base contains the required data. This work includes rock characteristics, initial conditions (in situ stress and temperature), geology (stratigraphy and structure as reported in the three-dimensional graphics model of Yucca Mountain), and design data (e.g., areal power density and borehole spacing).

The Reference Information Base is a controlled data base that summarizes data and information for use in site suitability evaluations, design and development activities, and performance assessment analyses. This data base is continually updated to reflect the progress in defining the data requirements of the primary data users, and in preparing reference properties for incorporation into the data base. This design activity is, therefore, fully implemented and controlled by procedure.

Forecast: Future progress reports will assume routine maintenance and expansion of the data base continues. Only noteworthy events, or changes to data requirements or submittals, will be reported.

4.1.5 Design Activity 1.11.2.1 - Compile Waste Package Information Needed for Repository Design

The objective of this design activity is to determine what waste package information is needed for design of the underground facility, to obtain such data, and to document it in the Repository Design Requirements Document (CRWMS M&O, 1994d).

The following data were developed, included in the Controlled Design Assumptions Document (CRWMS M&O, 1995a), and used in the repository conceptual design process. The following data were developed: waste package heat output vs. time; spent nuclear fuel thermal characteristics; waste package dimensions and weights (with and without filler material); maximum cladding temperature; and three time schedules for waste arrival, surface processing of waste packages, and underground emplacement of waste. These data will be incorporated in the Repository Design Requirements Document and the Engineered Barrier Design Requirements Document (DOE, 1994e) when they are next revised.

Forecast: Development of the above information is an ongoing effort, and the information used in repository design will be updated as changes occur. This design activity will continue to report information needs resulting from waste package and repository conceptual design processes.

4.1.6 Design Activity 1.11.3.1 - Area Needed Determination

The objective of this design activity is to determine the area required for the underground facility.

The emplacement area needed is typically expressed in one of two ways. The first is by dividing the total initial thermal output (kW) of the waste inventory by the local, or unit, thermal load (kW/acre). The second is by dividing the total waste inventory (MTU) by the local, or unit, waste loading (MTU/acre)[1]. The lower the thermal load or waste loading, the greater the area needed for emplacement. The total area needed is the emplacement area plus that for development, operations, performance confirmation, and any other needs.

[1]It should be noted that thermal output or power density in kW/acre changes with time as the waste decays, while the mass loading in MTU/acre does not. The relationship between mass loading and power density depends on the burnup and age of the spent nuclear fuel but at emplacement the conversion for the average fuel (average for boiling water reactor plus pressurized water reactor fuel) using a youngest fuel first selection criteria is about 1kW/MTU.

A design basis thermal load has not yet been selected by the Project. During the last two progress report periods, the Project assumed that the surface and subsurface configurations are to accommodate thermal loading operations for both a primary, high thermal load of 80 to 100 MTU/acre, an average local areal mass loading, and an alternative, low thermal load 25 to 35 MTU/acre (CRWMS M&O, 1995a). The repository, if limited to the primary area (CRWMS M&O, 1995a), as defined in Mansure and Ortiz (1984), cannot accommodate all of the 70,000 MTU statutory maximum at a low thermal loading. At 25 to 35 MTU/acre, only approximately 26,000 to 37,000 MTU can be disposed of within the primary area. Thermal management of waste during emplacement, as discussed later, would increase the amount that can be disposed, but still may not allow disposal of all 70,000 MTU. The current working concept for a repository layout (CRWMS M&O, 1995a) can accommodate 70,000 MTU at a thermal load of 82 MTU/acre or greater within the primary emplacement area located west (also referred to as the upper emplacement block) of the Ghost Dance fault. The combination of the primary emplacement areas east (also referred to as the lower emplacement block) and west of the Ghost Dance fault can accommodate a thermal load as low as 66 MTU/acre.

The current approach to thermal loading is to define a design thermal load that, taking into account design options and operating parameters, will accommodate the full statutory capacity of the repository. Near-term engineering activities will be focused on developing the reference design for an 80 to 100 MTU/acre areal mass loading and identifying the design features needed to maintain the alternative loading options. Flexibility related to waste package spacing and emplacement drift selection will be used to accommodate the waste for the alternative loading options.

It is widely recognized that a low thermal load limited to emplacement within the primary area would allow disposal of considerably less than the maximum 70,000 MTU allowed. This was considered unacceptable. Three approaches that could potentially address this problem include: (1) the development of a waste emplacement management strategy, (2) increase the area for emplacement by using the expansion areas, and (3) a combination of additional area and a waste emplacement management strategy.

The first strategy, waste emplacement management, is sometimes referred to as a thermal management strategy, but even though management of the thermal load is a major part of the strategy, it goes beyond strictly thermal aspects of the problem. Waste emplacement management is an attempt to reduce the effects of emplacement at a given thermal load (i.e., make the results of a given thermal load be the same as the results of an unmanaged lower thermal load). Waste emplacement management concepts include (a) varying the waste package spacing within the emplacement drifts, (b) initially placing waste packages in widely spaced drifts and later placing more in intermediate drifts, (c) repositioning the previously emplaced waste packages just before repository closure, (d) managing the waste stream to increase the waste age before emplacement, and (e) providing periodic or continuous ventilation through the emplacement drifts following emplacement. These concepts are currently the subject of thermal and ventilation studies.

The most obvious method of accomplishing the second approach, provide more area for emplacement, is to provide additional area outside of the primary area. Placement at 20 MTU/acre without any thermal management will require 3,500 acres to place all 70,000 MTU. As explained previously, the total area required would be greater. Because the primary area consists of only 1,055 acres, additional site characterization would be required. Such additional site characterization is not currently part of the Program Plan (DOE, 1994a). The cost, and any schedule impacts, have not been fully evaluated.

The third approach considers a combination of additional area and waste emplacement management. A concept that has recently been proposed to provide additional area within the primary area would be achieved by developing a multilevel repository. Three emplacement levels could be developed within the primary area west of the Ghost Dance fault, and two emplacement levels could be developed within the primary area east of the Ghost Dance fault. The emplacement levels would have a vertical separation of approximately 50 to 100 m. By placing the waste packages at 25 MTU/acre within each level, 70,000 MTU can be placed within all five levels (the additional levels would be smaller than the east and west emplacement areas in the current layout). Preliminary results indicate that the preclosure behavior of such a multilevel repository may be essentially the same as a single-level repository having a thermal load of 35 MTU/acre. The postclosure behavior would be essentially the same as a single-level repository having a thermal load of about 70 to 80 MTU/acre. More analysis is needed to determine if such a multilevel repository would have acceptable performance.

The waste emplacement management approach also points out the need to begin stating thermal loading requirements in terms of measurable performance because that is the only way the acceptance of a given thermal loading and thermal management approach can be judged.

Forecast: Waste emplacement management studies will continue with a goal of determining the maximum amount of waste that can be emplaced within the primary area for a given thermal load. A report of these studies is expected to be completed in June 1995 (CRWMS M&O, in prep.[f]). Efforts in determining areas to be characterized outside of the primary area depend somewhat on the preliminary results of the multilevel repository to be presented in that study.

4.1.7 Design Activity 1.11.3.2 - Usable Area and Flexibility Evaluation

The objective of this design activity is to analyze the three-dimensional structure and stratigraphy of Yucca Mountain to identify usable areas and ensure sufficient area is characterized to allow flexibility in design. This will be accomplished by producing graphic cross sections and maps that can be used for repository layouts to ensure they fit the geology.

Progress Report #11 stated that the Project assumed that the repository will be limited to the TSw2 geologic unit within the primary area (CRWMS M&O, 1995a). This assumption limited the scope of this design activity to investigation within the TSw2 unit and the primary

area. The assumption has since been revised to allow minor adjustments of the primary area boundary and to allow some emplacement areas in the TSw1 unit (CRWMS M&O, in prep.[f]).

An analysis was begun during the previous reporting period (CRWMS M&O, 1994e) to further define zones acceptable for waste emplacement within the limits established by the key assumption. The analysis considered geotechnical, thermal, and hydrologic characteristics of the rock and their application to repository construction. The analysis established vertical and horizontal limitations on repository development, mostly expressed in terms of standoff distances from certain features. The LYNX computer modeling software was used in the analysis to develop a three-dimensional model of the area. The model was based on interpretation of borehole geophysical logs and used the USGS LYNX Model YMP.R1.1 as a guide. Updates to this work are described below. A report summarizing the results of current efforts is scheduled for completion in April 1995 (CRWMS M&O in prep.[g]).

As originally defined by Ortiz et al. (1985), the TSw1/TSw2 contact was based on a change in lithophysal cavity content by volume from greater than approximately 10 percent in TSw1 to less than approximately 10 percent in TSw2. This contact was selected because of its thermal/mechanical significance. Some problems were encountered, however, when the USGS estimates of lithophysae, which Ortiz et al. (1985) used in their evaluation, were found to include not only the cavity, but also the vapor-phase mineral halo and alteration rind (Rautman, 1985). Several years later, at least two of the stratigraphic picks selected by Ortiz et al. (1985) were discovered to be inconsistent with the rest of the boreholes (Peck, 1991). A committee of evaluators examined core from five boreholes and concluded that the "contact of the TSw1/TSw2 units is a consistent lithologic contact" and "corresponds to the lithologic contact recognized by the USGS as the base of the upper lithophysal unit of the Topopah Spring Member." This statement redefined the TSw1 and TSw2 thermal/mechanical units, but ignored the significance of the original definition. Work on this design activity (1.11.3.2) has found that the original TSw1/TSw2 contact, as defined by Ortiz et al. can be recognized in core, and more significantly, can be recognized in borehole geophysical density logs. This has resulted in the proposal that the original definitions of the TSw1 and TSw2 thermal/mechanical units be reinstated because they have more significance in terms of the thermal and mechanical behavior of the rock, and more bearing on the siting of the emplacement horizon.

This analysis will be ongoing because its purpose is to update results as additional information becomes available from site characterization. New or revised information from all boreholes was included in the analysis performed during the current reporting period.

Results of the current efforts are being used to revise the boundaries of repository layouts previously developed. They also are the basis for the initial layouts of the multilevel repository mentioned in Section 4.1.6.

Forecast: The repository horizon definition will continue to be refined throughout FY 1995, concentrating on the vicinity of the primary area. Little or no study of potential expansion areas will be done until direction is received from the Project (CRWMS M&O,

1995a). A report describing the work to date on defining the potential repository block (CRWMS M&O, in prep.[g]) is expected to be issued in April 1995.

4.1.8 Design Activity 1.11.3.3 - Vertical and Horizontal Emplacement Orientation Decision

The objective of this design activity is to provide the performance evaluation to document the decision on emplacement orientation.

An evaluation of potential waste package emplacement modes (CRWMS M&O, in prep.[f]) was in process and is scheduled for release during the next reporting period. The emplacement mode selection will be used for the repository Advanced Conceptual Design but will require verification during subsequent License Application Design.

Forecast: The Emplacement Mode Evaluation Report will be released.

4.1.9 Design Activity 1.11.3.4 - Drainage and Moisture Control Plan

The objective of this design activity is to provide postclosure design requirements for the layout of the underground facility to limit the amount of water in contact with the container (emplaced waste package) to provide a favorable containment and isolation environment. The objective is not only to limit the amount of water in contact with the container, but also promote the migration of moisture away from the container.

Current work under this activity is closely related to activities reported in Section 4.1.16 and, to a lesser extent, to those discussed in Section 4.1.8. The current strategy is to develop a repository layout to accommodate a range of thermal loading from low to high (CRWMS M&O, in prep.[d]). Repository layouts being developed are considering combinations of waste package and emplacement drift spacing to accommodate the thermal loading strategy.

Current repository layouts provide for the entire repository emplacement level to drain to a low point (sump) at the northeast end with subsequent water removal. The emplacement drifts themselves are sloped so that no ponding will occur in them. This drainage concept applies as well to alternative layout concepts currently being studied.

As Advanced Conceptual Design proceeds, options for controlling moisture movement will be evaluated as part of the alternatives for improving repository performance.

Forecast: Work will continue in FY 1995 to further define the moisture control plan.

4.1.10 Design Activity 1.11.3.5 - Criteria for Contingency Plan

The objective of this design activity is to provide criteria for a contingency plan to deal with unexpected conditions that may be encountered during site characterization and repository construction to provide confidence that the repository, as constructed, will provide waste containment and isolation for the required repository capacity. Examples of unexpected conditions that may be encountered include small zones of perched water, localized heavy fracture zones, water recharge pathways, and localized heavily lithophysae-rich zones.

Studies to define the potential repository block, as described in Section 4.1.7, and, to a lesser extent, studies of a potential multilevel repository, as described in Section 4.1.6 support this activity. In addition, as reported in Progress Report #11, significant horizontal offsets of excavations from faults are being planned.

Forecast: Limited work on this activity will continue through FY 1995 and through License Application Design. The potential repository block definition will continually be examined as information is received from site characterization activities. In addition to the current allowances for offsets from faults, repository layout studies will make additional allowances for unexpected conditions.

4.1.11 Design Activity 1.11.4.1 - Chemical Changes Resulting From the Use of Construction Materials

The objective of this design activity is to quantify the chemical changes (e.g., change in pH) that result from the use of a given quantity of construction material (e.g., cement).

Related work is discussed under the appropriate activities of Chapter 5, Section 5.2.6.

Forecast: The related activities discussed in Chapter 5, Section 5.2.6, will provide the forecast information.

4.1.12 Design Activity 1.11.4.2 - Material Inventory Criteria

The objective of this design activity is to establish appropriate limits on the inventory of materials that will be used in construction and operation of the underground facility and write criteria for the appropriate limits on the inventory of materials that will be left in the openings after decommissioning, including backfill.

As part of performance assessment support of surface-based testing and ESF design, construction, and operation, a number of evaluations have been made to bound the potential for impacts to waste isolation capabilities of the site from both surface and subsurface materials that are expected to remain at the site postclosure. Specifically, these analyses provide input to the design process controls intended to regulate the use of materials at the site, which are implemented in the Determination of Importance Evaluations. The major

areas where quantitative bounding calculations for use of tracers, fluids, or materials were performed for specific materials are (a) muck storage, (b) discharge from the sanitary sewage leach field, (c) grouted instrumentation in boreholes, and (d) the North Ramp excavation (Design Package 2C). Because in most instances the links between geochemical perturbations and changes to the release of radionuclides are understood only qualitatively, bounding scenarios are evaluated relative to their impact to the ambient composition of the system, which for some compositional components includes the waste form itself.

The muck storage pad, located a few hundred meters southeast of the North Portal pad, was evaluated for its impact to the geochemical properties of the site. Because the excavated rock is so similar to the material at the surface, there should be little impact to local geochemistry from the natural material. Any entrained organic from accidental releases, however, could be mobilized from the muck pile into the subsurface. Therefore, the organic content of the excavated material was limited to no more than the lowest organic content of soils from the Midway Valley. In addition, if this material is to be used as backfill, more severe restrictions on organic content may be required and specific storage conditions may be needed to meet those requirements.

The sanitary sewage leach field is planned to be located about 1 km southeast of the North Portal pad. Compositional effect of the sanitary sewage leach field discharge was evaluated based on the amount organic material introduced into the "downstream" portion of the potential repository saturated-flow path below the area of the leach field. To bound the impact to waste isolation from this material, calculated areas of an organic plume were compared with a radionuclide plume from the potential repository. This calculation produced a conservative estimate that only about 12 percent of the radionuclide path would be overlapped by the affected area. Because the saturated zone is just one part of the mobile aqueous radionuclide pathway, and the indications that in this "downstream" environment organic material may enhance both fixation of dissolved metals and transport of constituents, this estimate was interpreted to indicate negligible potential for impact to waste isolation.

The potential impacts from grouted in-place borehole instrumentation were evaluated in terms of compositional perturbations from retained sulfate-bearing grout and interference with borehole sealing capabilities. These considerations led to the recommendation for estimating the amount of grout that would be left in the formation once the grouted instrumentation had been drilled out of the hole (for final sealing). In addition, no more than 50 percent of any identified sealing interval was recommended to have grout emplaced in it before the final sealing of the borehole.

For North Ramp Excavation and Construction (Design Package 2C), the potential impacts to waste isolation from retained constituents of diesel exhaust were bounded using (a) the estimated distribution of diesel usage throughout the North Ramp, (b) conservative assumptions on retention and dissolution of diesel particulate matter, NO_x gases, and SO_2 gas, and (c) a three-dimensional, advective-dispersive transport calculation. These three constituents were evaluated relative to their potential to perturb the concentrations of dissolved organic carbon, NO_3^-, and SO_4^{2-} in the aqueous phase at the closest potential waste package. On the basis of the evaluation, limiting emission rates for the diesel exhaust

constituents were provided to the design group, and tests were planned to measure actual retention of these constituents in the tunnel. A similar calculation provided limits for these constituents from *all* retained substances in the North Ramp.

The dry chemical used in the planned fire protection system was specifically evaluated. The extinguishing material, which consists primarily of monoammonium phosphate ($NH_4H_2PO_4$) and ammonium sulfate ($(NH_4)_2SO_4$), was evaluated for potential impacts to waste isolation resulting from perturbations to the nitrate (NO_3^-), sulfate (SO_4^{2-}), and phosphate (PO_4^{3-}) content of the ground water. The amount of potentially retained fire suppression material was based on a design fire that required the discharge of 200 lb (90.72 kg) of the compound over 40 ft (12.2 m) of the tunnel, together with the removal of 95 percent of the material via vacuuming and removing equipment with material adhering to it. The peak compositional perturbations at the closest potential waste package (37-m offset) were calculated using a three-dimensional advective dispersive transport equation. These values indicate that for the bounding scenario that changes to sulfate and nitrate can be expected to represent negligible impact for waste isolation. The perturbation to phosphate in the system was viewed as negligible because the spent fuel itself contains about 0.01 percent phosphorus, which vastly exceeds the amount potentially added from the fire system.

A procedure was prepared that requires reporting the use and removal of planned and actual tracers, fluids, and materials at the Yucca Mountain site by all affected YMP organizations and individuals. Data on planned use and removal are input to Determination of Importance Evaluations that evaluate potential impacts of use and removal of tracers, fluids, and materials on Q-List items, site characterization testing, and waste isolation. The Determination of Importance Evaluations may restrict use and removal of tracers, fluids, and materials (e.g., on underground water and organics use). Data on actual use and removal, including accidental spills/releases and associated cleanup, are provided to the tracers, fluids, and materials data base, a component of the YMP technical data base.

Forecast: The effects of materials on waste isolation and establishing controls will continue to be evaluated throughout FY 1995.

4.1.13 Design Activity 1.11.4.3 - Water Management Criteria

The objective of this design activity is to establish appropriate limits on the amount of water that will be used for underground facility construction and operation, indicating amounts and locations for individual operations, and to convey those limits to Issue 4.4.

Several analyses bounding the potential impacts of water use during construction and operation of the ESF have been developed and implemented in the repository surface and subsurface design packages. The primary analyses were developed for the underground discharge of dust control water during construction of the North Ramp and the discharge of septic tank effluent from the operation of the sanitary sewer.

The potential impact of water discharged in the North Ramp on repository performance was evaluated in terms of effects on aqueous radionuclide transport through the backfill portion of the Engineered Barrier System and unsaturated zone. The greatest sensitivity was related to the near-field aqueous radionuclide transport through the backfill portion of the Engineered Barrier System. Potential impacts were bounded using total system performance assessment calculations of expected variations in the integrated radionuclide releases from the Engineered Barrier System compared with the variations in near-field transport that could occur due to increased water saturation.

Septic tank discharge in the sanitary sewage leach field was analyzed to identify a suitable location for the effluent discharge such that the infiltrating water and contaminants could not encroach the conceptual repository or other potentially usable areas for waste emplacement. In addition, the analysis considered potential impacts to the saturated zone, particularly with respect to the migration of contaminants into areas below potential waste emplacement locations. The analysis established the nearest location to the North Portal such that the leach field discharge is not expected to affect existing conditions near potential waste emplacement locations or impact performance as a result of changes along aqueous radionuclide pathways.

Forecast: Water use during the construction and operation of the ESF will continue to be evaluated. The surface water use analysis will be updated to improve its consistency with field observations and measurements. The underground water use evaluation will be reviewed in light of any improved analyses for water movement, waste package corrosion, radionuclide release, and radionuclide transport in the geosphere.

4.1.14 Design Activity 1.11.5.1 - Excavation Methods Criteria

The objective of this design activity is to identify any constraints to be placed on excavation because of postclosure performance considerations. The concern is to limit excavation induced changes to rock mass permeability.

The status of this work is essentially described in Progress Report #11. The only change was a minor change in one of the assumptions regarding the excavation method. The previous assumption was that all repository drift excavation would be performed by mechanical methods. That assumption has been changed to allow drill-and-blast excavation where mechanical excavation is not feasible (CRWMS M&O, 1995a). Progress Report #10 stated that blasting constraints would be developed only if further Advanced Conceptual Design studies indicated significant excavation by blasting will be required for repository development. Significant excavation by blasting is not expected to be required for repository development. Therefore, special blasting constraints need not be developed, and standard controlled blasting specifications are sufficient.

Forecast: Tracking of progress in equipment development by the Colorado School of Mines, as discussed in Progress Report #11, will continue throughout FY 1995.

4.1.15 Design Activity 1.11.5.2 - Long-Term Subsidence Control Strategy

The objective of this design activity is to evaluate the potential for postclosure surface subsidence and also the impact of ground movement in the vicinity of the excavations on waste containment and isolation.

No progress was made during the reporting period; this was an unfunded activity.

Forecast: Subsidence mechanisms and roof stability will be studied as part of thermomechanical and ground control studies to be performed during FY 1995. Reports on each are planned to be issued during the next reporting period (CRWMS, M&O, in prep.[h] and in prep.[i]).

4.1.16 Design Activity 1.11.6.1 - Thermal Loading for Underground Facility

The objective of this design activity is to establish the allowable thermal loading as a function of waste age and burnup. Determination will start with far-field calculations and consider near-field effects to ensure practical waste distribution exists that meet near-field constraints.

A proposal for a Program Thermal Strategy was developed that provided the steps needed to obtain sufficient information to make a thermal loading recommendation. On the basis of available information and analyses, the thermal effects in the mountain have been determined to be complex and will require in situ thermal testing to resolve a number of the issues. Thus, the proposed strategy recommends maintaining flexibility and provides a phased approach to obtaining the necessary information.

The proposed thermal loading strategy provides the basis for moving forward in light of the uncertainties about thermal effects on engineered and natural barrier performance. The goal of the strategy is to focus design activities on reference design thermal load of 80 to 100 MTU per acre as a working hypothesis. This loading allows emplacement of up to the statutory maximum of 70,000 MTU in less than the primary repository area of approximately 1,200 acres.

Risks associated with this strategy will be mitigated by maintaining design flexibility to accommodate higher and lower areal mass loadings and by pursuing a robust performance confirmation program. A lower loading would be appropriate if testing and modeling show that the negative aspects of heat dominate the performance of the natural system. A higher loading would be appropriate if testing and modeling show that the reference thermal load is not a high enough loading to produce a prolonged dry environment for the Engineered Barrier System, and that preclosure can continue to be met at a higher thermal loading. The highest areal mass loading to be considered for emplacement will be specified in the license application, as the Maximum Design Thermal Loading. The license application will focus on a single reference design thermal load with alternative thermal load options in case that loading does not perform as required by the regulations.

Using this strategy, the evaluation of Technical Site Suitability in 1998 will rely on evaluations of preclosure and postclosure performance of the repository system for the reference thermal load and the alternative areal mass loadings that are being carried as options. Similarly, the 2001 license application will present the design and performance assessment predictions for a repository system that will safely operate at the reference thermal load, as well as for the alternative loadings. For the license update to receive and emplace waste in 2008, DOE will present test data that demonstrate adequate understanding of thermal effects to justify initial waste emplacement and will further refine the long-term performance confirmation program. Results of this testing program, together with experience gained during operation of the repository, will provide the basis for the license amendment for repository closure and decommissioning.

Forecast: The thermal strategy will continue to be refined as it is implemented in the engineering, site, and regulatory areas. The goal is to remain flexible and modify the approach as test results are obtained, and refine supporting analyses.

4.1.17 Design Activity 1.11.6.2 - Borehole Spacing Strategy

The objective of this design activity as originally planned was to develop a strategy for the spacing of waste packages within the repository, which included spacing of the emplacement boreholes and of the drifts containing the emplacement boreholes. As stated in Progress Report #11, however, the Project has changed from emplacement of waste packages in boreholes to in-drift emplacement of waste packages. Thus, the objective now is to develop a strategy for the spacing of waste packages that includes spacing of the emplacement drifts and waste packages within the drifts.

This activity is closely related to Section 4.1.16 (Design Activity 1.11.6.1). The emphasis in Section 4.1.16, however, is on developing an overall repository thermal load and related goals and constraints, while the emphasis here is in developing the details to achieve the selected thermal load and meeting the established thermal goals and constraints. This activity is also related to the waste emplacement management concepts discussed in Sections 4.1.6 and 4.1.8.

As explained in Progress Report #11, emplacement drift spacing and waste package spacing are interdependent. For a given thermal loading, waste package and emplacement drift spacing are inversely related. A small waste package spacing and a large emplacement drift spacing can produce the same overall thermal loading as a large waste package spacing and small emplacement drift spacing. The temperatures on the surface of the waste package and in the rock mass, however, will not be the same for each.

A high thermal load requires both the drift spacing and waste package spacing to be small, thus allowing little ability to vary spacing. Thus, the relationship and consideration mentioned above are less important. The ability to vary spacings increases as thermal loading decreases, and much ability to vary exists at low thermal loads. Current studies are on layouts that meet the range of thermal loads currently identified as preferred and options.

Current studies are considering two basic strategies to maintain flexibility with regard to thermal loading. One concept places closely spaced waste packages in widely spaced (90 m) drifts; the second concept places more widely spaced waste packages in more closely spaced (45 m) drifts (CRWMS M&O, in prep.[f]). The first concept is being called "localized disturbance." Because of the close waste package spacing, above-boiling conditions and dryout zones would be created immediately surrounding the drift. The drifts would be far enough apart that the boiling fronts of adjacent drifts would not coalesce, thus allowing mobilized water to move downward in the sub-boiling region between the drifts. The second concept is being called "minimal disturbance" and represents an attempt to distribute the heat as evenly as possible to create the least disturbance to the host rock. The decision as to which concept is considered more desirable has not been made. Thermal modeling of these concepts has begun.

Both concepts are superimposed on a pattern of parallel drifts spaced 22.5 m on center. In the first concept, waste packages are placed in every fourth drift, and in the second concept, they are placed in every other drift. This allows flexibility to emplace at higher thermal loads if desired.

Forecast: Modeling of thermal load emplacement concepts will continue through FY 1995. A report on waste emplacement management is expected to be issued in June 1995 (CRWMS M&O, in prep.[f]).

4.1.18 Design Activity 1.11.6.3 - Sensitivity Studies

The objective of this design activity is to determine predicted repository thermal and thermomechanical response to variations in model input data. This information will be used to evaluate adequacy of data gathered and to determine that goals have been met with proper confidence.

These studies continued during the reporting period. The systems study being conducted to evaluate the thermal loading that should be selected for the underground facility has progressed. A summary of the recent efforts follows:

Systems studies were done with the main objective of providing input to the design of the testing program. A limited sensitivity analysis on selected parameters important to waste isolation and thermal loading was done to establish the influence of heat on performance. As a part of this ongoing sensitivity analysis, the effect of the multi-purpose canister on the system will be examined. This effort will provide recommendations that can be translated into requirements for testing and/or analysis to ensure that the program has a robust characterization program.

Various uncertainties were identified as important to understand and resolve so that performance could be better established, to support the thermal loading decision. On the basis of the analyses completed, it is clear that critical factors contributing to the hydrologic uncertainties need to be better understood. They include bulk permeability, fracture densities,

and percolation flux. More effort needs to be done to obtain verification of hydrothermal models and ultimately validate these models with some underground data. The waste package corrosion performance and impact of fuel variability must be understood. Reducing uncertainty associated with thermal goals and establishing how important a particular goal is will be needed. Some uncertainties in cost related to site characterization, construction, and operation concepts must be resolved. Finally, the site characterization program must address the extent of usable repository area. The useable area will dictate the capacity of the repository once the appropriate thermal load is determined (see Section 4.1.6).

Thermal management, which can include aging of the waste, ventilating the emplacement drifts, and selecting specific waste packages based on heat output, has been found to provide a certain amount of flexibility toward tailoring the thermal effects in the mountain, particularly for the preclosure period. To further evaluate some of these thermal management options, an effort to couple a ventilation code with a thermohydrologic code was initiated under the Thermal Loading System Study. The VTOUGH code is being coupled with a ventilation code. The resultant coupled code should be able to estimate the amount of sensible heat and moisture that can be removed from the mountain during the preclosure period. Initial runs have been started and the results should be forthcoming in the near future.

Forecast: The FY 1995 Thermal Loading System Study will concentrate on identifying site related parameters that impact performance assessments and will recommend testing that can be used to help focus the testing program.

4.1.19 Design Activity 1.11.6.4 - Strategy for Containment Enhancement

The objective of this design activity is to document how design of the underground facility has taken into account containment, especially keeping the containers dry for 300 yr. The SCP suggested that temperatures around the edges of the underground facility will not be as high as in the middle. Therefore, decreasing the waste package spacing around the edges of the underground facility to increase the temperatures there should be considered.

Thermal studies performed to date show this "edge effect" is a long-term phenomena, taking 300 yr or so to develop. The edge effect is a significant consideration at a high thermal load. Its relevance at lower thermal load depends on whether the localized disturbance or minimal disturbance concept described in Section 4.1.17 (Design Activity 1.11.6.2) is selected. The effect does not apply to the minimal disturbance concept but may apply to the localized disturbance concept. For any thermal load, reducing the waste package spacing around the repository edges may cause higher short-term local temperatures. This result has not been fully demonstrated in studies to date, and its significance has not been evaluated. The edge effect is being considered as part of current waste emplacement management studies. Other aspects of these studies are mentioned in Sections 4.1.6 and 4.1.17.

The waste package containment lifetime also depends on waste package design and materials selection. Significant increases in containment lifetime are expected from past

changes in the design. The SCP described thin-walled containers of austenitic stainless steel, whereas current plans are to use a multibarrier container with both corrosion-resistant and corrosion-allowance barriers and a much greater total thickness. The selection of materials to provide long containment is discussed in Section 5.1.4 under Activity 1.10.2.4.1.

Forecast: The edge effect will continue to be considered as part of waste emplacement management studies, and will be discussed in a report to be issued during FY 1995. (CRWMS M&O, in prep.[f]).

4.1.20 Design Activity 1.11.6.5 - Reference Calculations

The objective of this design activity is to provide a set of calculations, documenting predictions of postclosure thermal and thermomechanical response of the host rock, which may be used to address performance assessment issues. Thermal and thermomechanical response analyses performed to satisfy this design activity can be divided into near-field and far-field analyses; the near-field analyses can be further divided into container scale analyses and drift scale analyses.

Container scale deals with rock behavior in the immediate vicinity of the waste package and its effect on the waste package. This portion of the analysis was originally intended to focus on the stability of the boreholes in which the waste packages were to be placed. With a change to in-drift emplacement by the Project, as explained in Progress Report #11, however, borehole stability is no longer a concern, and the canister scale analysis will now focus on effects of backfill on waste packages.

With the change to in-drift waste package emplacement, drift scale analyses, to the extent that backfill is considered, overlap some with the container scale analyses. This analysis deals with postclosure behavior of the rock in the immediate vicinity of the emplacement drift and the potential for that rock to move or collapse and develop new paths for radionuclides to reach the accessible environment.

No studies specifically addressing the near-field aspects of this activity were funded during the period. The only work related was a slight change in the Project assumption regarding backfill. It is still assumed that backfill will not be used in emplacement drifts, but the emplacement design now must not preclude the option to backfill (CRWMS M&O, 1995a).

Waste package thermal analyses include calculations of repository and emplacement drift temperatures. This work is reported in Section 5.1.3 under Activity 1.10.2.3.1.

Far-field analyses deal with the far-field performance of the repository. This mostly involves thermal response of the rock mass and the effect of temperature on rock joints. Studies regarding temperature distribution in the rock as caused by various repository thermal loads are relevant to this activity. Scoping studies for the Total System Performance Assessment are also relevant.

Forecast: Near-field thermal and thermomechanical studies of drift temperature and stability will be conducted during FY 1995, and reports will be issued (CRWMS M&O, in prep.[h],[i],[j]).

4.1.21 Design Activity 1.11.7.1 - Reference Postclosure Repository Design

The objective of this design activity is to establish what information will constitute the reference postclosure design for use in performance assessment and document this information in the Advanced Conceptual Design and License Application Design reports.

Advanced Conceptual Design for the repository continued with the "focused" Advanced Conceptual Design approach being fully implemented. In addition, two documents regarding the reference Postclosure Repository Design were published. The first document (CRWMS M&O, 1995a) contains a compilation of assumptions related to requirements, technical data, and design concepts which were necessary to facilitate the design process. The document also contains a list of repository/waste package functions and a first draft of a repository operations concept. The second document (CRWMS M&O, 1994f) contains a summary of the waste package and repository design concepts as they currently exist. The waste package design is nearing the end of Advanced Conceptual Design and the repository is in the very early stages of Advanced Conceptual Design. As the designs progress they will be documented in the Interim Advanced Conceptual Design Summary Report followed by the Final Advanced Conceptual Design Summary Report.

Forecast: The design effort will continue on the basis of horizontal in-drift emplacement of large waste packages.

4.1.22 Design Activity 1.11.7.2 - Documentation of Compliance

The objective of this design activity is to document that the issue has been resolved by determining if the postclosure design complies with the design goals of this issue and to document this compliance in the Advanced Conceptual Design and License Application Design reports. This activity draws from the results of many other activities.

Advanced Conceptual Design of the repository continued following the focused approach described in Progress Report #11. The Controlled Design Assumptions Document (CRWMS M&O, 1995a) was updated. The update consisted of consolidating and revising previous assumptions, creating new assumptions, revising and expanding the list of repository/waste package functions, and expanding the repository concept of operations.

Regulatory requirements for the waste package include containment during handling and emplacement, substantially complete containment after emplacement but during the containment period, and control of criticality. Progress has continued in these areas. Descriptions of the work are given in Sections 5.1.3 and 5.1.4.

As the designs progress, they will be documented in the interim and final Advanced Conceptual Design summary reports.

Forecast: The design effort will continue through FY 1995. Writing the summary reports is an out-year activity.

4.2 REPOSITORY DESIGN CRITERIA FOR RADIOLOGICAL SAFETY (SCP 8.3.2.3)

4.2.1 Design Activity 2.7.1.1 - Design Evaluation for Compliance with Radiological Safety Design Criteria and Performance Goals

The objective of this design activity is to evaluate the repository design against the radiological safety design criteria and performance goals at each phase of the design and provide feedback to the designers on needed corrections or modifications.

Among the specific objectives for this issue are performance goals for limiting the concentration of naturally occurring radon, for shielding properties of the host rock, and for limiting releases of radioactive materials based on eventual exposure of the workers and public.

Evaluating the repository design against radiological safety and performance goals was not funded during the period, but radiological design criteria are being considered during design. Design concepts to achieve worker radiological safety underground include (a) separating the emplacement and development areas, including their respective ventilation systems; (b) transporting the waste package inside of a cask shielded to stand-alongside radiation levels; (c) moving the waste packages into the emplacement drifts using remote control methods; (d) placing shielding doors over the entrances to emplacement drifts; and (e) excluding personnel from emplacement drifts containing waste packages. Some of these have been mentioned in other sections of this report.

Forecast: The following will be initiated during the next reporting period: identification and evaluation of radiological conditions, identification of radiological hazards for subsurface activities, outline of special radiological equipment design needs, description of special structural requirements for shielding, and evaluation of radiological impacts of off-normal situations.

4.3 NONRADIOLOGICAL HEALTH AND SAFETY (SCP SECTION 8.3.2.4)

4.3.1 Design Activity 8.3.2.4.1.1 - Design Activity to Verify Access and Drift Usability

The methods used to develop the conceptual design of the repository were based on preliminary data. The ESF offers an opportunity to verify these design activities and to substantiate or provide the basis for adjustment of the design techniques used. The extent of

the ESF is sufficient to ensure that the demonstrated design techniques, the data obtained, and the test results will generally be applicable throughout the subsurface facilities with only minor modifications.

A second set of analyses of the 2C section of the North Ramp was completed and transmitted to YMSCO. The analyses examined the impacts of in situ, thermal, and seismic loading on the stability of the North Ramp. In addition, large-scale body effects were identified that may have performance assessment implications. Specifically, large zones of tension and compression were predicted that may impact hydrologic flow paths. These results are currently being evaluated.

Forecast: A strategy and planning document for development of the scientific basis for design is planned to be developed. The document will outline a basis strategy, identify specific activities that contribute to development of the scientific basis for design, and show how these activities should be phased with the repository design activities needed to support a recommendation for Technical Site Suitability and for License Application.

Several design assumptions identified in the Controlled Design Assumptions Document will be substantiated through the consolidation of existing data and through making data readily accessible to Project participants. Specific areas that will be substantiated include those of rock mass thermal expansion coefficient, rock mass quality indices, and rock mass deformation moduli. Activities will focus on the substantiation needs concerning mechanical data in the technical data section of the Controlled Design Assumptions Document.

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

Studies are required to assess the impact of site characteristics on the ventilation requirements necessary to provide a safe working environment. Site characteristics will determine dust quantities produced during construction, in situ gas types and quantities, and the wall roughness required for the ventilation flow calculations.

During construction of the ESF, the influence of the construction method on dust generation and dust control methods can be evaluated. Similarly, the value of drift roughness used for the determination of delivery of sufficient air to the working areas of the repository, can be verified based on the construction method, the rock quality, and the support system used in the ESF construction.

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

Forecast: No activity is planned for FY 1995.

4.4 PRECLOSURE DESIGN AND TECHNICAL FEASIBILITY (SCP SECTION 8.3.2.5)

4.4.1 Design Activity 4.4.3.1 - Operations Plan to Accompany the Advanced Conceptual Design

The objective of this design activity is to produce an operations plan to accompany the Advanced Conceptual Design.

A draft Concept of Operations for the Mined Geologic Disposal System is in the revised Controlled Design Assumptions Document (CRWMS M&O, 1995a), but it will be made a stand-alone document. The Concept of Operations covers the period beginning with receipt of waste at the Mined Geologic Disposal System through establishment of postclosure institutional barriers. It describes, at a level of detail appropriate to Advanced Conceptual Design, all Mined Geologic Disposal System operations in the following major categories: surface operations, subsurface operations, system performance evaluation, Mined Geologic Disposal System support operations, and permanent closure. Some of the operational concepts are listed in the Controlled Design Assumptions Document as assumptions to be substantiated.

Forecast: The Concept of Operations will be updated as the Advanced Conceptual Design is further developed during FY 1995.

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

The objective of this design activity is to produce an operations plan to accompany the License Application Design.

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

Forecast: No activity is planned for FY 1995.

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

The objective of this design activity is to develop the design requirements for the repository for use in the License Application Design.

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

Forecast: No activity is planned for FY 1995.

..ARACTERISTICS (SCP SECTION 8.3.3.2)

ɔtudy 1.12.2.1 - Seal Material Properties Development

The Yucca Mountain sealing program concentrates on cementitious and earthen materials emplaced in shafts, ramps, boreholes, and underground openings for the proposed repository. The strategy for sealing the proposed repository is to place seals in the shafts, ramps, and boreholes so that they do not act as potential pathways for flow and to provide seals in selected underground openings to control water flow within the repository. Current efforts are focused on in situ and laboratory testing of cementitious seal components planned for used in sealing exploratory boreholes at Yucca Mountain. Potential sealing locations include nonwelded Topopah Spring Tuff and the Calico Hills nonwelded tuff.

The issue of primary importance for borehole sealing is seal material performance, both short term and long term. Seal performance is related to the emplacement technique(s), as well as the durability (mechanical, geochemical) of the emplaced seals. Laboratory testing is under way to evaluate cementitious seal performance under a range of environmental conditions. The cementitious seal materials include Portland-based cements identified in Licastro et al., (1990), which are expected to be geochemically stable in the host rocks at Yucca Mountain. Plans are being developed for a series of shallow in situ experiments near Yucca Mountain to evaluate the strategy for sealing exploratory boreholes at Yucca Mountain (Fernandez et al., 1994).

Activities 1.12.2.1.1 and 1.12.2.1.2. Preliminary laboratory experiments are under way to evaluate the performance of Portland and gypsum-based cementitious sealing materials. Rheologic properties of the viscous grouts and mechanical and fluid flow properties of the hardened grouts are being evaluated. In addition, prototypical lab tests in small-scale seals emplaced in 6-in- (15-cm) diameter cores of Topopah Spring Tuff with a central co-axial hole (for seal emplacement) are under way. These tests will provide critical information for in situ test design, as well as guide future laboratory efforts.

Forecast: Laboratory tests in candidate cementitious sealing materials will continue throughout FY 1995. Testing will focus on the mechanical and fluid flow performance of Portland-based and gypsum-based cements emplaced in small-diameter co-axial holes in 6-in- (15-cm) diameter cores of TSw2. These tests will include push-out tests of hardened cements to evaluate interface shear strength between seal and rock as well as gas and water permeability tests on intact and sheared seal plugs. Durability testing of hardened seal plugs is also planned; however, the actual tests (which may include heat and wetting and drying) will probably begin in FY 1996.

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

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

Forecast: No activity is planned for FY 1995.

4.5.3 Study 1.12.2.3 - In Situ Testing of Seal Components

Study Plan 8.3.3.2.2.1, "In Situ Testing of Seal Components" provides the control for this work. Pretest planning and preparation are under way so that preliminary estimates of in situ seals performance can be made. These tests will represent the first evaluation of the strategy for sealing exploratory boreholes at Yucca Mountain. A potential surface test site is being identified. Two types of tuff are currently being investigated: the densely welded Topopah Spring welded tuff (TSw2) and the nonwelded Paintbrush unit (PTn). A tentative site near Fran Ridge has been identified for the TSw2 tests. Site selection activities for the nonwelded Paintbrush unit are ongoing. These shallow-surface-based tests can be used to evaluate initial seal performance using typical emplacement techniques, as well as provide a test-bed to begin evaluating of the durability of the seals. Seals are planned to be routinely tested to evaluate potential deterioration of seal performance through time. Because the emplaced seals will be shallow [< 20 ft (6 m)], they can be overcored at time intervals for laboratory tests to evaluate geochemistry changes of the seal materials.

Forecast: Pretest planning and preparation for in situ borehole sealing tests will be completed in FY 1995. This includes completing of site selection activities for the nonwelded Paintbrush unit tests. All necessary documentation, including criteria letters and job packages, will be completed.

4.5.4 Design Activity 1.12.4.1 - Development of the Advanced Conceptual Design for Sealing

Design Subactivity 1.12.4.1.1 - Define subsystem design requirements. The objective of this design subactivity is to develop design requirements that will assist the designer in the development of sealing components.

Work is under way to support the Advanced Conceptual Design for sealing. This input is primarily aimed at evaluating the design assumptions and repository design concepts in light of the sealing requirements and concepts outlined in the SCP and by Fernandez et al. (1987). Designs for sealing will be finalized after in situ testing has been completed.

Design Subactivity 1.12.4.1.2 - Perform trade-off studies to support advanced conceptual design development. The objective of this design subactivity is to provide technical justification for the selection of specific design options.

No progress was made during the reporting period; this was an unfunded activity.

Design Subactivity 1.12.4.1.3 - Develop advanced conceptual design for seals. The objective of this design subactivity is to provide design details during Advanced Conceptual

Design that can be used to develop the License Application Design and to support the performance assessment activities.

No progress was made during the reporting period; this was an unfunded activity.

Forecast: The evaluation of design assumptions relative to sealing will be completed.

4.5.5 Design Activity 1.12.4.2 - Development of the License Application Design for Sealing

Design Subactivity 1.12.4.2.1 - Define subsystem design requirements The objective of this design subactivity is to refine design requirements that will assist in the development of sealing components for the License Application Design.

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

Design Subactivity 1.12.4.2.2 - Perform trade-off studies to support license application design development The objective of this design subactivity is to provide technical justification for the selection of the final seal designs.

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

Design Subactivity 1.12.4.2.3 - Develop license application design for seals The objective of this design subactivity is to provide the License Application Design for seals.

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

Forecast: No activity is planned for FY 1995

CHAPTER 5 - WASTE PACKAGE

The waste package consists of the waste form (spent nuclear fuel or high-level waste glass), possibly a multi-purpose canister, and a disposal container. The waste package program includes the development of waste package design bases, design analysis, materials testing and modeling, development of a reference design, waste form testing and modeling, and characterization of the waste package emplacement environment. Progress in the waste package program is described in this section.

5.1 WASTE PACKAGE DESIGN (SCP SECTION 8.3.4.2)

5.1.1 Design Activity 1.10.2.1 - Concept Development

Significant progress was made in integrating the design efforts for the multi-purpose canister and its disposal container. Five design analyses have been prepared or are being prepared that consider the requirements that the Mined Geologic Disposal System places on the multi-purpose canister to ensure that it will be compatible with disposal. The analyses were prepared in accordance with applicable Quality Administrative Procedures. The subjects of the analyses are weight, dimensional envelope, and configuration (CRWMS M&O, 1995), dryness of the multi-purpose canister cavity and composition of fill gas (CRWMS M&O, 1995), access for addition of filler materials (CRWMS M&O, in prep.), criticality control (CRWMS M&O, in prep.), and materials (CRWMS M&O, in prep.). Several of these analyses are discussed in more detail in the following sections. The process of comment resolution on these analyses has significantly clarified the interface between multi-purpose canister design and disposal container design.

A major upcoming deliverable is the Waste Package Conceptual Design Report (CRWMS M&O, in prep.). This report will summarize progress in waste package development for all Advanced Conceptual Design, and its publication will mark the end of that design phase. Because of its broad scope, the report is already being prepared and drafts of several sections have been written.

Activity 1.10.2.1.1 - Advanced Conceptual Design concepts. The three previously reported concepts for multibarrier disposal containers are still in use. But because both low and high thermal loads are now being considered, effort has been made to consider a disposal container that is suitable for a low thermal load. A low thermal load is expected to impose greater requirements for corrosion resistance on the disposal container because the environment is expected to be humid, whereas for a high thermal load a dry environment is expected based on currently unverified modeling predictions. One approach to providing additional corrosion resistance is to add a third metallic barrier, but it is not clear whether three barriers are necessary or sufficient.

Activity 1.10.2.1.2 - Design basis fuel. The design basis fuel analyses reported in the previous two progress reports (DOE, 1994c; DOE, 1995m) have been modified and extended with the following features:

- Thermal statistics (percentiles) are taken with respect to heat per assembly, rather than heat per MTU
- Design basis fuel is now extended to boiling water reactor fuel. (Such fuel was omitted previously because it is generally less stressing than pressurized water reactor fuel and because a parameterization for criticality of boiling water reactor fuel is not available yet)
- A 10 yr age is used throughout, for consistency.

Percentiles are computed with respect to performance parameters based on the scenario of receiving the oldest fuel first. Details of the calculations will be given in a design analysis (CRWMS M&O, in prep.).

Recommended pressurized water reactor design basis fuel. A heat output of 800 watts per assembly was chosen for the thermal/shielding design basis. This is more stressing than that specified for the multi-purpose canister because a larger coverage was desired. This heat output can be produced by a range of values of age, burnup, and initial enrichment. For a given heat, the older fuel will have higher burnup, and will decay more slowly (giving a higher integrated heat over the repository life); therefore, the more conservative design basis would have the older fuel at the higher burnup. Most of the hot fuel, however, will be close to 10 yr in age, and so the older fuel is not very representative. Therefore, an age of 10 yr was used. The burnup giving 800 watts per assembly at this age is expected to be somewhat less than 50 GWd/MTU so an initial enrichment of 4.2 percent was chosen. This is slightly less than the average initial enrichment in the characteristics data base for 50 GWd/MTU. For an age of 10 yr and an initial enrichment of 4.2 percent, the characteristics data base indicates that 48.086 GWd/MTU burnup will give 800 watts per assembly.

For the criticality design basis, the fuel characteristics are an age of 10 yr, a burnup of 20 GWd/MTU, and an initial enrichment of 3 percent. This design point was selected from the range of values giving the target $k_\infty = 1.13$, where k_∞ is the neutron multiplication factor for an infinite system. The burnup was chosen so that the enrichment which gives $k_\infty = 1.13$ falls in middle of the range of actual enrichment values for fuel having that burnup (20 GWd/MTU).

These design basis recommendations are summarized in the following table.

Table 5-1.
Recommended Pressurized Water Reactor Design Basis Fuel,
for 93 percent Combined Coverage

Parameter	Thermal/shielding	Criticality
Burnup	48.086 GWd/MTU	20.000 GWd/MTU
Initial enrichment	4.2%	3%
Age	10 yr	10 yr
Oldest-Fuel First Coverage (93.1%)[a]	94.3%	97.6%

a. These figures refer to the parameters heat per assembly, and k_∞ ; they *do not* refer to burnup and initial enrichment.

Recommended boiling water reactor design basis fuel. The thermal requirement for boiling water reactor fuel is much less stressing than that for pressurized water reactor fuel. Computations indicate that the boiling water reactor fuel that would be thermally equivalent to the pressurized water reactor design basis fuel as follows:

1. The total heat for a waste package with 21 pressurized water reactor assemblies at 850 watts each is 17.85 kW; to get the same amount of heat from a package with 40 boiling water reactor assemblies would require over 400 watts per assembly, which is greater than any of the boiling water reactor fuel in the oldest-fuel-first scenario.

2. The largest boiling water reactor burnup in the characteristics data base is 49 GWd/MTU; that burnup, however, gives only 388 watts per assembly at 10 yr after discharge; 49 GWd/MTU is used for the thermal design basis, simply because it is the largest burnup in the data base for boiling water reactor fuel, even though it does not give as high a heat per package as the pressurized water reactor thermal design basis fuel. The boiling water reactor fuel simply cannot be as stressing as the pressurized water reactor thermal design basis fuel.

Although the criticality control requirement for boiling water reactor fuel is generally expected to be less stressing than that for pressurized water reactor fuel, a design basis fuel must nevertheless be chosen so that waste package designs can be evaluated. The approach used for pressurized water reactor fuel cannot be used because a parameterization for the reactivity of boiling water reactor fuel is not available yet. Until such a formula is developed, the boiling water reactor criticality design basis fuel will be as close to the corresponding pressurized water reactor fuel as is appropriate. If the age and initial enrichment are taken to be the same as those for the pressurized water reactor design basis fuel (10 yr and 3 percent), the smallest burnup that can be found in the characteristics data base is 21 GWd/MTU, and so

that figure will be used. The fraction of boiling water reactor fuel covered by these parameters can be estimated as follows.

For a criticality design point specified by age, burnup, and initial enrichment, all the fuel having higher enrichment and lower burnup will have a higher k_∞, and higher effective neutron multiplication factor k_{eff}. But higher values of k_{eff} can occur either at higher enrichments and higher burnups or at lower enrichments and lower burnups. To estimate the actual fraction of boiling water reactor fuel not covered, an analogy with pressurized water reactor fuel is used.

For pressurized water reactor fuel with 20 GWd/MTU and 3 percent initial enrichment, 2.4 percent of the fuel will have a higher k_∞. From tabulated statistics in the referenced analysis, 1.26 percent of pressurized water reactor fuel is found to have a higher enrichment and lower burnup. Thus, the ratio of the amount of fuel having a higher k_∞ to the amount having a higher enrichment and lower burnup is 1.9. The design analysis also shows that 2.23 percent of boiling water reactor fuel will have higher enrichment and lower burnup than the design basis fuel (21 GWd/MTU and 3 percent initial enrichment). By using the ratio above, it is estimated that 2.23 percent × 1.9 = 4.2 percent of the fuel that will have higher k_∞ than that for the design basis fuel, so this design basis fuel will be more stressing, with respect to criticality, than 95.8 percent of the fuel. Since the thermal/ shielding design basis covers 100 percent of the boiling water reactor fuel, the combined coverage is the same as the criticality coverage. These parameters are summarized in the following table.

Table 5-2.
Recommended Boiling Water Reactor Design Basis Fuel
(approximately 96 percent combined coverage)

Parameter	Thermal/shielding	Criticality
Burnup	49 GWd/MTU	21 GWd/MTU
Initial enrichment	3.74%	3.0%
Age	10 yr	10 yr
Oldest-Fuel First Coverage (95.8%)	100%	95.8%

Forecast: The design analyses on multi-purpose canister requirements currently being prepared will be completed. Waste package Advanced Conceptual Design will be completed, and the Waste Package Conceptual Design Report issued.

5.1.2 Design Activity 1.10.2.2 - Design Tools

The design and analysis programs for which verification and validation were reported previously are still in use. Work has begun on verification and validation of SCALE (Standardized Computer Analyses for Licensing Evaluation), a comprehensive set of programs for shielding, criticality, burnup, and related analyses.

Forecast: The verification and validation of SCALE will be completed during the next reporting period.

5.1.3 Design Activity 1.10.2.3 - Design Evaluations

Activity 1.10.2.3.1 - Thermal. The focus of the thermal design efforts has been on four main areas: (1) evaluation of the repository and emplacement drift thermal behavior and its effect on waste packages, (2) evaluation of waste package thermal conditions with regard to meeting the required licensing requirements, (3) benchmarking spent nuclear fuel effective conductivity models against experimental data to ensure that the peak cladding temperatures are predicted accurately, and (4) generating evaluations and sections of the Waste Package Conceptual Design Report (CRWMS M&O, in prep.[o]). The Program Plan (DOE, 1994a) affects this work heavily with regard to generating different repository thermal load requirements and waste package spacing/loading requirements, and determining whether the waste package designs will meet the licensing requirements. A change in the Program Plan concerning the spent nuclear fuel receipt requirements, repository thermal loading, or acceptance of a specific transportation package can result in new thermal evaluations to ensure that all Mined Geologic Disposal System and licensing requirements will be met for the new plan.

The thermal evaluation can be divided into three parts: (1) an analysis of the repository and emplacement drift temperatures, (2) an analysis of the internal waste package temperatures, and (3) an analysis of peak cladding temperatures. Each analysis provides information to the next analysis. Three sets of finite element models were generated to represent the repository, the waste package, and a spent nuclear fuel assembly.

A set of three-dimensional finite element models of the repository was constructed to determine near-field thermal behavior for a high and three low thermal loading scenarios. The high thermal loading scenario assumed a repository loading of 20.5 kg U/m^2 (83 MTU/acre). The three low thermal loading scenarios maintained a 6.18 kg U/m^2 (25 MTU/acre) loading but investigated the effects of various waste package spacings and drift spacings. At a high thermal loading, waste package surfaces were maintained above the boiling point for more than 1,000 yr. At low thermal loadings, near-field temperatures were significantly different between large and small waste package spacings at the same areal mass loading. Larger waste package spacings result in a larger heat sink area and lower near-field temperatures. Because of the importance of the first few years to the fuel cladding temperature, a minimum waste package spacing for a given waste package capacity and thermal output could be derived that is otherwise independent of thermal loading.

Specific finite element models were constructed for multi-purpose canisters with capacities of 12 and 21 pressurized water reactor assemblies and 24 and 40 boiling water reactor assemblies. Each of the models is based on the Multi-Purpose Canister Conceptual Design Report (CRWMS M&O, 1994). Individual vendor designs will be evaluated in the future to ensure that the Mined Geologic Disposal System licensing requirements are met. Each of these models was evaluated for each of the four repository thermal loading scenarios. Three pressurized water reactor and one boiling water reactor design basis fuel types were examined for each scenario. Results for waste package performance and peak cladding temperatures indicate that the multi-purpose canister conceptual designs are compatible with the Mined Geologic Disposal System thermal requirements. Peak cladding temperatures were evaluated with both the effective thermal conductivity model and the Wooton-Epstein correlation.

A key thermal goal for waste package design is the 350°C cladding temperature limit. Peak cladding temperatures in the waste package can be determined by assuming an effective conductivity in the waste package model, applying the Wooton-Epstein correlation, or using a finite element model that represents a spent nuclear fuel assembly in the waste package. A finite element model of an assembly was constructed to (a) benchmark the model against dry storage cask experiments that provide experimental data for cask container, basket, and spent fuel cladding temperatures and (b) develop a better smeared/homogeneous effective conductivity. The benchmark calculations indicate that using the Wooton-Epstein correlation is conservative. The improved thermal conductivity model based upon the experimental data provides a sound basis for a conservative best estimate of peak cladding temperatures.

Over-prediction of spent nuclear fuel cladding temperatures caused by excessive conservatism can constrain waste package design and limit capacity. While the results of the experimental data benchmarks for effective conductivity model are preliminary, the test cases indicate that the effective thermal conductivity model for spent nuclear fuel is more accurate than other approaches. Further, the calculated effective thermal conductivities were primarily a function of temperature. Dependable smeared properties for spent nuclear fuel could be used in the waste package thermal model to predict cladding temperatures and simplify waste package thermal analyses so that only two models are needed.

Activity 1.10.2.3.2 - Structural. Structural analyses include preliminary analyses of the effects of a rock drop onto a drift-emplaced waste package and drops of waste packages onto unyielding surfaces. The results of these analyses will be reported in the Waste Package Conceptual Design Report (CRWMS M&O, in prep.[o]).

Rock Drop Analyses

A three-dimensional finite-element model of a multibarrier waste package for uncanistered fuel was developed to explore the resistance of such a waste package to rock falls. The particular waste package modeled had an interlocking basket and a capacity of 12 pressurized water reactor assemblies. The model includes the outer barrier, inner barrier, and the basket assembly. The orientation of the waste package for the drop was with the

basket members at 45 degrees to vertical. This orientation gave the highest stresses in the barriers during the rock drop.

In the analysis, it was conservatively assumed that all the kinetic energy of the falling rock is imparted to the waste package as mechanical energy. Thus, no energy is absorbed by shattering of the rock, and the deflection of the rock is negligible compared with the deflection of the waste package. Another important assumption is the modeling of the impacting rock as a sphere. This geometry was selected because the impact of a sphere will result in a broad distribution of stress onto the waste package, whereas with a sharp wedge geometry, the pointed region of the rock would deform because of the high stress concentration at the impact point.

The elastic-plastic response of the waste package was determined for three drop heights corresponding to the starter tunnel, ESF tunnel, and emplacement drift tunnel sizes. The highest of these drops is that for the starter tunnel, 8.4 m. Preliminary results indicate that this waste package can withstand the impact of a 19,100 kg rock falling from this height without the breaching of any barriers.

Correlations were developed to determine the responses of multi-purpose canisters with disposal containers to rock falls, and the results will be reported in the Waste Package Conceptual Design Report. The distance of the rock fall depends on waste package size because the drop height is calculated as the difference between the height of the tunnel and the height of the top of the waste package when stored on its side. Using the correlations to the preliminary analysis, it has been determined that for drops in the starter tunnel, the minimum rock masses that could fail the waste packages could withstand are as follows:

Waste Package Capacity	Minimum Rock Mass
21 pressurized water reactor assemblies	≈ 31,600 kg
40 boiling water reactor assemblies	≈ 33,100 kg
24 boiling water reactor assemblies	≈ 25,200 kg
12 pressurized water reactor assemblies	≈ 24,800 kg

Waste Package Drop Analyses

One of the accident conditions that the waste package must be able to withstand is a drop of the waste package itself. The most damaging drop scenario is a corner drop, which is composed of two separate drop events: initial impact and slap down. For waste package impact angles near vertical, the initial impact dominates and the waste package response resembles the end drop condition. For impact angles near horizontal, the slap down phase dominates, and the assembly response resembles the side drop condition.

Two waste package models have been created to analyze the waste package drop accidents. The waste packages modeled are (a) a multi-purpose canister with 21 pressurized

water reactor assemblies in a disposal container and (b) a multi-purpose canister with 24 boiling water reactor assemblies in a disposal container. In the corner drops analyzed, the center of mass of the waste package was directly above the point of impact. In each instance, this resembles the end drop condition and results in the largest deformation pattern on the barrier. Thus, the effect of second impact on the opposite side of the waste package will not be as severe as that of the first. The slap down case was analyzed separately.

A one-half symmetry three-dimensional finite-element model was developed for each waste package. The analysis includes the basket assembly, fuel assembly weight, multi-purpose canister shell, and disposal container. Elastic and plastic properties of each material are considered as inputs to the finite-element analysis. Taking advantage of the symmetry reduces the model size, allowing more detail in the half that is modeled. Some minor simplifications, however, such as closing the gap between the disposal container and multi-purpose canister shell to provide element connectivity and applying the fuel load by increasing the basket density, were still required to control run times and output file size.

The skirt on the outer barrier works as an impact limiter during the 2-m corner drop. Sharp curvature bending of the impacted corner is the reason for very high stresses, which may result in ductile rupture. Failure is expected in this part of the disposal container. Preliminary analysis indicates that the maximum principal stress in the skirt is greater than the ultimate tensile stress of the outer barrier material; so it can be concluded that there is a localized material breach around the region of impact in the skirt. The analysis concludes that a 2-m drop will cause ductile rupture of the skirt, but neither breaching of the outer barrier nor yielding of the basket will occur for either type of waste package.

For impact angles near horizontal, the slap down phase dominates and the response resembles that for a side drop. The hypothetical slap down accident analyzed here is that of a waste package striking a flat, essentially unyielding horizontal surface in a position for maximum expected damage. The waste package models described above were used again in this analysis. The geometry was the same, but the starting orientation was changed. In each model, the waste package is initially in contact with the unyielding surface and is constrained at the point of contact, allowing rotation only. The angle of the waste package with respect to vertical was chosen so the waste package will overturn.

The results indicate that the maximum compressive stress is located near the end of the waste package away from the initial contact point. The maximum tensile stress is near the maximum compressive stress, but away from the line of impact. The maximum tensile stress is less than the ultimate tensile stress of the outer barrier material, so it can be concluded that slap down will not result in a breach of the outer barrier. Analysis of the basket loads is in progress for the waste package with 21 pressurized water reactor assemblies, as is analysis of both shell and basket for the waste package with 24 boiling water reactor assemblies.

The other types of multi-purpose canister in their respective disposal containers were not modeled because their behavior would be nearly identical. The only difference in waste packages of the same weight classification, 125 ton or 75 ton, is the mass of the multi-purpose canister. The differences in mass are small, and, according to conservation of energy

calculations for impact, the impact forces will vary less than 1 percent between the two, 125-ton waste packages and less than 1.5 percent between the two, 75-ton waste packages.

Activity 1.10.2.3.3 - Criticality. The neutronics activities performed during this reporting period have included work in the following areas: supporting the burnup credit effort, writing the disposal criticality analysis reports, supporting evaluations of the multi-purpose canister, writing the multi-purpose canister section of the Waste Package Conceptual Design Report, preparing for the start of License Application Design, developing a fault tree and probabilistic risk analysis for a criticality event, and other supporting efforts concerning neutronics issues for disposal. The work performed in each of these areas is discussed below in more detail.

Supporting the efforts to obtain burnup credit has remained a major activity in this reporting period. Mined Geologic Disposal System Development has supported Waste Acceptance Storage and Transportation in preparing the Burnup Credit Topical Report. Mined Geologic Disposal System Development provided the information needs on isotopic data for disposal burnup credit, for incorporation into the overall test plan being managed by Waste Acceptance Storage and Transportation. Many of the isotopes that are important for burnup credit during storage and transportation are also important for disposal. Some major tasks were started to refine the methodology for disposal criticality control using burnup credit.

Preparation of the disposal criticality analysis reports--started during the reporting period--is a large effort that will take several years. The Disposal Criticality Analysis Topical Report will present the methodology for performing disposal criticality analysis (including the use of burnup credit) for any fissile waste form, waste package design, and proposed repository. The report is to be released late in FY 1999 and will contain a great deal of supporting data. The Disposal Criticality Analysis Technical Report will contain the same methodology as the topical report, but will not contain the supporting data, and will be released late in FY 1996. The technical document preparation plan for the topical report was prepared.

A white paper was written comparing the use of neutron absorbers in panels and rods for criticality control in the multi-purpose canister. A design analysis was created that gives the Mined Geologic Disposal System "specific long-term criticality control requirement," to support the updating of the multi-purpose canister subsystem design procurement specification. The Mined Geologic Disposal System and Waste Acceptance Storage and Transportation worked together on integrating the multi-purpose canister and disposal container design plans. Mined Geologic Disposal System Development has been creating various contingency plans and options in case vendor-supplied multi-purpose canisters are later found unacceptable for disposal.

The neutronics subsection of the multi-purpose canister section of the Waste Package Conceptual Design Report was written. This section contains the previously reported results for the multi-purpose canister conceptual design, as well as additional analyses for the multi-purpose canister conceptual designs. The results reported include the standard criticality and

radiation shielding performance of the four standard multi-purpose canister conceptual designs (125 ton and 75 ton sizes, configured for pressurized water reactor and boiling water reactor fuel) plus special evaluations of the effectiveness of filler material in multi-purpose canisters, the effectiveness of disposable control rods in multi-purpose canisters, and the effects of replacing the aluminum-boron alloy criticality control materials with zirconium alloys containing hafnium.

In anticipation of finishing the Waste Package Conceptual Design Report, and concluding the waste package Advanced Conceptual Design activities, preparations have been under way to start the initial License Application Design activities. The initial activities consisted of preparing qualified design analyses for candidate material properties, formally qualifying additional computer codes, establishing what exact fuel assembly types to expect from the reactor sites that are unable to use multi-purpose canisters, and supplying input into the Mined Geologic Disposal System licensing strategy document.

Fault tree analysis focused on the three basic initiating events capable of introducing water into the local drift environment in a manner that could create the conditions necessary for a waste package criticality, and on the principal immediate consequences of these initiating events. The initiating events are (a) the possible concentration of the episodic infiltration flux by a fracture directly over a waste package (hereinafter referred to as the "concentration" scenario), (b) concentration as in the first scenario but with a greatly enhanced flow rate, and (c) the possible flooding of a drift caused by an external event that produces a significant rise in the water table (for which the principal mechanisms are changing of the climate to wetter conditions or a severe tectonic event) or by high infiltration combined with poor drift drainage. The main immediate consequences are (a) breaching of the waste package by corrosion, and (b) subsequent dissolution of the basket and/or leaching of the neutron absorber from the basket.

These events and consequences can be interpreted as failure modes and organized as in Table 5-3. These events and consequences can also be interpreted as interrelated events. Complete results of the analysis will be given in a design analysis.

Other neutronics efforts include reviewing and commenting on various documents that address disposal neutronics issues and performing conceptual evaluations of disposal of various additional waste forms.

Activity 1.10.2.3.4 - Cost Estimation. A report on waste package cost estimates was issued (CRWMS M&O, 1995). The cost update information presented is the result of the initial Title I effort to reevaluate waste package costs associated with particular fabrication scenarios (step-by-step fabrication simulation). This is an ongoing activity; the cost estimates will be subject to continuing refinements.

Table 5-3. Summary of Failure Modes and Effects Leading to Criticality (Page 1 of 2)

Component	Function	Failure Modes	Mechanisms	Effects	Comments
Emplacement drift: immediate rock environment	Provide an environment that ensures long waste package life by limiting contact with water and other hazards	Permits water contact at a moderate flow rate	Hydraulically conductive ceiling fracture concentrates infiltrating water onto waste package	Eventual corrosion of barriers, and possible filling of waste package, and leaching of neutron absorber.	Requires infiltration of surface water to initiate sequence. Requires proper corrosion hole configuration to fill waste package.
		Permits water contact at a high flow rate	Flow concentrated and increased by moderate climate change	Same as above	Same as above, but much less likely.
		Permits flooding	Flooding from cataclysmic climate or tectonic change	Eventual corrosion, filling and leaching of absorber	Impossible for at least 20,000 years
		Fails to prevent mechanical damage to waste package	Rock fall or faulting incident on waste package.	Possible breach of waste package barriers depending on amount of applied stress and degree of barrier degradation. Immediate filling if flooded conditions occur.	Sequence not included in current fault tree.

Table 5-3. Summary of Failure Modes and Effects Leading to Criticality (Page 2 of 2)

Component	Function	Failure Modes	Mechanisms	Effects	Comments
Waste package barriers	Isolate spent nuclear fuel from environment and prevent intrusion of water to interior.	Waste package barriers breached, allowing moderator entry and neutron absorber removal.	Corrosion of barriers by intruding water.	Waste package eventually breached. Immediate filling under flooded conditions. Specific corrosion hole configuration required for filling by overhead dripping.	Rate of corrosion varies according to drift conditions. Rates of sufficient magnitude to cause breach in the time frame of this analysis are conditional on water intrusion.
			Pre-existing through-wall defect in both barriers	Waste package barriers breached. Immediate filling if flooded conditions occur.	Sequence not included in current fault tree.
Waste package basket	Maintain spent nuclear fuel in a subcritical condition	Insufficient neutron absorber available to maintain subcriticality under moderated conditions	Sufficient neutron absorber leached from basket material by intruding water	Waste package criticality if fuel assemblies maintain appropriate geometry and basket filled with water.	Leaching is conditional on waste package breach and intrusion of water.
			Basket material doped with insufficient absorber during fabrication	Waste package criticality if fuel assemblies maintain appropriate geometry and basket filled with water.	Sequence not included in current fault tree.

Forecast: The thermal analyses reported above will be described in a draft section of the Waste Package Conceptual Design Report in April 1995. The remainder of FY 1995 will be spent performing a detailed thermal analysis of the defense high-level waste container and the uncanistered spent fuel waste package, writing and issuing the Waste Package Conceptual Design Report, and performing Title I waste package design.

The slap down analyses of multi-purpose canisters in disposal containers will be completed. Analyses for rock drops and waste package drop accidents will be described for the Waste Package Conceptual Design Report. The sections include those for the multi-purpose canister disposal containers, for the defense high-level waste containers, and the uncanistered fuel waste packages.

5.1.4 Design Activity 1.10.2.4 - Material Selection Design Support

A three-volume report was issued (Van Konynenburg et al., in prep.), which serves several purposes. The first volume introduces the engineered materials effort for the YMP. It defines terms and outlines the history of selection and characterization of these materials, and lists current candidate materials. The second volume tabulates design data for engineered materials, and the third volume is devoted to corrosion data, radiation effects on corrosion, and corrosion modeling. The second and third volumes are intended to be evolving documents, to which new data will be added as they become available from additional studies. Initially, volume three provides information currently available for environments most similar to those expected in the potential repository.

Activity 1.10.2.4.1 - Materials selection process. A paper was issued on testing strategy for substantially complete containment (CRWMS M&O, 1994). The paper described future testing efforts on container materials in support of substantially complete containment. Testing of both inner and outer container materials was considered for both high and low thermal loads. For a high thermal load, the corrosion-allowance outer container will be initially subjected to hot and dry air, and then to cooler and somewhat moister air. For these conditions, data on air/stream oxidation, as well as aqueous corrosion resistance, will be needed. For a low thermal load, these barriers will be subjected to cooler and moist air for most of the containment and post-containment periods. For these conditions, data will be needed for air/stream oxidation, as well as aqueous corrosion resistance, with strong consideration for the effect of microbiologically influenced corrosion.

Corrosion data are needed for corrosion-allowance materials as a function of temperature and humidity. In an aqueous environment, these materials may be susceptible to general corrosion, galvanic corrosion, and microbiologically influenced corrosion. While localized attack such as pitting and crevice corrosion may also occur in this class of material, its susceptibility may be significantly less than that of corrosion-resistant materials.

Although the ground water in the vicinity of the proposed repository is known to be benign with a near-neutral to slightly alkaline pH, the corrosion-allowance materials will be tested in the following four environments:

- Simulated ground water (similar to J-13 water)
- Concentrated ground water (20 to 100 times ionic concentration of UE-25 J#13)
- Acidified concentrated ground water (pH ≈ 2)
- Alkalized concentrated ground water (pH ≈ 12).

The concentrated ground water was considered to simulate a dry-out condition followed by resaturation with concentration of ionic salts. The acidified concentrated ground water would represent an extreme case of microbiologically influenced corrosion. As for the alkalized concentrated ground water, the acidified concentrated ground water would simulate reactions between man-made materials, such as concretes or grouts, and the aqueous environment. A long-term (up to five years) test plan will be pursued, which will include a wrought carbon steel (ASTM A 516), a cast carbon steel (ASTM A 27), and an alloy steel (2-1/4Cr - 1Mo). Tests will be conducted at temperatures below boiling, preferably at 60° and 90°C in water, in the vapor phase above the water, and in some instances at the water line.

For corrosion-resistant materials, general corrosion, localized corrosion, galvanic corrosion, microbiologically induced corrosion, resistance to stress corrosion cracking, and hydrogen embrittlement will be evaluated. Susceptibilities to general corrosion, pitting/ crevice corrosion, galvanic corrosion, and microbiologically induced corrosion will be evaluated by using coupons. Fracture mechanics-based notched compact tension specimens will be used to understand the initiation and propagation of stress corrosion cracks in simulated ground water and concentrated ground water, mentioned earlier. Crack growth rate tests currently incorporate Types 304L and 316L stainless steel, Alloy 825, Alloys C-4 and C-22, and Ti Grade 12. In addition to these materials, moderately corrosion-resistant alloys such as Alloy 400 and CDA 715 will be tested. Furthermore, Ti Grade 16 will be included in this testing program. The generated data will be used in developing predictive models. The following test matrix is recommended.

Degradation Mode	Corrosion-Allowance Materials	Moderately Corrosion-Resistant Materials	Highly Corrosion-Resistant Materials
Oxidation	+	o	•
Aqueous Corrosion	+	o	o
Galvanic Corrosion	+	+	+
Pitting Corrosion	o	+	+
Crevice Corrosion	o	+	+
Stress Corrosion	o	o	+
MIC	+	+	+

Key to symbols:
+ : Major effort in testing and modeling
o : May be tested
• : Need not be tested

Activity 1.10.2.4.2 - Container shell. Progress in selection of container shell materials is described under Activity 1.10.2.4.1.

Activity 1.10.2.4.3 - Shield plug. A shield plug is not included in the design of the disposal container. Accordingly, no effort has been made in selecting shield plug materials.

Activity 1.10.2.4.4 - Spent nuclear fuel basket (structural). Selection of basket structural materials for the multi-purpose canister is discussed in a design analysis (CRWMS M&O, in prep.[n]). Materials similar to those recommended for the multi-purpose canister are being considered for disposal containers for spent fuel.

Activity 1.10.2.4.5 - Spent nuclear fuel basket (criticality). Selection of basket structural materials for the multi-purpose canister is discussed in a design analysis (CRWMS M&O, in prep.[n]). Austenitic stainless steel with boron is still the material of choice for disposal containers for spent fuel. Should this prove to have insufficient durability for long-term criticality control, more costly and corrosion-resistant materials (such as zirconium-hafnium alloys) will be considered. Such materials might be more effective in disposable control rods than in a basket.

Activity 1.10.2.4.6 - Filler material. Iron shot remains the first choice for filler material. Current efforts are described in Section 5.5.5.

Activity 1.10.2.4.7 - Fill gas. The fill gas requirements for the multi-purpose canister were analyzed to determine whether the fill gas might cause unacceptable degradation of the performance of the Mined Geologic Disposal System. The Multi-Purpose Canister Subsystem Design Procurement Specification provides requirements for vacuum drying of the multi-purpose canister and subsequent filling. Different readers have proposed various interpretations for the specification. A design analysis (a) analyzed the wording of the specification to determine limits on the quantity of water and the composition of the gases that will be present, and (b) determined limits on amount of degradation that could result from the available gases (CRWMS M&O, 1995). The analysis considered nominal loading conditions only, not accidents.

Close examination of the specification showed that liquid water would not be present. The amount residual of water is small enough that it would not significantly damage the multi-purpose canister or the spent nuclear fuel that it contains. Effects of potentially reactive gases in the multi-purpose canister were also analyzed. The gases included hydrogen, oxygen, and nitrogen, which could be present from residual gases left after vacuum drying, and impurities in the fill gas. The damage that could be caused by these gases is negligible. It was concluded that the specification places sufficiently stringent conditions on the dryness requirements for the multi-purpose canister cavity environment after loading and closure operations at the purchaser site. No reason was found to impose additional restrictions on water or gases.

Forecast: Work on materials selection will continue. The design analysis on materials requirements for key components of the multi-purpose canister will be approved and issued.

5.1.5 Design Activity 1.10.2.5 - Performance Evaluations

This design activity includes work on materials performance. Activities addressed are container oxidation and corrosion, degradation by mechanical stress, and thermal degradation of fuel cladding.

Activity 1.10.2.5.1 - Container oxidation and corrosion. Corrosion calculations were previously reported for degradation of a carbon steel barrier in humid air. For these calculations, the time-temperature-humidity results were taken from Buscheck's mountain-scale thermohydrologic model of a repository (Buscheck et al., 1994). The conditions for the repository horizon as functions of position and time were used as input to an equation (McCoy, 1994) for corrosion rate as a function of temperature, relative humidity, and thickness of corrosion product layer.

A shortcoming of the corrosion calculation is that the temperatures and relative humidities are inaccurate. In the thermohydrologic model, the waste packages are smeared into a disk heat source. Since the heat input is spread over the repository horizon, the predicted temperatures are lower and the humidities are higher than what will be seen at the surface of a waste package. The corrosion calculations were extended in three ways during the current reporting period. Each of the extensions represents an attempt to better estimate the temperature and humidity at the waste package surface.

The first extension of the calculations improved the temperatures and humidities by using results from a drift-scale thermohydrologic model. The drift-scale model differed from the mountain-scale model in that the waste packages were represented by infinite cylindrical heat sources in open drifts. Periodic boundary conditions are imposed, with the effect of simulating an infinite array of drifts. Because it more accurately reflects the local heating of the waste packages, the drift-scale model predicts rapid dry-out at the waste package surface. In contrast, the mountain-scale model predicts that dry-out takes tens of years at high thermal loads and never occurs at low thermal loads. These differences in conditions are reflected in the results of the corrosion calculations. In the original calculations, corrosion was rapid at short times. With results from the drift-scale model, corrosion is suppressed for hundreds to thousands of years.

The second extension used results from the mountain-scale thermohydrologic model, as in the original calculation, but the temperature and humidity for the repository horizon were corrected to account for the local heating by the waste packages. The temperature correction was calculated from a heat transfer correlation that was derived from calculations by Bahney (McCoy, 1995) for a waste package in an empty drift. The relative humidity at the surface of the waste package was calculated assuming that the absolute humidity at the surface of the waste package and at the repository horizon are identical. Because the vapor pressure of water increases with increasing temperature, the relative humidity at the surface of the waste package was reduced.

The results of this calculation agreed with those from the first extension in that corrosion is suppressed for hundreds to thousands of years. They also provide information on

how corrosion rate varies from the center to the edge of the repository. For a low thermal load, a moderate corrosion rate is seen for all packages, regardless of position. At short times, local heating keeps the waste packages dry and suppresses corrosion. At longer times, humidity and corrosion rate rise for all packages. The results for a high thermal load are strikingly different. For most of the packages, corrosion performance is excellent because repository-scale drying keeps humidity and corrosion rate low for a long time. At the extreme edge of the repository, substantially larger corrosion rates are seen because humid conditions return earlier. Both high and low thermal loads, however, provide acceptable performance.

The third extension was like the second, but the heat output of the waste packages was varied in three ways: (1) by multiplying the standard heat output by a constant (as a simulation of different burnups), (2) by changing the age of the fuel at emplacement, and (3) by using heat outputs for high-level waste glass rather than for spent nuclear fuel. The purpose of this extension was to determine the effects of having different waste packages with different heat outputs. The approach is most applicable if waste packages are commingled at a fine scale.

Multiplying the standard heat output for spent nuclear fuel by 0.5 or 1.5 resulted in modest changes (typically about a factor of two) in corrosion depths. These changes reflect the differing amounts of local heating and drying. Varying the age of the emplaced fuel from 10 to 50 yr resulted in negligible changes in corrosion depths. At short times, the heat output is large enough that corrosion is suppressed for either age. At long times, the heat output changes so slowly that young and old fuel are barely different in heat output. For high-level waste glass, heat output drops drastically between 100 and 1,000 yr. After the first few hundred years, the corrosion penetration curves closely resemble those for the original calculations without local heating.

Activity 1.10.2.5.2 - Waste package degradation by mechanical stress. Activities on stress analysis are described under Activity 1.10.2.3.2 (Section 5.1.3).

Activity 1.10.2.5.3 - Thermal degradation of fuel cladding. Fuel cladding is potentially significant as a barrier that will help to provide compliance with the requirements for controlled release of radionuclides. Even perforated cladding will provide significant confinement because the perforations are typically quite small. In contrast, grossly failed cladding would allow relatively easy release of radionuclides from the fuel. Under certain conditions, oxidation of the fuel cladding and pellets could cause such gross failure. A study was recently performed to evaluate the significance of oxidation for degradation of spent nuclear fuel (McCoy, 1995).

Intact fuel rods can perforate by creep rupture if they are stored at a high temperature, but it is generally agreed that a creep rupture failure will produce only a small perforation. Once the cladding is perforated, the gas pressure equalizes between the inside and outside of the cladding, and creep degradation ceases. If the rod is stored in an inert atmosphere, as in an intact disposal container, no additional degradation occurs. If the atmosphere is oxidizing, however, two types of oxidation become possible. The simpler is oxidation of the cladding,

which could gradually thin the cladding until it is gone. The second type is oxidation of the fuel pellets. Einziger (1994) distinguishes two steps in this process, and his description focuses on the cladding: First, the spent nuclear fuel oxidizes locally in the vicinity of the perforation. This eventually leads to a volume increase of the fuel and to formation of a macroscopic split in the cladding. Second, after the split forms, continued oxidation of the fuel pellets near the ends of the split causes the cladding to gradually "unzip," that is, split axially. These two steps are called "split initiation" and "split propagation" here. The first of Einziger's steps lasts until U_3O_8 begins to form; the second corresponds to oxidation of the remainder of the fuel to U_3O_8.

Einziger has presented rate equations for cladding oxidation, split initiation, and split propagation. These equations were combined with information on fuel rod geometry to determine characteristic times for the various degradation processes for a typical pressurized water reactor fuel assembly.

Fuel temperatures will depend on the mass loading and the choice of backfills. For waste packages emplaced without backfill, temperatures for fuel in multi-purpose canisters were taken directly from calculations by Bahney (1994). The calculations are conservative because Bahney's results are for the hottest fuel. Bahney did not analyze waste packages emplaced with backfill. Fuel temperatures were estimated, however, for steady-state, conductive heat transfer through the backfill.

For mass loadings being considered by the Project and emplacement without backfill, fuel temperatures will be low enough that oxidation of the cladding will cause negligible damage even if the disposal container provides no protection. For emplacement with immediate placement of backfill, destruction of the cladding by oxidation is possible only if the disposal containers fail very early. Such degradation can be controlled by delaying emplacement of backfill.

For perforated fuel rods, temperatures are sufficiently high at short times that some protection by the disposal container is necessary. For a low mass loading (5.93 kg U/m^2) and no backfill, the fuel must be protected from oxidation for about 35 yr to prevent the cladding from splitting at some later time; for a high mass loading (20.5 kg U/m^2), the fuel must be protected from oxidation for about 130 yr. These times are extended to 150 yr and 510 yr, respectively, if a crushed tuff backfill is used.

Because the requirements for protection by the disposal containers are small, intact fuel rods are expected to remain intact unless perforation occurs by some other mechanism, such as creep rupture. Fuel rods with perforations are not expected to split unless the disposal container fails very early.

Cladding oxidation and splitting of the cladding as a result of fuel pellet oxidation are significant only at high temperatures. But when the fuel rods are hot enough for significant degradation to occur, the surface of the disposal container will be above the boiling point. As a result, failure of the disposal container by corrosion is unlikely during this period.

Forecast: Additional information will be sought on the dependence of corrosion rate on relative humidity, and calculations of the effects of other humidity dependencies will be performed.

5.2 POSTEMPLACEMENT NEAR-FIELD ENVIRONMENT (SCP SECTION 8.3.4.2)

5.2.1 Design Activity 1.10.1.1 - Consideration of 10 CFR 60.135(a) Factors

Analysis of Thermal Loading Design Options: Localized Disturbance to Extended Disturbance

A significant portion of the modeling efforts in both the near-field hydrology task and the thermal loading systems study has been devoted to addressing a wide range of thermal loading design options. Modeling efforts are directed at developing a complementary suite of in situ heater tests that (a) adequately resolve the major hypotheses for thermal-hydrological flow, (b) determine the extent to which coupled thermal-hydrological-geomechanical-geochemical phenomena may affect the outcome of those hypotheses, and (c) support the thermal design of the repository system in a timely manner.

The proposed thermal loading strategy provides the basis for moving forward in light of the uncertainties about thermal effects on engineered and natural barrier performance. The goal of the strategy is to focus design activities on an areal mass loading of 80-100 metric tons uranium per acre as a working hypothesis. This loading allows emplacement of up to the statutory maximum of 70,000 metric tons of uranium in less than the primary repository area of approximately 1,200 acres.

Risks associated with this strategy will be mitigated by maintaining design flexibility to accommodate higher and lower areal mass loadings and by pursuing a robust performance confirmation program. A lower loading would be appropriate if testing and modeling show that the negative aspects of heat dominate the performance of the natural system. A higher loading would be appropriate if testing and modeling show that the working hypothesis is not a high enough loading to produce a prolonged dry environment for the Engineered Barrier System, and that preclosure requirements can continue to be met at a higher thermal loading.

Very distinct advantages with a phased repository loading approach that initially uses widely spaced drifts emplaced with closely spaced waste packages were identified. Initially, waste packages would be emplaced at a low repository-wide areal mass loading, by skipping every other drift (or perhaps by emplacing every third or fourth drift). Drifts that are not initially emplaced would be used for monitoring the performance around the emplaced drifts. If every other drift is initially emplaced and emplacement occurred over a 24-yr period, there could be up to 12 yr of monitoring before the decision whether to use the remaining drifts had to be made (or the decision made to emplace waste packages in the expansion areas). The initial lower areal mass loading phase of the phased repository loading approach could be called the localized disturbance concept, while the higher areal mass loading phase could be called the extended disturbance concept. It is reasonable to assume that the decision to increase the repository-wide areal mass loading from a localized disturbance to an extended

disturbance concept would not occur unless the extended disturbance concept could be shown to be associated with extended-dry repository conditions.

A significant issue for the thermal loading systems study is the compatibility of large multi-purpose canisters containing either 12 or 21 pressurized water reactor fuel assemblies per waste package, with various thermal criteria being considered for a low areal mass loading repository. These criteria include the following:

1. Peak waste package temperature
2. Peak drift-wall temperature
3. Duration of the boiling period on the waste package
4. Duration of the boiling period on the drift wall
5. Maximum spatial extent of the boiling point isotherm
6. Temperature histories in various hydrostratigraphic units such as the basal vitrophyre (TSw3).

Criteria 1 and 3 are related to thermal goals associated with waste package performance. Criteria 2 and 4 are related to thermal goals associated with the near field and Engineered Barrier System). Criterion 2 is also related to thermal goals associated with mechanical stability of the emplacement drifts. Criteria 4 through 6 are related to the extent to which the thermal effects may influence the ambient hydrological system, with criterion 4 having a near-field focus, criterion 5 having both a near-field and far-field focus, and criterion 6 primarily having a far-field focus.

The Effect of Repository Thermal Design on Water Contact Modes

A major concern for waste package performance is how water contacts a waste package, thereby affecting its integrity and (if containment is breached) affecting radionuclide dissolution and transport to the water table. The degradational mechanisms of greatest concern for waste package integrity, such as stress corrosion cracking, pitting corrosion, or microbial attack, require the presence of liquid water. The rates for many of these mechanisms are increased under warm, humid conditions.

The two primary modes of water contact on the waste package are (1) advective aqueous-phase flow and (2) condensation of water vapor on the waste package surface. The critical factors for the second mode are the relative humidity *RH* and temperature at the waste package surface. Regardless of whether mobile liquid water is present, ambient relative humidity at the repository horizon is humid (approximately 98 to 99 percent). If the ambient relative humidity could be sufficiently reduced, waste package corrosion rates would be minimal (Stahl et al., 1994). Moreover, even for breached waste packages, waste-form dissolution is minimal if no mobile liquid water is present.

There are two ways to reduce relative humidity at the waste package surface: (1) drive a large fraction of the initial pore water from the vicinity of the waste packages and (2) maintain a steep enough temperature gradient away from the waste package.

The primary means of reducing the pore water are repository-heat-generated drying and ventilation. To reduce relative humidity to 70 percent, the liquid saturation S_l (the fraction of the pore space filled with liquid water) must be reduced to less than 20 percent. An areal mass loading that does not drive repository temperatures well above the boiling point will only slightly reduce average relative humidity conditions.

Even if repository heat does not substantially reduce average relative humidity conditions in the repository, it is still possible to substantially reduce relative humidity at the waste package surface itself for a considerable period of time. The relative humidity at the waste package surface can be quite low even if ambient (humid) relative humidity conditions prevail in the host rock immediately adjacent to the emplacement drift. A large difference in relative humidity between the emplacement drift wall and the waste package can arise as a result of the temperature difference between these locations. This local reduction of relative humidity within the emplacement drift is called the "local-ΔRH effect." Various concepts for the Engineered Barrier System need to consider the impact of an engineered temperature drop from the waste package to the drift wall on reducing relative humidity on the waste package surface.

During the initial heating stage of the repository, the waste packages act as point-heat sources. If spaced close enough, these point-heat sources coalesce into a line-heat source. Heat flow away from the line-heat source will be radial until interference with heat flow from the neighboring drifts nulls out the lateral component of heat flow, resulting in heat flow that is primarily vertical (upwards and downwards). If the line-heat loads are spaced far enough apart, there will always be a lateral component to the heat flow away from the drifts. This persistent lateral component of heat flow facilitates a larger temperature drop between the waste package and drift wall than would occur for more closely spaced line-heat loads. Consequently, closely spaced waste packages in widely spaced drifts allow for a more persistent temperature drop between the waste package and the drift wall than does the approach of using closely spaced drifts, and thereby facilitate a more substantial reduction in relative humidity on the waste package that persists after the host rock has rewetted back to ambient (humid) relative humidity conditions.

Major Categories of the Localized Disturbance Concept

As mentioned earlier, there are several thermal criteria to be considered with regard to the localized disturbance concept. In general, there are varying degrees of localization of the thermal effects on the ambient hydrological system; but several major categories of the localized disturbance concept can be classified, including the following:

1. Sub-boiling waste package, sub-boiling host rock

2. Above-boiling waste package, sub-boiling host rock

3. Above-boiling waste package, above-boiling host rock during the preclosure period

4. Above-boiling waste package, above-boiling host rock within localized (cylindrical) boiling zones

5. Above-boiling waste package, above-boiling host rock, and boiling zones that eventually coalesce; with emplacement drifts far enough apart to promote preferential shedding for some period of time in the pillars and a significant local-ΔRH effect.

The first localized disturbance category would preclude boiling effects within the Engineered Barrier System as well as within the near-field host rock; but it may be incompatible with backfill or large multi-purpose canisters. The second localized disturbance category attempts to minimize heat-mobilized water in the near-field host rock since that water may be brought into the emplacement drifts. The third localized disturbance category does not eliminate the possibility of heat-mobilized water entering the emplacement drifts, but limits its occurrence to the preclosure period during which time the effectiveness of measures to mitigate the boiling effects (such as ventilation and drip shields) could be monitored.

The fourth localized disturbance category does not eliminate the possible occurrence of heat-mobilized water; but because the boiling zones do not coalesce, the possibility of ponding significant quantities of either condensate or naturally infiltrating water above the repository is reduced. The effectiveness of shedding these sources of water around the emplacement drifts (and through the repository horizon) can be monitored for 100 yr. Moreover, the spatial scale over which the observations are made during the monitoring period is comparable to the spatial scale over which maximum boiling effects will occur. Consequently, the fourth localized disturbance category avoids the "scaleup" problem between the scale of observations and the scale over which (boiling-driven) thermohydrological behavior must be sufficiently understood.

Because the boiling zones eventually coalesce, the fifth category listed above is not a true localized disturbance category, but rather a hybrid of the localized disturbance and extended disturbance concepts. Category 5 may pond more water than category 4. With wide drift spacing, however, the period of boiling coalescence may be relatively short; moreover, there is still a substantial component of lateral heat flow that tends to drive vapor flow radially away from the emplacement drifts and that continues to yield a significant local-ΔRH effect in the drifts themselves. In addition to the local-ΔRH effect, this category may also be shown to benefit from an overall reduction in relative humidity in the repository (including much of the pillar areas) for an extended period of time. Areas in the repository where average relative humidity conditions are not substantially drier than ambient will still benefit from the local-ΔRH effect.

Forecast: On the basis of an extensive suite of calculations, the transitions between these five major categories of the localized disturbance concept will be mapped as a function of areal mass loading, lineal mass loading, drift spacing, spent nuclear fuel age, and ventilation.

5.2.2 Study 1.10.4.1 - Characterize Chemical and Mineralogical Changes in the Postemplacement Environment

The objective of this study is to establish, to the degree required in Performance Issues 1.4 and 1.5 (SCP Sections 8.3.5.9 and 8.3.5.10), the information necessary to characterize the chemical and mineralogical properties and processes of the waste package environment for expected and certain unexpected conditions. To accomplish this objective, the study will determine the effects of chemical reactions on the rock-water system of the repository horizon over a range of temperatures and chemical conditions that bound the postclosure waste package environment.

Activity 1.10.4.1.1 - Rock-water interactions at elevated temperatures. This activity is being deleted by a change to the Site Design and Test Requirements Document. Its objectives have been moved to new Activities 1.10.4.1.8, 1.10.4.1.9, and 1.10.4.1.11.

Activity 1.10.4.1.2 - Effect of grout, concrete, and other repository materials on water composition. This activity is now reported under Activity 1.10.4.5.1, as a result of changes to the Site Characterization Program Baseline, Revision 8.

Activity 1.10.4.1.3 - Composition of vadose water from the waste package environment. This activity is being deleted by a change to the Site Design and Test Requirements Document. Its objectives will be met by Study 8.3.1.2.2.7.

Activity 1.10.4.1.4 - Dissolution of phases in the waste package environment. This activity is being deleted by a change to the Site Design and Test Requirements Document. Its objectives have been moved to new Activity 1.10.4.1.10.

Activity 1.10.4.1.5 - Effects of radiation on water chemistry. This activity is being deleted by a change to the Site Design and Test Requirements Document. Its objectives have been moved to new Activities 1.10.4.1.12 and 1.10.4.5.7.

Activity 1.10.4.1.6 - Effects of container and borehole liner corrosion products on water chemistry. This activity is reported under Activity 1.10.4.5.2, as a result of changes to the Site Characterization Program Baseline, Revision 8.

Activity 1.10.4.1.7 - Numerical analysis and modeling of rock-water interaction. This activity was divided between geochemistry and man-made material activities in Site Characterization Program Baseline, Revision 8. This activity is being deleted by a change to the Site Design and Test Requirements Document. Its geochemistry objectives have been moved to new Activities 1.10.4.1.13, 1.10.4.1.14, and 1.10.4.1.15.

Activity 1.10.4.1.8 - Hydrothermal testing of vitric and tuffaceous rocks under saturated conditions. The objective of this activity is to conduct a series of long-term saturated tests to determine the solid phase reaction products and chemical characteristics of the water that develop during interaction of rocks within the vicinity of the potential repository horizon, with reference ground water and other waters at elevated temperatures.

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

Activity 1.10.4.1.9 - Hydrothermal testing of vitric and tuffaceous rocks under unsaturated conditions. The objective of this activity is to conduct a series of long-term tests similar to those of Activity 1.10.4.1.8, except that water activity will be controlled to ensure that the activity is always less than 1.0. These tests will evaluate how pore water chemistry and secondary mineralogy may evolve under conditions where water activity is less than 1.0. Reaction rates and mechanisms may also be substantially changed under these conditions. Furthermore, changes in degree of hydration may occur for hydrous phases, with a corresponding change in mineral volume. This work is designed to complement other work addressing mineral stability and geochemical evolution of the site (Studies 8.3.1.3.3.2 and 8.3.1.3.3.3). This work will examine mineral stability issues for temperature conditions, fluid conditions, and mineral assemblages not considered by the work performed under those study plans.

Studies of the effect of changes in relative humidity on rocks that occur within the vicinity of the repository horizon were started. These studies will evaluate the rates of reaction, the extent and mechanism of reaction, and the impact on water chemistry. Results to date demonstrate that dramatic alteration of the material occurred within four months of the start of the experiments. Alteration was evident at relative humidities as low as 70 percent, consistent with literature reports in which the rate of glass alteration decreases significantly at relative humidities of less than 70 percent. These experiments are continuing.

Activity 1.10.4.1.10 - Mineral dissolution and precipitation. The objective of this activity is to obtain knowledge of the dissolution kinetics of the phases present in the host rock of the near-field environment, and the precipitation kinetics of product mineral phases. This information is required to interpret observed changes in fluid composition and associated development of product mineral phases in hydrothermal rock-water interaction studies.

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

Activity 1.10.4.1.11 - Ion exchange and sorption. The objective of this activity is to obtain knowledge of the effect that ion exchange and sorption may have on the composition of mineral phases and the composition of coexisting water. This information is required to interpret observed changes in fluid composition and associated development of product mineral phases in hydrothermal rock-water interaction studies.

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

Activity 1.10.4.1.12 - Rock-water interaction and water chemistry changes in the presence of a radiation field. The objective of this activity is to obtain knowledge of the interaction of ionizing gamma radiation with the air-steam atmosphere and pore water in the near-field environment, with the concomitant spectrum of possible effects on the rock, pore water, and emplaced materials.

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

Activity 1.10.4.1.13 - Simulation of rock-water interaction. The objective of this activity is to conduct simulations of the rock-water interaction experiments described in Activities 1.10.4.1.8 and 1.10.4.1.9, using as appropriate, models and data generated from Activities 1.10.4.1.10, 1.10.4.1.11, and 1.10.4.1.12. The activity will also conduct simulations of natural systems in which processes of interest occur. The activity evaluates computer codes and data bases, but does not actually develop codes or data bases. The results of this activity will allow simulations of repository conditions thousands of years into the future.

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

Activity 1.10.4.1.14 - Validation of EQ3/6 reaction path modeling codes. The objective of this activity is to validate the EQ3/6 code package to be used in Activity 1.10.4.1.13. This activity will use laboratory hydrothermal experiments not used in previous modeling efforts, analogous natural systems, field-based studies, and ESF studies to validate the calculational approach.

This activity includes work on the New Zealand process analog site that is being used to:

- Develop conceptual and analytical models of dissolution and precipitation kinetics relevant for Yucca Mountain conditions by resolving conflicts that exist between laboratory-based and field-based measurements of dissolution rates

- Test relevant thermodynamic data and modeling techniques by simulating rock-water interaction in hydrothermal systems relevant to Yucca Mountain

- Develop techniques and strategies for using natural systems to accomplish necessary code and model testing

- Define the envelope of uncertainty that bounds simulations and projections of geochemical processes.

Work on the New Zealand site was temporarily stalled because of changes in DOE procurement policies during the contract renewal process. The contract has been completed, and work will continue as planned, but with a five month delay. This subcontract will allow work to be continued in:

- Evaluating fluid mixing and mineral-fluid equilibria at elevated temperatures in silicic volcanic rocks to test the EQ3/6 code and its thermodynamic data base GEMBOCHS

- Measuring and evaluating rates of solid dissolution/corrosion in thermal features

- Determining rates and controls of silica precipitation from heated fluids, and measuring of the naturally occurring actinide-series isotopes in geothermal rocks and

fluids as a function of temperature, lithology, water chemistry and colloid content to evaluate the transport of radionuclides in repository-type environments

To evaluate historical discrepancies between laboratory- and field-based measurements of precipitation, a field-based study was started that examines the mechanisms and controls on silica precipitation in concrete-lined drain fields.

Activity 1.10.4.1.15 - Rock-water interaction simulation of scenarios for license application. The objective of this activity is to use the EQ3/6 code to simulate rock-water interactions for short- and long-term periods, for specific scenarios required for license application. The results will establish the geochemical and mineralogical characteristics of the waste package environment for expected and certain unexpected conditions. The characteristics will include the expected changes in primary and secondary mineralogy that would occur as a result of interaction of the vadose water with the waste package environment thermal and radiation fields, and with the host rock. The compositional evolution of the vadose water will also be established for the range of temperatures and radiation doses expected in the waste package environment.

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

Activity 1.10.4.1.16 - Experiments and simulations to determine the effect of geochemical processes on hydrological processes. The objective of this activity is to determine, through experiments, simulations, and study of natural systems, how geochemical processes couple with hydrological processes. The geochemical processes include dissolution and precipitation of minerals. The hydrological properties of fracture apertures, pore sizes, pore and fracture connectivity, and imbibition properties of the rock will in turn modify the flow pathways and flow rates of water and vapor as heating and cooling of the repository occur. This activity will evaluate the extent to which chemical changes will modify the hydrological properties. It will also determine under what conditions these changes are of greatest significance for geochemistry.

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

Forecast: The activities outlined above will continue throughout FY 1995.

5.2.3 Study 1.10.4.2 - Hydrologic Properties of Waste Package Environment

The objectives of this study are to conduct experimental and modeling studies relevant to the range of potential thermal loads to (a) identify hydrological and transport processes at Yucca Mountain that significantly affect waste package performance, radionuclide release and transport; (b) develop a detailed conceptual and quantitative understanding of repository-heat-driven flow processes that govern the waste package environment, including temperature, relative humidity, and flow conditions throughout the repository and Engineered Barrier System; (c) conduct experiments and develop related models to assess the impact of repository-altered matrix and fracture properties on nonequilibrium fracture flow; and

(d) develop and conduct laboratory and in situ tests for model validation and hypothesis testing that provide the basis for confidence building and substantiation of compliance with the substantially complete containment and controlled Engineered Barrier System release requirements.

Related International Work. See Section 5.2.7 for related work (under the heading Design and Analysis of Disturbed Zone Experiments) performed under the auspices of the OCRWM international program.

Activity 1.10.4.2.1 - Single-phase fluid system properties. This activity is being deleted by a change to the Site Design and Test Requirements Document. Its objectives have been moved to new Activities 1.10.4.2.4. and 1.10.4.2.5.

Activity 1.10.4.2.2 - Two-phase fluid system properties. This activity is being deleted by a change to the Site Design and Test Requirements Document. Its objectives have been moved to new Activities 1.10.4.2.4 and 1.10.4.2.5.

Activity 1.10.4.2.3 - Numerical analysis of flow and transport in laboratory systems. This activity is being deleted by a change to the Site Design and Test Requirements document. Its objectives have been moved to new Activities 1.10.4.2.5 and 1.10.4.2.6.

Activity 1.10.4.2.4 - Laboratory hydrological property measurements. The objectives of this activity are to determine the hydrological properties of repository horizon Topopah Spring Tuff samples and other rock units that may fall within the altered zone. The properties include effective porosity, saturated liquid- and gas-phase permeability, matric suction potential vs. liquid saturation, effective coefficient for the binary diffusion of air and water vapor, and Klinkenberg coefficient. The properties will be measured under ambient conditions and thermally altered conditions that are relevant to the heating and cooling cycle for a range of potential thermal loads.

The experiment to determine the effect of confining pressure on fracture healing, as observed previously by project geophysicists, has been completed. A fractured Topopah Spring Tuff sample from the USW G-4 hole was used. Saturated water permeability in the sample was measured as a function of temperature at a confining pressure of 1 MPa and a pore pressure of 0.5 MPa. The confining pressure was further increased to 2, 3 and 5 MPa, while the pore pressure was kept at 0.5 MPa, and the measurements were repeated at each pressure. The overall permeability decrease during this 6,100-hour experiment was from about $18 \times 10^{-15} m^2$ to about $2 \times 10^{-15} m^2$. About 69 percent of this permeability decrease occurred during the first temperature cycle at 1 MPa confining pressure. The chemical analyses and scanning electron microscopy examinations indicate that deposition of silicate minerals may have occurred during the first heating of the sample; dissolution and deposition may have occurred in the subsequent heating and cooling cycles. Freshness of the fracture surfaces may have stronger effect on the rock-water interaction than confining pressure. A paper describing this work has been prepared (Lin et al., 1995, in prep.).

Measurement of electrical resistivity as a function of water saturation and temperature continued. The measurements at 95°C are almost complete. Most of the samples broke during the experiment. Preparations of more samples from the USW G-4 hole and the Large Block Test cores to complete the measurements at 95°C were completed. Gold electrodes have been deposited on these samples, and the samples are being dried so that the weights of the gold electrodes can be determined. The electrical impedance data collected so far have been modeled using a complex nonlinear least square routine to fit the frequency dependent response. Preliminary results show distinct impedance responses depending on saturation level. Cation exchange capacity can be estimated by using a form of the Waxman-Smits equation and obtaining fits to the resistivity vs. saturation data. A paper to be submitted to a peer reviewed journal is being prepared.

For the experiment of determining the moisture retention curve and one-dimensional imbibition, the moisture retention experiments using USW G-4 cores at high temperatures continued. Measurements at 95°C were completed. The samples are in the cooling phase. The temperature was lowered to 80°C, and the relative humidity was started at 20 percent. Fresh samples were added so that the effect of test history (i.e., cycling to high temperatures) on the measurement can be assessed. Additional samples from the Large Block Test core have also been prepared.

Some feasibility tests were conducted to evaluate the possibility of using a resonant cavity to measure relative humidity in rock samples in the laboratory. These tests were to determine the effect of rock proximity on the calibration of a resonant cavity and to solve the droplet formation problem. These tests indicated that it is feasible to use the resonant cavity to measure relative humidity in laboratory rock samples. Means of more accurately controlling the relative humidity at elevated temperatures for the calibration of the resonant cavity are being investigated. One of the methods is to use appropriate salt solutions in an autoclave type container in an oven that can control temperature accurately.

X-ray imaging to determine water saturation continued. A small block of 2.5 x 10 x 10 cm of Topopah Spring Tuff from Fran Ridge, with a tensile fracture in the middle, was used to test the x-ray scanning capability. Water doped with potassium iodine was added to the top of the sample, and radiographs are being taken as a function of time to try to determine the distribution of water content. Two tests have been conducted on this sample. First, the two halves of the block were put together well matched. Water was observed entering the fracture and the matrix very slowly. A v-shaped imbibition front with its tip on the fracture was observed. More than one month after this experiment started, however, the tip of the imbibition front only moved through about half of the block. The block was re-packed with 25-micron shims on the fracture surfaces, and the experiment was repeated. Water flowed along the fracture within a couple of hours. The water then imbibed into the matrix almost uniformly from the fracture. The images are being processed to determine saturation as a function of time, and the wetting front location as a function of time. A video of the images of the second experiment is being produced to show the fracture flow vs. imbibition process.

A progress report (Roberts and Lin, 1994) summarizing the hydrological properties of Topopah Spring Tuff, measured in the laboratory, was published.

Activity 1.10.4.2.5 - Model validation experiments. The objectives of this activity are to develop and conduct laboratory tests for model validation and hypothesis testing that provide the basis for confidence building and substantiation of compliance with the substantially complete containment and controlled Engineered Barrier System release requirements. The experiments will test the adequacy of the models to represent hydrological and transport processes at Yucca Mountain that significantly affect waste package performance radionuclide release and transport.

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

Activity 1.10.4.2.6 - Model development and analysis of thermal hydrological flow and transport. The objectives of this activity are to conduct modeling studies for the range of potential repository thermal loading options and for the thermal loading cycle to:

1. Identify coupled thermal-hydrological-geochemical-geomechanical processes, transport processes, and ambient site conditions (e.g., bulk permeability distribution) that significantly affect the waste package and Engineered Barrier System environment (i.e., affect waste package performance and radionuclide dissolution, release and transport), with emphasis on their effect on temperature, relative humidity, and flow conditions throughout the repository and Engineered Barrier System.

2. Determine the parameter sensitivity of the thermohydrological behavior in the near-field and Engineered Barrier System to a range of expected site conditions, waste package designs, repository configurations, waste package loading scenarios and repository operational options (e.g., ventilation and backfill). Of particular importance is dryout and rewetting behavior.

3. Develop mathematical and numerical models of repository-heat-driven flow and radionuclide transport, emphasizing the waste package and Engineered Barrier System environment. These models should be capable of treating the importance of coupled thermohydrological-geochemical-geomechanical and transport processes in the thermally altered zone, including (a) nonequilibrium fracture-matrix interaction, (b) coupled reactive transport, (c) the effects of coupled fracture-aperture deformation, and (d) the effects of heat-altered thermal and hydrological flow and transport properties.

4. Establish hypotheses critical to the prediction of thermohydrological behavior and EBS performance. Design laboratory- and field-scale experiments that critically test these hypotheses.

5. Develop validated subsystem models of the waste package and Engineered Barrier System environment. The experiments of Activity 1.10.4.2.5 will be used, in part, to validate the models.

Code Development, Qualification, and Maintenance

Version 7.7 of the V-TOUGH code was certified for use in quality-affecting work. Substantial improvements to the NUFT code have been implemented during this period. Several new direct matrix solution methods have been implemented as well as several new preconditioning options into the conjugate gradient method solver. These new solvers are robust enough to efficiently solve problems with highly nonlinear characteristic curves and widely varying grid element sizes. With the use of the new solvers, NUFT is capable of solving typical two-dimensional and three-dimensional thermohydrological problems four to six times faster than the V-TOUGH code. A nested mesh option has also been implemented in the NUFT code. A driver program that integrates the NUFT code with University of Nevada-Reno's CLIMATE code (Danko and Mousset-Jones, 1993) has also been developed.

Integration of Modeling with Laboratory and Field Experiments

The goals of laboratory and field experiments are to (a) measure fundamental material properties for input into the codes, (b) determine consistency of conceptual models with processes observed in experiments, (c) partially validate mathematical models by calibration, and (d) perform hypothesis tests. Conversely, the model will be used to design experiments and interpret collected data. An extensive suite of scoping calculations has been conducted for both the Large Block Test and in situ heater tests that will be conducted in the ESF. This progress report describes the major issues that need to be considered in designing these tests. Subsequent progress reports will describe the scoping calculations for heater test design and the conclusions from those calculations.

A key issue that will require integration of modeling studies with laboratory and field experiments is the evaluation of the effects of thermal loading on the capability of the Mined Geological Disposal System to contain and isolate radionuclides.

The proposed thermal loading strategy provides the basis for moving forward in light of the uncertainties about thermal effects on engineered and natural barrier performance. The goal of the strategy is to focus design activities on an areal mass loading of 80-100 metric tons uranium per acre as a working hypothesis. Design flexibility will be maintained to accommodate higher and lower areal mass loadings and by pursuing a robust performance confirmation program.

Hypothesis testing can help determine the impacts of areal mass loading on heat-mobilized fluid flow in the unsaturated zone. The primary hypotheses concern the following:

- Whether buoyant, gas-phase convection significantly affects unsaturated zone moisture movement

- Whether binary gas-phase diffusion significantly affects unsaturated zone moisture movement

- Whether heterogeneity in the heat load distribution and/or gas- and liquid-phase pathways focuses enough condensate drainage to cause this heat-mobilized water to contact waste packages and drive radionuclide transport.

For repository systems with thermal loads that significantly mobilize fluid flow, as with a high areal mass loadings repository, these hypotheses address how that mobilization occurs. Field tests, including the Large Block Test, to be performed at Fran Ridge (Lin et al., 1994), and in situ heater tests to be conducted in the ESF (e.g., the Engineered Barrier System Field Test) will help evaluate issues associated with thermal loading, including resolution of the major hypotheses. These tests are described in Study Plan 8.3.4.2.4.4. Portions of these heater tests should be conducted under sub-boiling conditions to address the post-boiling period of a high areal mass loading repository system. Portions of the heater tests will be conducted under above boiling conditions to address the effect of boiling for either a low or high areal mass loading repository system, and to establish the technical justification for an increase in the repository areal mass loading.

Hypothesis testing can help determine the extent to which a well-planned thermal management scheme can generate conditions in the repository that promote waste package integrity and reduce the potential for radionuclide dissolution and transport. The primary hypotheses concern the following unknowns:

- Whether heat conduction dominates heat flow

- Whether above-boiling temperatures (or the temperature drop between the drift wall and the waste package) correspond to a sufficient reduction in relative humidity and the absence of mobile liquid water near waste packages

- How long rewetting the waste package environment to humid conditions lags behind the end of the boiling period (or how long the temperature drop between the drift wall and waste package results in a sufficient reduction in relative humidity on the waste package)

- Whether enough condensate buildup occurs to significantly affect drying and rewetting.

The above-boiling portions of the heater tests are needed to support the resolution of this second set of major hypotheses and to further support the resolution of the first set of hypotheses. The significance of buoyant, gas-phase convection is easier to evaluate when thermal testing is conducted under above-boiling conditions (Buscheck et al., 1993b).

Thermohydrological scoping calculations are being conducted to design Large Block Test and ESF heater tests that provide useful and timely information for resolving the major hypotheses and to observe potentially critical coupling between thermohydrological processes

and geomechanical and geochemical processes. How the heat load is applied to the rock during the heater tests must be relevant to repository conditions, and the experimental design must allow the resolution of hypothesis tests. A primary concern is that the heated area of rock must be large enough to accomplish the following:

- Incorporate a network of fractures that is sufficiently connected to examine important heat-driven processes such as buoyant gas-phase convection
- Allow the development of condensate perching above the boiling zone
- Examine whether heterogeneities in the gas- and liquid-phase pathways focus enough condensate drainage to cause water to drip into drifts and possibly onto waste packages
- Prevent edge-cooling effects from dominating thermohydrological flow processes
- Determine the significance of buoyant gas-phase convection on moisture movement and heat flow.

Model calculations are being carried out (Buscheck et al., 1993a; Buscheck et al., 1993b) to address the question of in situ heater test size. To meet the above criteria, a minimum heated area of 500 m^2 is required (i.e., a disk with a radius of 12.5 m).

The other potentially important mechanism for heat-driven fluid flow mobilization during sub-boiling conditions is binary gas-phase diffusion. Analysis of potential heater tests clearly shows that under above-boiling conditions, the effects of binary gas-phase diffusion (even if substantially enhanced) tend to be swamped by boiling effects. Thus, a sub-boiling heater test will be required to diagnose the potential importance of binary gas-phase diffusion.

Forecast: Laboratory testing of core and small block samples will continue. Analysis of consolidated thermal test geometries and of localized-disturbance repository geometries will continue.

5.2.4 Study 1.10.4.3 - Characterization of the Geomechanical Attributes of the Waste Package Environment

The objective of this study is to characterize the geomechanical response of the rock in the near field to the changing conditions expected to occur over the lifetime of the repository. This includes providing data from laboratory, field and modeling investigations that can be used to support technical site suitability and a high-level finding for rock properties. Particular emphasis is on coupled processes and behavior at elevated temperatures and at long times.

Activity 1.10.4.3.1 - Block stability analysis. This analysis will provide information on the potential for impact and static loads on the waste package caused by rock blocks moving along pre-existing fractures.

The purpose of the modeling task is to evaluate several different constitutive thermal-mechanical models for applicability in simulation of geomechanical behavior in the near-field, and to develop coupled models for rock behavior at elevated temperature. Current efforts are oriented toward the Large Block Test and a time-dependent finite difference method is being used. The code being used, FLAC, is capable of treating both mechanical and thermally induced stresses and deformations. It is a two-dimensional code in which materials are represented by arbitrarily shaped quadrilateral zones. The code is based on a Lagrangian scheme and is capable of using several built-in material models, including the ubiquitous joint model that has previously been used to simulate thermomechanical behavior in tuff.

During the reporting period, the input modules for thermomechanical simulations were revised to accommodate the revised Large Block Test conditions, and to be compatible with the simulations being conducted for hydrological analysis of the Large Block Test. The input model was formulated assuming elastic behavior for the rock mass and using values of bulk density determined from laboratory measurements of cores, and bulk and shear moduli determined from laboratory velocity measurements discussed above. This is a two-dimensional model and assumes plane strain, equivalent to assuming a large thickness in the third dimension. The model assumes dry conditions and is being used to find the displacements and stresses resulting from the heating under these conditions.

The thermal boundary conditions are adiabatic at the sides of the block, isothermal at 60°C on the top of the block and 20°C at the ground surface around the block, together with fixed isothermal boundaries at the far edges of the model 34 m from the block and at a depth of about 25 m below the block. The loading is gravitational loading plus atmospheric pressure at the surface, and achieves stress equilibrium before heating. The heating program in the model uses the same parameters as the hydrologic model (i.e., heating using 1500 W for about 75 days followed by a period of reducing the heating at a rate of 16.7 W/day for 18 days, then a slower reduction of heating at a rate of about 1.7 W/day for 87 days, and a final step reduction to zero power).

Thermomechanical calculations are currently under way using an elastic constitutive model to verify the model behavior. After these preliminary calculations are completed, the ubiquitous joint and Mohr-Coulomb constitutive models will be used in the future to represent the rock mass.

Activity 1.10.4.3.2 - Borehole damage analysis. The objective of this activity is to provide information on the potential for static loads on the waste package and for radionuclide releases caused by spalling or borehole breakup.

No progress was made during the reporting period; this is an unfunded activity.

Activity 1.10.4.3.3 - Geomechanical properties analysis. This analysis will provide information on the nature of changes in the geomechanical properties of the rock in the near-field environment and how these changes will affect the performance of the waste package and Engineered Barrier System over the lifetime of the repository. Two types of laboratory tests are being conducted under this task; tests on small blocks to determine rock mass properties at the 0.5 m scale, and tests on cores to determine the effect of radiation on mechanical properties.

The purpose of the small block tests is to investigate the coupled thermomechanical, thermohydrological, and thermochemical response of the rock to conditions similar to the near-field environment of the potential nuclear waste repository. A small block of Topopah Spring Tuff, obtained from the Fran Ridge site was prepared for testing. This block is approximately 64 x 32 x 25 cm, and it exhibits the typical Topopah Spring Tuff fabric of subhorizontal vugs in pink and gray densely welded tuff. The block was instrumented with displacement transducers configured to measure displacement over several different length scales, and across fractures as well as regions of matrix material

Two sets of compression tests have been conducted. Each set consisted of a series of five tests. In the first test of a series, the axial stress was raised to 1 MPa and then reduced to ambient. In the remaining tests, the axial stress was raised to 2, 3, 4, and 5 MPa respectively, followed by lowering the axial stress to ambient. The purpose of this design was to test the apparatus measurement devices and to gather information on hysteresis in the stress strain behavior at low stress levels. Preliminary analysis of the stress-strain behavior for the first set of tests indicates that for axial stress in the range 0 to 5 MPa, the Young's modulus for this sample is approximately 3 GPa and that, as expected, most of the deformation occurs across fractures. This value for Young's modulus is considerably lower than the value of approximately 40 GPa determined for core samples.

A second suite of uniaxial compression tests was conducted on the block approximately four weeks after the first set. Analysis of the stress-strain behavior indicates a similar modulus to that reported for the first set and that, as expected, most of the deformation occurs across fractures. In addition, noticeable spalling occurred at several locations on the block. This was not observed during the first cycle of testing and indicates that subcritical crack growth occurs even at very low stresses in this rock when it is subject to cyclic loading. This may be relevant for evaluating the effect of seismic shaking of the potential repository over long times and at elevated temperature and humidity.

A block of about 30 x 30 x 70 cm is being tested under a uniaxial load of about 5 MPa at room temperature to measure its bulk deformation, deformation of fractures, and deformation in the matrix. Boundary heaters will be installed on the block to conduct tests at elevated temperatures planned for later this fiscal year.

Compressional wave velocity was also measured in a few blocks of Topopah Spring Tuff from the Fran Ridge site at ambient temperature and pressure conditions. Preliminary results show the P-wave velocities are in the range 3.8 to 4.7 km/s, which agrees with results from the G-Tunnel tests. In addition, elastic waves traveling through unfractured tuff were

about 10 percent faster than waves that had significant parts of the travel path passing through fractured rock.

Testing to determine the effect of radiation consists of a series of laboratory compression tests on irradiated and non-irradiated core samples to determine if radiation affects mechanical properties. To ensure that appropriate quality controls are used in collection of the data, a Technical Implementation Procedure was prepared, and the first draft is currently being reviewed. Thirty core samples of Topopah Spring Tuff from the Fran Ridge site have been prepared and are currently being irradiated using a Cobalt-60 radiation source. A hydraulic press suitable for the compression testing has been set up. Several load cells and displacement transducers appropriate for the tests have been located and are being calibrated. Testing is planned to start in early May.

Forecast: Laboratory tests and Large Block Test simulations will continue, as noted above.

5.2.5 Study 1.10.4.4 - Engineered Barrier System Field Tests

The laboratory tests described in Studies 8.3.4.2.4.1 through 8.3.4.2.4.3 require validation by in situ field tests in the repository horizon to establish the applicability of the laboratory studies to the repository block. The objective of this study is to investigate the geomechanical and geochemical behavior and movement of water in the rock mass under the influence of the thermal loading of the waste package. The study will investigate heat-flow mechanisms, fracture aperture change, geochemical reactions, the relationship between boiling and dryout, and the rewetting of the dryout region when the repository is cooled down. Coupling between heat, hydrology, geomechanics, and geochemistry, will be included in the study.

Activity 1.10.4.4.1 - In situ testing. The objectives of this activity are to develop detailed planning documents for the Engineered Barrier System field test, to checkout and debug techniques and hardware, to perform comparative evaluations of candidate test component methods, to procure equipment, to purchase or manufacture test components, to calibrate and install test components, and to conduct in situ testing.

Large-Block Test

The Large Block Test has recently been replanned to eliminate loading with a stress similar to the in situ horizontal overburden stress at the potential repository horizon. The purpose is to improve the understanding of some of the thermal-hydrological processes and to obtain data and properly plan tests that will support license application. The Large Block Test is designed to be consistent with the Program Plan. This test focuses on processes that are associated with the emplacing of waste in accordance with the current strategy (i.e., emplacement to achieve minimum thermal disturbance at the early stage of a repository, then increase the thermal loading later) but the understanding of processes can be applied to other emplacement scenarios.

The Large Block Test will meet three objectives:

1. It will develop and evaluate techniques and instrumentation for monitoring changes in thermal and hydrological, and to a limited extent, mechanical properties in a heated unsaturated zone rock mass. These techniques will be used in the Engineered Barrier System field tests.

2. It will improve understanding of the coupled thermohydrological processes required to develop models that can be used to predict the hydrologic responses of the near-field environment. The analyses of the near-field environment will be part of the evaluation of isolation capabilities required for any license application.

3. It will provide preliminary data both for the development of models as mentioned above, and for performing the scoping calculations that will be the basis of the test design of the Engineered Barrier System field test. The later Engineered Barrier System field test will provide site related data and process evaluation that will serve as the basis for license application. The Large Block Test is prototyping and scoping in nature, but the Quality Assurance Requirements and Description will apply. The appropriate level of controls will be specified in grading reports. The testing phase will be conducted as a quality-affecting activity.

The following critical thermohydrological issues are to be addressed in the Large Block Test:

- Whether heat conduction dominates heat transfer in fractured welded tuff.

- Whether heating (even low thermal load) promotes relative humidity reductions (drier) in this fractured rock mass where fracture density and connectivity are somewhat representative of that expected for Yucca Mountain, and where saturation and matrix properties are also representative.

- Whether heating can generate significant condensate buildup above the heaters, and whether condensate shedding affects the moisture movement.

- The extent to which heterogeneity in the gas- and liquid-phase pathways can focus condensate drainage. If this were to occur in the repository, it could cause heat-driven moisture to contact waste packages and drive radionuclide transport.

- How long rewetting to humid conditions lags behind the end of the heating period.

- The significance of buoyant, gas-phase convection in affecting moisture movement.

- The significance of binary gas-phase diffusion in moisture movement.

Each of these issues will be posed as a hypothesis to be tested; these hypotheses and the associated pre-test calculations will be documented before test start-up.

Thermal and moisture barriers and guard heaters will be installed around the outside of the block so that the movement of moisture in the block is as close to one-dimensional as possible. The deformation of the fractures during the test will not be constrained. The effect is probably not significant for those portions of the thermohydrological processes that are largely dominated by the matrix. Those processes that depend on fracture aperture or asperity contact/stress will very likely be affected by the differences between in situ tests and the Large Block Test. In the Large Block Test, the fracture system may open up because of applied thermal loading. To minimize the potential for block instabilities or disintegration, a restraint system will be designed that consists of vertical tie downs and horizontal banding or straps, similar to that on the block now. These independent systems are designed to prevent toppling, block mobilization, and fracturing, but they cannot prevent twisting or similar deformations that could result in shearing along fractures. The rock may fracture between the heater holes, but these fractures will not invalidate the test as long as the block remains stable.

The test will be conducted in stages, starting with sub-boiling heating, that can be reached quickly. Then the block will be heated to a maximum temperature of about 140°C at the heater plane followed by a cool-down phase that will be conducted so that the hypotheses that have been identified can be evaluated, and test methodology/instrumentation can be tested to temperatures that would be appropriate for the Engineered Barrier System field tests.

An engineering plan was developed for the Large Block Test. Included in the plan are detailed construction operation procedures. The draft plan was revised after the test was rescoped to eliminate the load retaining frame and is currently in review.

The large block was protected with insulation material so that the influence of weather on the block was minimized. The high wall to the west of the large block was determined to be safe. The excavation to prepare the ground for the concrete pad around the large block was completed. The drilling of the horizontal instrument holes was started in mid March.

Fracture mapping of the five exposed surfaces of the large block was completed. Modeling of the fracture data using Earth Vision was used to project the fracture distribution within the block. The model was used to specify the location of the horizontal instrument boreholes and the surface instruments. The fracture locations will be verified during the drilling of these holes.

A progress report was prepared (Lin et al., 1995).

Small Block Tests in the Laboratory

The initial moisture content of some small samples obtained adjacent to the large block during the excavation was determined using the drying/saturation technique. All samples showed a level of saturation above 95 percent, which is greater than the 60 to 80 percent determined previously in some of the vertical boreholes by using neutron logging. The discrepancy is probably caused by the water used in drilling the pre-split holes before the excavation.

A few dozen small blocks were shipped to the laboratory for testing. Laboratory activities are summarized in Sections 5.2.3 and 5.2.4.

Exploratory Studies Facility Tests

A Project-wide effort was initiated to consolidate thermal test planning in support of ESF tests in this study and studies in SCP Section 8.3.1.15.

Activity 1.10.4.4.2 - Sampling and Sample Analyses. The objective of this activity is to collect and analyze material samples (rock, gas, and water) before, during, and after heating of the rock. The laboratory analyses of the samples will determine hydrologic and geochemical properties of the rock and chemistry of the gas and water.

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

Activity 1.10.4.4.3 - Pre- and post-test calculations. The objective of this activity is to perform scoping calculations in support of test design, planning document development, and reducing and analyzing test data. This activity includes the verification and validation process necessary to qualify the numerical methods to be used if such verification and validation has not been accomplished by another activity.

Three pre-test model calculations have been conducted. These models are homogeneous permeability, horizontal heterogeneous permeability, and vertical heterogeneous permeability. The temperature distribution in the block is not sensitive to the heterogeneity; however, the moisture distribution in the block strongly depends on the heterogeneity distribution. A progress report on the pre-test scoping calculations was written (Lee, 1995).

Forecast: The Large Block Test instrument holes will be drilled and the core analysis will be used to refine the Earth Vision fracture model. Gas permeability measurements will be used to analyze the fracture network. Instrument procurement will continue.

5.2.6 Study 1.10.4.5 - Characterize the Effects of Introduced Materials on Water Chemistry in the Postemplacement Environment

The objective of this study is to identify significant chemical modifications of the near-field environment from what would be expected under natural conditions. The modifications are caused by the construction and operation of the repository. The natural conditions are defined by Study 1.10.4.1 (Section 5.2.5). A complete picture of the modified chemical system thus includes, in addition to construction materials, introduced air and water, the reintroduction of crushed tuff or muck and the introduction of accompanying microbial populations.

Activity 1.10.4.5.1 - Effect of grout, concrete, and other repository materials on water composition. This activity is being deleted by a change to the Site Design and Test

Requirements Document. Its objectives have been 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. This activity is being deleted by a change to the Site Design and Test Requirements Document. Its objectives have been 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. This activity is being deleted by a change to the Site Design and Test Requirements Document. Its objectives have been moved to new Activity 1.10.4.5.7.

Activity 1.10.4.5.4 - Numerical analysis and modeling of introduced materials/water interaction. This activity is being deleted by a change to the Site Design and Test Requirements Document. Its objectives have been moved to new Activity 1.10.4.5.11.

Activity 1.10.4.5.5 - Integration: Program Planning; identification, characterization and screening of materials; and bibliographic maintenance and literature review. The objectives of this activity are to prepare planning documents, to develop a list of materials that might be used in the repository (including locations, quantities, and concentrations), to develop a chemical data base regarding the materials, to rank the materials on the basis of aggressiveness under expected and certain unexpected repository conditions, to identify materials for which information is inadequate, and to gather, synthesize, and evaluate data from the literature. These objectives are not necessarily sequential, and some products will be updated throughout the study.

Organizational work has begun on developing activity plans. Authors were selected to write plans for the ESF swipe tests (part of SCP Activity 1.10.4.5.7), microbial effects testing (part of SCP Activity 1.10.4.5.9), and computer module development (1.10.4.5.11).

An activity intended to support the identification of significant construction materials is being developed. Ultimately this activity will provide a decision-making matrix of materials, chemical consequences and alternative materials. An annotated bibliographic reference data base is being developed to support the materials activities. Background materials concerning microbially induced corrosion and the proposed Yucca Mountain repository are being assembled and examined in support of the bibliographic data base. Work has also begun to assemble literature for the selection of appropriate historical analogs for study. The literature will augment the bibliographic data base. A literature review of microbially mediated chemistry is also being developed.

Activity 1.10.4.5.6 - Solubility and stability experimental studies at ambient and elevated temperatures. The objective of this activity is to conduct dissolution and precipitation kinetics experiments to determine the sensitivity of the kinetics to temperature and fluid composition. Stoichiometric and nonstoichiometric dissolution, and saturated and unsaturated environments will be addressed. The experiments are intended to identify dissolution and precipitation mechanisms, the effects of solid solution on rates of dissolution and precipitation,

the solid reaction products, and the resulting water chemistry. Solid, liquid, and gas phase stability will be addressed.

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

Activity 1.10.4.5.7 - Chemical reactivity stability experimental studies at ambient and elevated temperatures. The objective of this activity is to conduct chemical reactivity experiments on soluble products of introduced solid phases, on introduced organic and inorganic fluids, on introduced material interactions with water and vapor in the presence of a radiation field, on the potential effects of introduced materials on predicted natural chemical reactions, and on the significance of natural mineral moderation (e.g., zeolites and buffering effects) on the aggressiveness of introduced materials.

Scoping experiments in the diesel fuel hydrous pyrolysis area have been completed. The final report is presently in technical review, and is expected to be published by November 1995.

The present focus of the Project in the area of introduced materials is the use of diesel fuel in the ESF. The isotopic composition of the stable isotopes (C, N, and O) in diesel exhaust and its associated particulate materials has the potential for altering the isotopic composition of materials in or around the ESF, particularly water. Stable isotopic signatures are routinely used in hydrologic studies. These emissions could potentially alter the isotopic composition in natural systems and therefore warrant careful characterization.

The isotopic composition of water and other aspects of the natural environment may be significantly altered by the construction of the ESF. This construction can be viewed as the imposition of a larger and more complex chemical system of interdependent effects. Diesel fuel/exhaust is only one part of the potential chemical modification alteration of the natural environment. For example, the exposure of the local rock to air by excavation may have a major impact on stable isotopic signature. The isotopes of other important elements such as chlorine may be affected by introduced materials. In addition to the disturbance of isotopic systems, an environment having altered CO_2 concentrations could possibly have other effects. For example, increased carbonation of concrete has been observed in the biosphere, where there are elevated CO_2 levels (Severinghaus, 1994).

Activity 1.10.4.5.8 - Colloid stability experimental studies at ambient and elevated temperatures. The objective of this activity is to identify introduced materials that can produce colloids, their nature, and their stability. This activity is intended to complement other work being conducted in Study 8.3.1.3.5.2.

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

Activity 1.10.4.5.9 - Biodegradation stability experimental studies at ambient and elevated temperatures. The objective of this activity is to identify and characterize microbes that might be introduced into the repository, and microbes (both native and introduced) that derive nourishment from introduced materials that could be brought into the repository. The

activity will identify introduced materials that will encourage microbe growth, identify chemical products of microbial degradation, and identify and evaluate the potential for introduction and growth of microbes from external sources. This activity is intended to complement other work being conducted in Study 8.3.1.3.4.2.

The ESF swipe test isotopic study described in Activity 1.10.4.5.7 can be used to define important aspects of microbial ecology (e.g., CO_2 metabolism) in the ESF, which will be of significance to understanding test interference and can be used as an analog to a repository environment.

A Technical Workshop on Microbial activity at Yucca Mountain was scheduled for the second week of April 1995. The Project enlisted the expertise of the microbial biology scientific community at large as well as key technical representatives within the Project, to help develop the subactivity plan for work in microbial degradation. The immediate aim is to define the relevance of microbiologically influenced corrosion-related processes on the design of a radioactive waste repository under conditions similar to those at Yucca Mountain, to determine key parameters that must be considered in evaluating microbiologically influenced corrosion in a disturbed subterranean environment, and to direct the most effective means of investigating the identified factors.

Activity - 1.10.4.5.10 - Historical analogs. The objective of this activity is to identify sites of interest (determined from the materials list developed in Activity 1.10.4.5.5) to collect samples from these sites, to analyze the samples for the information identified in Activity 1.10.4.5.5 to provide constraints for the experiments in Activities 1.10.4.5.7, 1.10.4.5.8, and 1.10.4.5.9 and to provide long-term data not obtainable from experiments for the development of the introduced material-rock-water interaction simulation activity (1.10.4.5.11).

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

Activity 1.10.4.5.11 - Computer modeling and code development. The objective of this activity is to develop the necessary codes (if not otherwise available) and to conduct predictions and simulations of experiments, natural analogs, and repository performance with respect to introduced materials effects on the near-field environment. Validation of developed models is included in this activity. This activity is complementary with Study 8.3.4.2.4.1.

The present approach to this activity is that the most efficient and cost-effective direction in chemical modeling is to produce material-class-specific chemical modeling modules. Each module will highlight the significant chemical concerns of a chemical class of materials. Each module will incorporate the appropriate, EQ3/6-based, abiotic and microbial sub-modules. Many of the microbial aspects of the sub-modules will be addressed in the biochemical workshop that is described in Activity 1.10.4.5.9. The material-class-specific chemical modules will create a tractable modeling effort, because the modules can be process and location specific. The modular approach also appears to be the most efficient manner to develop and maintain flexibility in predictive capabilities, and to address inevitable modifications in repository construction and design features.

Related International Work. Please see Section 5.2.7 for related work (under the heading Fundamental Materials Investigations) performed under the auspices of the OCRWM international program.

Forecast:. Study plan comments will be resolved and three activity plans will be completed. Development of computer modules will continue. A preliminary report on historical analogs will be completed.

5.2.7 Related International Postemplacement Near-Field Environment Work

Design and Analysis of Disturbed Zone Experiments

The following is work related to Study 1.10.4.2 (Section 5.2.3), conducted cooperatively with Sweden under the auspices of the OCRWM international program.

During the previous reporting period, laboratory experiments in transparent fracture replicas demonstrated that (a) the magnitude of liquid flow reduction caused by gas phase formation following pressure reduction is controlled by fracture geometry, and to a lesser degree by the partial pressure of the dissolved gas, and (b) the gas phase accumulates in the larger apertures and does not go back into solution as predicted by theoretical models that assume chemical equilibrium between the gas and liquid phases. An understanding of this phenomenon is necessary to apply the results of hydrologic characterization conducted in the near-drift region to the undisturbed formation. In all cases modeled using TOUGH2, flow reductions due to degassing were comparable to analytical solutions developed in FY 1993, but significantly smaller than observed in the laboratory experiments. The study included finite and infinite systems and examined transient and steady state behavior. Preliminary modeling of degassing using actual aperture distribution of fracture replicas used in the laboratory experiments suggested that nonequilibrium effects will have to be added to TOUGH2 to represent degassing effects in the laboratory properly. Degassing refers to the formation of two-phase flow conditions when the reduction in ground-water pressure causes dissolved gases to come out of solution. Laboratory degassing experiments with radial flow geometry (converging flow) indicated the same order of flow reduction compared with the linear flow tests. Simulations with TOUGH2 are utilizing data from the field and laboratory experiments to test the prevailing conceptual model of two-phase flow for degassing conditions. Corresponding work is not planned for investigations at Yucca Mountain. Nevertheless, the insights to be obtained will advance the fundamental understanding of two-phase flow in fractured rock, relevant to issues of fast-path flow at Yucca Mountain, as well as, the understanding of likely changes in the unsaturated zone that will be caused by heating, degassing, and vaporization induced by the emplacement of waste. A test plan for degassing and two-phase flow experiments at the Hard Rock Laboratory (Äspö, Sweden) was developed by the project participants. Core samples of fractures in the region of the test site were shipped to participants.

During this reporting period, a pilot degassing test at the Hard Rock Laboratory in Äspö, Sweden, was conducted. The purpose of the pilot test was to study the effect of

degassing on borehole inflow rates, as a function of borehole pressure. Tests during December 1994, showed no evidence of degassing; however, tests conducted during January and February 1995 indicated a reduction in transmissivity that could have been caused by degassing. The difference in test results is attributed to an increase in gas contents measured between December and January. The low gas contents measured in December suggest that the borehole pressures below the partial pressure of the dissolved gases in the ground-water were not obtainable with the existing equipment configuration.

Forecast: A second series of degassing tests has been proposed, to be conducted in another borehole at the Hard Rock Laboratory where the ground-water dissolved gas contents are higher. The proposed test series includes gas injection tests to measure two-phase flow parameters. The TOUGH2 numerical model will be tested with laboratory data from additional fracture replicas and flow geometries to assess how to improve the model representation of experimental results. The focus will be on improved representation of fracture aperture distribution and the incorporation of nonequilibrium degassing and dissolution processes. Laboratory degassing experiments will be conducted on replicas from the Hard Rock Laboratory and Yucca Mountain fractures to test the current hypotheses of the importance of fracture geometry on the extent of flow reduction due to degassing for a wider range of fracture geometries.

Effects of Grouting Around an Excavation

The following is work, related to Activity 1.5.5.2 (Section 5.6.12), and Activity 1.6.2.1 (Section 6.5.1), conducted cooperatively with Sweden under the auspices of the OCRWM international program.

The original intent of this task was to use data on grouting to determine the value of a homogeneity parameter (σ), which has been found to be a useful quantitative measure of the field-scale heterogeneity of permeable media, in an analytic model (the log-normal transport model) for transport through fractured permeable media. The basic analytical development of the log-normal transport model has been completed, and some applications have been developed for bounding radionuclide release at Yucca Mountain. Chesnut (1994a) describes the model in Section 6.5 of this report. Applications to the ground-water travel time issue and forecasts of radioactivity release to the accessible environment are discussed in Sections 6.5 and 5.6.12 of this report and have also been published (Chesnut, 1994b).

Currently, investigators are using all available data, including probe hole inflow measurements and tracer tests to determine the heterogeneity parameter (σ). A draft report on analyses of these data will be completed shortly. In addition, work is under way to extend the theoretical development to nonisothermal systems for application to the near field environment at Yucca Mountain. This involves a combination of analytical development and numerical modeling, and a progress report is almost complete.

All of this work has direct application to Yucca Mountain. Subject to continuing comparisons of the log-normal transport model with field observations and numerical models, it appears to offer a realistic bound to field-scale transport processes that replaces the classical

dispersion approach. A particularly useful result is that the parameter is much less sensitive to the spatial and temporal scale of the transport process than is the apparent dispersivity, making it possible to scale up from short-term tests over limited distances.

Forecast: The basic analytical development of the log-normal transport model has been completed, and some applications have been developed for bounding radionuclide release at Yucca Mountain. Parameters for Yucca Mountain will be determined by analysis of cosmogenic and bomb-pulse isotope data. Work on data from Sweden will include application to new tracer experiments as data become available, and comparison with more detailed modeling efforts to determine if they can be adequately represented by this simplified approach. The method will be modified to accommodate uncertainty in the parameters.

Fundamental Materials Investigations

The following is work related to Study 1.10.4.5 (Section 5.2.6), conducted cooperatively with Canada under the auspices of the OCRWM international program.

During the previous reporting period, experimental work began to obtain thermodynamic data for crystalline phases present in cementitious materials that may be emplaced in a repository at Yucca Mountain. Experiments have been initiated to determine the phases that may occur at elevated temperatures, with emphasis on calcium silicate hydrates in cement-based grouts and concretes. The behavior of these materials during the lifetime of the repository may affect the chemistry of associated fluid phases with which they are in contact, analogously to the response of the host rocks. Heating of these materials has the potential to release large quantities of water from the hydrated phases.

During this reporting period, the following progress was made: (a) Ca-Si-H_2O phases (pure phases of 1.1 nm tobermorite, xonotlite, and hillebrandite) have been synthesized and are ready for distribution to the sites selected for thermodynamic measurement; (b) thermodynamic measurement of Ca-Si-H_2O phases began (sample encapsulation began for samples to be measured by drop calorimetry, and development of sample encapsulation methodology for samples to be measured by differential scanning calorimetry and by heat pulse calorimetry began); (c) relative humidity studies continued (experimental work continued on the stability of calcium silicate phases as a function of relative humidity); (d) chemical modeling work began (work began to develop the abiotic chemical module for cementitious materials, which will have EQ3/6 as its base, but will be far more flexible for the application to Portland cement-based materials and will allow quick assessment of new and expanded data base sets that have been developed as a result of present and previous work in this program).

Forecast: Syntheses of 1.4 nm tobermorite, afwillite, gyrolite, and okenite are planned. In addition to the phases noted above, these minerals are required to model the chemical degradation of cementitious materials that would be emplaced in a repository. These phases will be characterized by nuclear magnetic resonance and x-ray diffraction. In addition, their hydration and dehydration behaviors will be investigated and investigations conducted to provide information on water availability as a function of temperature and repository life and to determine their thermodynamic properties in a more definitive manner than presently exists.

The equipment required to pursue these experiments, at elevated temperature, is expected to arrive. Much of the planned work is described by Meike et al. (1994).

5.3 CHARACTERISTICS AND BEHAVIOR OF THE WASTE FORM (SCP SECTION 8.3.5.10)

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

Subactivity 1.5.1.1.1 - Integrate spent fuel information. The Preliminary Waste Form Characteristics Report was published and distributed. An assessment of the spent fuel testing data and model needs is being written in support of the Controlled Design Assumptions Document (CRWMS M&O, 1995a).

Subactivity 1.5.1.1.2 - Integrate glass waste form information. As part of the glass model development effort, work is continuing on collecting and evaluating borosilicate glass dissolution data that are obtained outside of the Project. These data will be evaluated for inclusion in the next version of the Waste Form Characteristics Report.

Subactivity 1.5.1.1.3 - Integrate waste package and repository design information. The waste form characterization staff collaborated with the design staff to ensure that the characterization envelope is consistent with the design features being considered.

Forecast: Data obtained will be incorporated into a draft revision to the Waste Form Characteristics Report. This report is expected to be revised by section, rather than as a whole.

5.3.2 Activity 1.5.2.1 - Characterization of the Spent Fuel Waste Form

Subactivity 1.5.2.1.1 - Dissolution and leaching of spent fuel. The purpose of spent fuel waste form testing is to develop the predictive models and the technical bases for determining the rate of release of radionuclides from failed disposal containers under conditions appropriate to the potential repository. A systematic effort has been ongoing for several years to determine the effect of temperature and water chemistry on the dissolution response of the spent fuel inventory from unirradiated UO_2 to high burnup spent fuel. The current dissolution/release testing techniques in progress are flow-through tests and unsaturated tests. The flow-through tests have large ratios of water volume to surface area, and test solution concentrations remain below the solubility limits for the actinides. The unsaturated tests have low ratios of water volume to surface area, resulting in a drip/film flow mode of dissolution/release testing. The test solutions have colloidal formations. This effort also includes dissolution testing of the higher oxidation states of uranium because of the potential degradation of spent fuel by oxidation in a repository, before water contact.

Flow-Through Dissolution Testing of Oxidized Fresh Fuel

A flow-through test plan for UO_{2+x} experiments delineated a minimum of 16 experiments to determine the effects of temperature and water chemistry on the dissolution of the higher uranium oxides. By the end of December, all original 16 experiments were completed. Also, 8 additional experiments, consisting of the remaining temperature pairs of the original 16, were finished. The spent fuel flow-through plans have test matrices that will determine the dissolution rate response for the different spent fuel types (pressurized water reactor/boiling water reactor) over the range of burnup and fission gas release plus some aggressive water chemistries and temperatures of potential environments in a repository.

On the basis of the above dissolution testing, a series of EQ3/6 computer calculations were completed to better understand the observed dissolution response of $UO_3 \cdot H_2O$ in equilibrium with high carbonate solutions and the consequent lowering of the solution pH. Various uranyl carbonate complexes form when carbonate solutions contact uranium oxides. The formation of these complexes releases hydrogen ions into solution from the bicarbonate anion, thus lowering the pH of the solution.

Flow-through Dissolution Testing of Spent Fuel

Gray and Wilson (in prep.) documents progress and results for continuing studies of the dissolution behavior of spent fuel.

Unsaturated Dissolution Testing of Spent Fuel

The unsaturated dissolution tests are in progress to evaluate long-term dissolution/release performance of spent fuel. The current test matrix has two approved testing materials [approved testing material-103 (30 MWd/kgU pressurized water reactor fuel) and approved testing material-106 (43 MWd/kgU pressurized water reactor fuel)]. These tests examine the dissolution behavior of pressurized water reactor fuels in a saturated water vapor atmosphere and in dripping water at two drip rates. Initial results from the two low-drip-rate tests indicate spent fuel alteration has occurred and suggests a possible oxidation mode of the fuel in the repository that occurs by contact between the fuel and liquid. These tests have also shown that waste form colloids are a significant means of release for transuranics for low water volume modes of wetting. This colloidal mode of radionuclide transport needs to be addressed in the waste package/Engineered Barrier System release models. The observations made in both of these test activities have ramifications for the performance of waste in the Engineered Barrier System, the design of the Engineered Barrier System, and the performance of the repository.

Subactivity 1.5.2.1.2 - Oxidation of spent fuel. The oxidation response of spent fuel under repository conditions depends primarily on temperature and time after the spent fuel is exposed to atmospheric oxygen. The oxidation response of spent fuel is a degradation/alteration mode that can significantly increase the potential radionuclide release rate in the repository. This is because the UO_2 phase of spent fuel transforms to a U_4O_9 lattice (slight volume decrease) and then to U_3O_8 (~30% volume increase), increasing the spent-fuel surface

area exposed relative to the original pellet fragment/grain area. The U_3O_8 phase can split the Zircaloy cladding open lengthwise. Dry bath oven tests are in progress to determine spent fuel oxidation response. These are long-term weight gain tests conducted in a hot cell. These tests are primarily providing low-temperature (less than 200°C) oxidation response, but one dry bath recently was set to operate at 255°C to accelerate the oxidation rate. On the basis of information obtained from the dry bath oven tests, thermogravimetric apparatus tests were initiated at a higher range of temperature (250° to 320°C). These two types of tests will provide temperature-time-phase response as UO_2 spent fuel oxidizes to U_4O_{9+x}, to U_3O_8, and finally UO_3.

The dry bath oven tests show an initial oxidation response of UO_2 by a U_4O_{9+x} phase front propagating into the UO_2 spent fuel grains. This U_4O_{9+x} phase has an oxygen-to-uranium metal ratio of ~2.4. The $UO_{2.4}$ is considered a metastable phase structure, and at low temperatures (less than 200°C), a plateau in the oxygen to uranium metal ratio vs. time curve is observed. To assess the stability time of the plateau domain, one dry bath is currently being operated at 255°C. Thus, dry bath oven data are currently being obtained at temperatures of 110°, 130°, 175°, 195°, and 255°C.

The thermogravimetric apparatus tests are complementary to the dry bath tests and can provide higher temperature-time response data. Also, the thermogravimetric apparatus tests provide a better weight gain versus time response data set, which, in conjunction with microscopy, can be used to gain a mechanistic understanding of the time-temperature kinetics and the transition from the $UO_{2.4}$ plateau phase to U_3O_8. On the basis of preliminary scoping thermogravimetric apparatus tests, a test plan and an activity plan were completed. The first test matrix in this activity plan addresses the data needs for the influences of temperature on the $UO_{2.4}$ plateau time interval before the initiation of the U_3O_8 phase transition. The formation of the U_3O_8 phase has significant impacts on spent fuel release rate performance in potential repository environments.

Subactivity 1.5.2.1.3 - Corrosion of zircaloy. No progress was made during the reporting period; this was an unfunded activity.

Subactivity 1.5.2.1.4 - Corrosion of and radionuclide release from other materials in the spent fuel waste form. No progress was made during the reporting period; this was an unfunded activity.

Subactivity 1.5.2.1.5 - Evaluation of the inventory and release of carbon-14 from zircaloy cladding. No progress was made during the reporting period; this was an unfunded activity.

Subactivity 1.5.2.1.6 - Other experiments on the spent fuel waste form. No progress was made during the reporting period; this was an unfunded activity.

Forecast: The flow-through and unsaturated dissolution release rate testing of spent fuels will continue as per the existing test matrices in the activity plans. The oxidation/

degradation spent fuel testing in the oven dry baths and in the thermogravimetric analysis apparatus will continue per the existing test matrices in the activity plans.

5.3.3 Activity 1.5.2.2 - Characterization of the Glass Waste Form

Subactivity 1.5.2.2.1 - Leach testing of glass. Long-term unsaturated tests (drip tests) of two glass compositions (Defense Waste Production Facility and West Valley approved testing material-10) continue in two test series labeled the N2 and N3 series. These tests are being used to determine the types and quantities of radionuclide elements released from waste glasses when subjected to an intermittent dripping water contact scenario. Both soluble and colloidal radionuclide releases of actinides and technetium are being measured. A 304L stainless steel sample holder is also present in these tests to ascertain the influence of the pour canister material on glass waste form behavior.

The Defense Waste Production Facility glass is being tested in the N2 test series, which has been in progress for over nine years as of March 31, 1995, and were sampled on December 19, 1994. The West Valley glass (approved testing material-10) is being tested in the N3 test series, which has been in progress for almost eight years as of March 31, 1995, and were sampled on January 12, 1995. Solution samples from both series were subjected to sequential filtering and the particles are to be analyzed using analytical electron microscopy.

These tests are providing data on radionuclide release mechanisms and degradation/alteration rates of glass waste forms. These data are being used to constrain and guide ongoing model development for glass corrosion. Additional glass waste form testing will be required to model glass degradation/alteration modes and the subsequent dissolution/release of radionuclides as soluble and colloidal species over the range of potential repository environments.

Subactivity 1.5.2.2.2 - Materials interactions affecting glass leaching. The N2 and N3 test series contain stainless steel holders that simulate the presence of the 304L pour canister in the repository. Colloidal-sized iron particles have been identified in the N2 and N3 test solutions, which is important because sorption of radionuclides onto these particles provides a transport mechanism for radionuclides that is not solubility controlled.

Preliminary results from the N3 tests show variability in the extent of iron metal corrosion from the 304L holder. The controls on the extent of metal corrosion are important because this corrosion provides a source of iron colloids for radionuclide transport.

Subactivity 1.5.2.2.3 - Cooperative testing with waste producers. No progress was made during the reporting period; this was an unfunded activity.

Forecast: Degradation/alteration testing of the glass waste form in these long-term unsaturated tests will continue. Analysis of colloids from previous tests will be limited because of restricted funding. Ongoing long-term scoping tests on additional glass compositions will be brought up to quality affecting status as funding becomes available.

5.3.4 Activity 1.5.3.1 - Integrate Scenarios for Release From Waste Packages

Subactivity 1.5.3.1.1 - Develop scenario identifications. The development of the Yucca Mountain Integrating Model (YMIM) code (Gansemer 1995) continued. Information pertaining to this development is provided in Section 5.3.8.

Subactivity 1.5.3.1.2 - Separate scenarios into anticipated and unanticipated categories. No progress was made during the reporting period; this was an unfunded activity.

Subactivity 1.5.3.1.3 - Development of parameters describing the scenarios. Information pertaining to this subactivity is provided in Section 5.3.8.

Subactivity 1.5.3.1.4 - Determine adequacy of design envelope of waste package. No progress was made during this reporting period; this was an unfunded activity.

Forecast: A preliminary list and description will be developed of anticipated features, processes, and events that may have to be considered in analyzing the substantially complete containment requirement. Model development for the features, processes, and events will continue; see the forecast for Section 5.3.8.

5.3.5 Activity 1.5.3.2 - Develop Geochemical Speciation and Reaction Model

Subactivity 1.5.3.2.1 - Develop data base for geochemical modeling. Participants proposed a strategy for qualifying data for the GEMBOCHS database.

A five-year strategy for work in the Thermodynamic Data Determination Task has been developed by the intraproject Solubility Working Group. The work scope includes funding for the United States contribution to the Organization for Economic Coordination and Development/Nuclear Energy Agency Technical Volumes on thermodynamic data. Funding for FY 1995 supports the Organization for Economic Coordination and Development/Nuclear Energy Agency volumes for technetium, neptunium, plutonium and americium. The readiness review process is nearly complete for the laboratory effort to determine thermodynamic constants for Am(III), Pu(V), and U(VI) as a function of temperature.

Two manuscripts describing this work were being prepared. One paper (Johnson and Lundeen, in prep.[a]) describes the standard seven-element suite of thermodynamic data bases distributed with EQ3/6; emphasis is placed on describing the theoretical and empirical algorithms used to calculate thermodynamic properties at elevated pressure-temperature, and the specific modeling applications for which the individual data bases are particularly well suited. The second paper provides a complete set of user documentation and tutorials for the Jewel code (Johnson and Lundeen, in prep.[b]).

The GEMBOCHS data base itself was augmented significantly by incorporation of the CHEMVAL4 and CHEMVAL5 thermodynamic data bases, each of which contain approximately 1,000 chemical species. These stand-alone data bases, which are now available

for use with EQ3/6, are commonly used for comparative radiological assessment calculations in Europe. In addition, incorporation began on the comprehensive NIST (Smith-Martell) data base of critical stability constants for metal complexes (over 4,000 species). Many smaller-scale improvements in GEMBOCHS data (and software) were also completed.

A new Individual Software Plan for the GEMBOCHS system was generated, formally reviewed, and the review comments resolved; the plan was approved and is now in place. A revised Software Configuration Management system was also established.

Related International Work. See Section 5.3.12 for related work (under the heading Thermochemical Data Base) performed under the auspices of the OCRWM international program.

Subactivity 1.5.3.2.2 - Develop geochemical modeling code. This subtask is developing geochemical modeling software (EQ3/6) for analysis and simulation of interactions among water, rock, nuclear waste, and other repository components in the near-field environment, the altered zone, and the far-field environment. In FY 1994, the independent verification and validation activity for the Version 7 series of the software was completed, and Version 7.2a become the first version of EQ3/6 to be certified for use in quality-affecting work. New capabilities for thermodynamic pressure corrections and ion-exchange modeling (incorporating the Gapon and Vanselow models) were added to Version 8.0. This followed the earlier addition of a capability to deal with redox disequilibrium in reaction-path calculations. In FY 1995, the Version 7 software is being maintained, an independent verification and validation activity leading to the certification of Version 8.0 is being conducted, and capabilities for modeling phenomena associated with boiling are being added to the software. These new capabilities will be applied in other work breakdown structure elements, principally those dealing with the geochemistry of the altered zone and the near-field environment. Version 8.0 was set up for in-house beta testing, which may last all or part of the verification and validation period.

The development of EQ3/6 to deal with phenomena associated with boiling is planned as a two-year effort (FYs 1995 and 1996). In FY 1995, the software is being modified to include a capability for dealing with a general multi-component gas phase, with an emphasis on the case of a steam-dominated phase. In boiling systems, the loss (or gain) of other, minor volatile components such as CO_2 may have a major effect on concomitant processes such as mineral deposition. To complete the gas phase submodel, various published models for calculating fugacity coefficients are being examined for their usefulness for application to steam-dominated phases. Calculations of enthalpy and volume balances are being added to the software, but during FY 1995, this will be restricted to the calculations of changes in enthalpies and volumes. In FY 1996, capabilities to use the corresponding balance equations to compute, for example, the change in temperature associated with a given heat input, will be included.

In FY 1995 and FY 1996, the software may be improved to deal with the possibility of formation of concentrated solutions caused by boiling. As time permits, there also may be

some further additions to the ion-exchange modeling capability, such as the addition of the Gaines-Thomas model and a general site-mixing model.

In recent work, the Version 8 input files for EQ3NR and EQ6 have been improved for ease of use. The descriptive strings used in the menu-style input format have been upgraded for succinctness, accuracy, and understandability. Several numerical parameters used by the EQ6 code have been removed from the EQ6 input file and are now simply set in the code itself. A recent minor change was made to allow the pressure to be set to follow the 1.013-bar/steam-saturation curve value even if the data file reference pressure curve is something different, such as a constant 500 bars.

In response to the recent concern in performance assessment about the reported high solubilities of neptunium observed in experimental systems (Nitsche, 1991), calculations were made of likely neptunium mineral solubilities in UE-25 J#13 water (under oxidizing conditions, at 25°C using EQ3/6 Version 7.2a). If the solubility-governing phase is assumed to be NpO_2(c), the predicted concentration is 1.331×10^{-13} molal (87.02% NpO_2^+). Such ground water is vastly undersaturated with other neptunium minerals.

However, if the solubility-governing phase is assumed to be Np_2O_5 (one of the two neptunium solids identified in Nitsche's experiments), the predicted concentration is 2.679×10^{-3} molal, a 10 order of magnitude increase (the speciation of dissolved neptunium is barely changed). The solution is vastly supersaturated with respect to NpO_2, as expected. The UE-25 J#13 water that is saturated with NpO_2 is also very nearly saturated with respect to $NaNpO_2CO_3$:$3.5H_2O$ (the other neptunium phase observed by Nitsche, though with some stoichiometric variation) and NpO_2OH(am). The concentrations of dissolved neptunium corresponding to equilibrium with these phases are 7.791×10^{-4} and 8.202×10^{-4} molal, respectively. The calculated concentrations for Np_2O_5, $NaNpO_2CO_3$:$3.5H_2O$, and NpO_2OH(am) are all close to the values observed by Nitsche (1991).

To summarize, NpO_2 is a very stable phase; solubility equilibrium yields an extremely low concentration of dissolved neptunium. If NpO_2 does not form rapidly (as was apparently the case in Nitsche's experiments), then the concentration of dissolved neptunium is controlled at approximately the 1×10^{-3} molal level by metastable equilibrium with one of the two metastable phases: Np_2O_5 or $NaNpO_2CO_3$:$3.5H_2O$. Whether or not NpO_2 controls the level of dissolved neptunium in a real system appears to be a problem of kinetics. Apparently it does not readily form in UE-25 J#13-like waters at low temperatures (<90°C) and the relatively short time frame of benchtop experiments (60 to 150 days). There is no reason to suspect that the thermodynamic stability of NpO_2 is grossly in error. Considering that the time scales involved for a real repository are so much longer than those that pertain to the benchtop experiments, NpO_2 formation is likely to have an effect in the repository. Some understanding of the kinetics of the process, however, will be necessary if any credit for this can be taken in repository performance assessment. Similar calculations, providing qualitatively the same result, were done by Los Alamos and reported as part of the work for developing the solubility models for the dissolved species concentration limits (see Activity 8.3.1.3.5.1.2).

Examples of very stable (insoluble) minerals which are slow to form in real systems on short time scales, are not unknown in geochemistry. Dolomite ($CaMg(CO_3)_2$) is perhaps the best known example. The dolomite problem has been studied, in part, by conducting experiments at elevated temperatures (150° to 200°C), where the formation of this mineral can be observed (for a review of such work, see Sibley et al., 1994). An approach to the neptunium problem might be to conduct analogous studies.

Forecast: Three accomplishments are expected in the next reporting period. These are a letter report on software maintenance activities, a progress report on the development of capabilities for modeling boiling systems, and a letter report on the independent verification and validation activities and the QA status of the software.

5.3.6 Activity 1.5.3.3 - Generate Models for Release From Spent Fuel

Subactivity 1.5.3.3.1 - Generate release for spent fuel models. The model development for release of radionuclides has been guided primarily by the flow-through dissolution rate data from spent fuel and unirradiated UO_2 testing. Because the water chemistries of these flow-through tests are aggressive, the preliminary models are believed to be upper bounds for actual repository dissolution rates. These flow-through tests have large ratios of water volume to wetted fuel surface area. In providing release rates for more general cases, however, functional forms are multiplicatively coupled in the release model. The functional forms describe the amount of spent fuel area wetted, the spent fuel degradation/alteration oxidation phase state, the above-mentioned dissolution rate data, and now, a possible dependence on the wetting mode.

The spent fuel area wetted will depend on the failed state of the cladding. For cladding failures with small cracks, significant reduction (several orders of magnitude) in exposed fuel surface area can be attained. This reduces the release rate response proportionally. The surface area reduction models, however, will require future characterization of cladding failures for use in any quality-affecting design analysis, as well as dissolution/release tests to substantiate the modeling concepts. Activities are in progress to provide data for the degradation/alteration oxidation phase state and the dissolution rate data. The last functional form, the wetting mode, has been sub-classified according to the flow-through testing (large flowing water volumes relative to the surface area wetted), the saturated testing (large non-flowing water volumes relative to the surface area wetted), and the unsaturated testing (small water volumes, a film flow mode relative to the surface area wetted). The last testing technique has also been termed the drip test, and only recent and limited test data are available. Results from these tests indicate significant concentrations of colloid formation. The colloid formation and the film flow wetting regime of these unsaturated tests require that new and more complex functional expressions be incorporated into dissolution/release rate models.

Forecast: Extension of the preliminary dissolution/release rate modeling to include solid-liquid interface effects, wetting mode effects, colloidal effects, and thermodynamic

chemical potential terms will continue. A semi-empirical modeling approach for a spent fuel degradation/alteration oxidation response will continue.

Related International Work. See Section 5.3.12 for related work (under the heading Spent Fuel Dissolution Model Development) performed under the auspices of the OCRWM international program.

5.3.7 Activity 1.5.3.4 - Generate Models for Release From Glass Waste Forms

Subactivity 1.5.3.4.1 - Generate release models for glass waste forms. The glass waste form dissolution model is being interfaced to the Yucca Mountain Integrating Model performance assessment model. The present glass dissolution model embodied in the EQ3/6 geochemical modeling code is being simplified by fitting the model results to empirical equations. The primary relationship involves the rate of dissolution of the glass as a function of temperature, pH and dissolved silica concentration. Two additional empirical relationships were also needed for the current YMIM glass submodel: (1) pH vs. the amount of dissolved glass and (2) the ratio of silica released to solution vs. silica contained in alteration phases as a function of surface area to volume ratio in the tests. These latter two relationships allow YMIM to model intermediate behavior between open (flow-through) and closed (bathtub)-type water contact regimes.

Forecast: Work to interface the present glass dissolution model to the YMIM model will continue.

5.3.8 Activity 1.5.3.5 - Waste Package Performance Assessment Model Development

Subactivity 1.5.3.5.1 - Development of system model. The Yucca Mountain Integrating Model code (Lamont, 1994) was developed and a Users Guide published (Gansemer and Lamont, 1995). This code combines summary models of many of the features and processes of the near-field environment and the Engineered Barrier System to calculate container breach times and radionuclide release rates. See Section 5.3.10 for applications. Development was started on the next revision of YMIM to be used in an FY 1995 analysis of the Engineered Barrier System performance and in the FY 1995 Total System Performance Assessment. This version will include several enhancements in container corrosion, near-field thermohydrological environment, and glass waste form processes.

A YMIM verification activity was started in accordance with the YMIM Individual Software Plan. The first stage is to state the program's representational and functional goals and the program's structure, which provides the baseline for review and concurrence by subject-matter experts, for Program implementation, and for test control. This baseline also provides the medium for change control and configuration management at the design-drawing level rather than only at the report and source-code levels. A software-engineering package was selected and acquired to provide graphical and data base representation of the requirements and design, and to provide specific form for review and configuration

management of this level of information. Staff training on the software was completed. A draft version of the YMIM design in this format was developed and is in review.

Subactivity 1.5.3.5.2 - Development of uncertainty methodology. No progress was made during the reporting period; this was an unfunded activity.

Subactivity 1.5.3.5.3 - Water flow into and out of a breached container. No progress was made during the reporting period; this was an unfunded activity.

Forecast: The YMIM model will be further enhanced in preparation for preliminary analyses for technical site suitability and for advanced conceptual design. The next version will be available for project use during the next reporting period. The enhancements will be prioritized for near-term analysis requirements. The YMIM qualification activity will continue.

5.3.9 Activity 1.5.4.1 - Deterministic Calculation of Releases from the Waste Package

In this reporting period, no calculations were performed. See Sections 5.3.10 and 5.6.10 for related calculations.

Forecast: See Section 5.3.10

5.3.10 Activity 1.5.4.2 - Probabilistic Calculation of Releases from the Waste Package

Zircaloy cladding creep strains were predicted from various constitutive equations reported in the literature (Rosen and O'Connell, in prep.), and the reduced effect of the increasing fuel rod gas volume with strain was added to the models. The creep strain is the first step in predicting whether the cladding will undergo creep rupture under the cumulative thermal effects of dry storage and permanent disposal. Knowledge of cladding breach is required to determine the rate of release of radionuclides from the waste packages. There is a variability in the cladding creep strain predictions based on various experimental data sets. Including the increasing-volume effect reduces this variability. Even within a recognized range of variability, useful predictions may be possible, constraining the release rates of radionuclides.

Forecast: Analyses will be performed as a preliminary assessment of the ability of the advanced conceptual design to meet the requirements of substantially complete containment and controlled release of radionuclides. Updated models or analyses will be produced to support the source term component of Total System Performance Assessment. Analyses of the Engineered Barrier System/near-field environment subsystem will be analyzed to support the preliminary Technical Site Suitability assessment. Results will be used as feedback to guide priorities in additional data acquisition and model enhancement activities.

5.3.11 Activity 1.5.5.1 - Determine Radionuclide Transport Parameters

Subactivity 1.5.5.1.1 - Radionuclide distribution in tuff wafers. Adsorption of radionuclides, such as cesium, strontium, uranium and neptunium onto and into the zeolite clinoptilolite is expected to retard their transport through clinoptilolite-bearing formations and/or fractures. Laboratory sorption measurements have shown that clinoptilolite is an effective sink for cesium and strontium. Cesium and strontium adsorption by clinoptilolite can be described by cation exchange and is a relatively rapid and reversible process for systems in which the crystal size of the clinoptilolite is small (on the order of 1 to 2 μm). Preliminary analysis of the experimental data suggests that diffusion rates (on the order of 1×10^{-22} to 1×10^{-17} m^2/s for strontium and cesium, respectively) may be slow enough to limit the attainment of equilibrium between cesium and strontium-bearing ground waters and clinoptilolite for situations in which fluid flow is relatively rapid and clinoptilolite crystals are relatively large (e.g., in fractures). Laboratory sorption measurements over relatively short time scales (weeks to months) suggest that adsorption of uranium and neptunium by clinoptilolite is limited (small partition coefficients) and appears to occur on the external surface of the crystal. Studies are beginning using the same techniques developed for cesium and strontium to directly assess whether there is a potential for intracrystalline adsorption of uranium and neptunium in clinoptilolite, and if so, whether the rates of diffusion are rapid enough to allow clinoptilolite-bearing rocks, such as the Calico Hills Formation, to retard uranium and neptunium movement over repository time scales.

Subactivity 1.5.5.1.2 - Radionuclide distribution in tuff cores. An experimental protocol has been decided on and transport experiments using conservative tracer-bearing solutions have been initiated for samples of Topopah Spring Tuff at ambient, 60° and 90°C. Preliminary results indicate that the experimental apparatus is performing according to expectations. Experiments using conservative tracers are continuing, and experiments using adsorbing tracers (uranium, neptunium) are being planned. A summary of results of characterizing colloids from Nevada Test Site ground waters and fluids that have contacted Topopah Spring Tuff samples in flow experiments indicate that the colloids are primarily layer silicates and silica polymorphs, and are similar for both field and laboratory fluids.

Forecast: Laboratory sorption measurements for cesium and strontium will be completed and the uranium and neptunium studies will continue. Temperature dependence flow studies involving conservative and non-conservative tracer-bearing solutions through Topopah Spring Tuff core samples will continue. Mechanistic modeling studies of radionuclide transport through Topopah Spring Tuff core will be initiated.

5.3.12 Related International Characteristics and Behavior of the Waste Form Work

Thermochemical Data Base

The following is work, related to Subactivity 1.5.3.2.1 (Section 5.3.5), conducted cooperatively with the Nuclear Energy Agency of the Organization of Economic Cooperation and Development under the auspices of the OCRWM international program.

During the previous reporting period, significant progress was made in compiling and reviewing existing thermochemical data. For the planned volume on plutonium and neptunium, both tetra- and hexavalent states, data on the aquo-ions and the hydroxy and carbonate complexes have been assembled and critically reviewed by American and foreign scientists. The draft report for americium was distributed to and reviewed by an external peer review panel; the review panel consisted only of Americans, but was recommended by the Nuclear Energy Agency. Progress was made on the technetium volume by foreign scientists. The data recommended in the final data bases for these radionuclides will be used by YMSCO as part of the thermodynamic data base for the EQ3/6 and possibly other geochemical codes. The corresponding Nuclear Energy Agency data for uranium are already in use. These reviews provide substantially increased confidence in the reliability of data critically needed in performance assessment in calculating solubility and transport.

During this reporting period, progress continued in compiling and reviewing existing thermochemical data. A subcontract was issued to complete the work on plutonium and neptunium data on aquo-ions and the hydroxy and carbonate complexes they form in the tetra and pentavalent states. The draft report of these two volumes should be completed in FY 1996. The comments made by the external peer review panel on the americium volume were by the technical review panel. Publication of the volume should be forthcoming in the near future. An increased effort is being made to complete the draft of the technetium volume by the end of the fiscal year.

Data recommended in the final data bases for these radionuclides, as well as the already published uranium volume, will be used by YMSCO as part of the thermodynamic data base for the EQ3/6 and possibly other geochemical codes. These reviews provide substantially increased confidence in the reliability of data critically needed in performance assessment in calculating solubility and speciation and predicting transport.

Forecast: The americium volume should be published during FY 1995. Work will continue on the plutonium, neptunium and technetium volumes with the expectation they will be ready to submit to external peer review at the end of the year or early in FY 1996.

Spent Fuel Dissolution Model Development

The following is work, related to Subactivity 1.5.3.3.1 (Section 5.3.6), conducted cooperatively with Canada under the auspices of the OCRWM international program.

During the previous reporting period, the original sixteen and eight additional experiments in the UO_{2+x} test matrix were completed. The dehydrated schoepite, $UO_3 \cdot H_2O$, was shown to dissolve much faster than the U_3O_8, particularly at high carbonate concentrations. The results also showed that the dissolution rates of U_3O_8 strongly resemble those of UO_2 under analogous conditions. Raising the temperature to 75°C enhances the rate by a factor of 2 to 4 for the two higher oxides. Initial modeling showed similar response for UO_2 and spent fuel, except for the effect of oxygen. For UO_2 the dissolution data show a half-order response in respect to oxygen at 25° and 75°C. Spent fuel showed no effect in relation to oxygen at room temperature and variable response at 75°C. Modeling was modified to include solid-liquid interface and chemical potential terms. Regression fits with these models were not so robust as earlier ones that relied on classic empirical chemical rate equations for homogeneous solutions and pure polynomial fits. Comparisons, where appropriate, of test results among LLNL, Pacific Northwest Laboratory, and Atomic Energy of Canada Limited showed good agreement. More details were provided by Gray et al., (1994), Steward and Gray (1994), and Rudnicki et al. (1994). These experimental results have direct applicability to dissolution of spent fuel in liquid water, which is the only viable release mechanism for most radionuclides from waste that may be emplaced in Yucca Mountain. They provide a broader data base for both fuel types and water chemistries thereby carrying potential for developing a substantially more robust model for the source term.

During this reporting period, all test series were conducted at 8 ppm dissolved oxygen (20 percent oxygen in the gas phase). The temperature (25° to 75°C), pH (8 to 10) and total carbonate concentration (2×10^{-4} to 2×10^{-2} molar) varied. X-ray Diffraction and nuclear magnetic resonance spectra of the $UO_3 \cdot H_2O$ samples were acquired. Particle size measurements were made with both $UO_3 \cdot H_2O$ and U_3O_8 samples, using both optical microscopy and sedimentation techniques.

The multi-laboratory UO_2 powder dissolution experiments have continued for two and one-half years. For comparison, similar experiments using samples from the same batch of powder were run for shorter times at two other laboratories. The first buffer composition was 0.02 M sodium bicarbonate at a pH of 8, and the second composition a 'standard' saline solution with 0.01 M sodium bicarbonate and 0.1 M sodium chloride saturated with air; the pH was not controlled. After being shut off for several months, they were restarted during summer, 1994. During the subsequent two months, the dissolution rate of the 'carbonate only' experiment increased immediately and dramatically to over 15 $mg \cdot m^{-2} \cdot d^{-1}$. The rates have trended downward since then to values seen previously of about 4 $mg \cdot m^{-2} \cdot d^{-1}$. The dissolution rate in the 'standard saline solution' remained low initially at about 2 $mg \cdot m^{-2} \cdot d^{-1}$, but increased to a value similar to the 'carbonate only' experiment during the last two months of the calendar year. The experiments were momentarily stopped in early January to examine and weigh the UO_2 samples. There was some grain fragmentation, but the grains generally retained their size and sharp edges.

A variety of electrochemical and corrosion science methods, as well as the technique of photothermal deflection spectroscopy, have been used in joint Canadian and American investigations of the mechanisms of oxidative dissolution processes in UO_2. These techniques are leading towards an active-passive kinetics model and away from a grain boundary

explanation. The grain boundaries are more active because of oxygen content, not structural effects. The reactivity of crystalline material can be increased by oxidation. Further oxidation decreases reactivity. An active-passive model is consistent with previous electrochemical and studies and with flow-through studies, which usually show initial high dissolution rates. Such an explanation explains the differences between electrochemical and chemical dissolution studies. The electrochemical studies occur at short times, before a passive film can form. This recent work leads to the conclusion that oxygen stoichiometry is key to the reactivity of UO_2. Changes in oxygen stoichiometry make the crystalline material behave similarly to the sintered material. The work continues to support the contention that dissolution occurs from localized sites, related to oxygen stoichiometry, as opposed to the entire surface.

A joint Canadian and American draft report on factors affecting the dissolution rate of U from UO_2 and spent fuel was prepared to address a milestone on the differences in reactivity between UO_2 and spent fuel. This report identified important parameters that control the dissolution rate of U from UO_2. The UO_2 matrix phase of spent fuel forms the basis for the development of a release model for radionuclides from spent fuel that can be used in waste package design and performance assessment studies. The report discusses results from flow-through leaching experiments, electrochemical experiments and photothermal deflection spectroscopy studies carried out at laboratories in both countries.

Forecast: A model for dissolution of spent fuel, utilizing both the experimental data and enhanced understanding in how to perform the calculations, will be completed.

5.4 CHARACTERISTICS AND CONFIGURATIONS OF THE WASTE PACKAGES (SCP SECTION 8.3.4.3)

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

Forecast: No activity is planned for FY 1995.

5.5 WASTE PACKAGE PRODUCTION TECHNOLOGIES (SCP SECTION 8.3.4.4)

5.5.1 Design Activity 4.3.1.1 - Waste Package Fabrication Process Development

The objective of this activity is to determine, by using the logical sequence described for this issue, the processes to be used in fabricating the nonwaste form components of the waste packages.

A report on waste package cost estimates was issued, which is discussed under Activity 1.10.2.3.4 (Section 5.1.3).

A design analysis was prepared and issued in response to a request from Waste Acceptance and Storage Transportation Design (CRWMS M&O, 1995). The analysis first examines general limitations upon the multi-purpose canister sizes and weights, as established

by the Multi-Purpose Canister Subsystem Design Procurement Specification, and then concludes that the Mined Geologic Disposal System does not require any additional limitations upon the weight or nominal envelope of the multi-purpose canister. The Mined Geologic Disposal System will design the disposal containers to accommodate all sealed waste-containing multi-purpose canisters that have been produced in accordance with the final production Multi-Purpose Canister Subsystem Design Procurement Specification.

5.5.2 Design Activity 4.3.1.2 - Waste Package Closure Process Development

The objective of this activity is to determine, by using the logical sequence described for this issue, the process to be used in the final closure of the waste package containers.

A technical requirements document on waste package closure was issued (CRWMS M&O, 1995). The document presents the objectives, technical information, and work scope relating to the waste package closure development task and its subtasks. A technical requirements document is issued before soliciting a test plan for the waste package closure development task.

5.5.3 Design Activity 4.3.1.3 - Waste Package Closure Inspection Process Development

The objective of this activity is to determine, by using the logical sequence described for this issue, the process to be used in inspecting the final closure of the waste package containers.

Efforts on production technologies focused on filler material and integrating of fabrication process with multi-purpose canister design. Preparation began on a technical requirements document for nondestructive evaluation of closure welds.

Forecast: The technical requirements document will be completed and issued during the next reporting period.

5.5.4 Design Activity 4.3.1.4 - Remote In-Service-Inspection Development

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

Forecast: No work on this activity is planned for FY 1995.

5.5.5 Design Activity 4.3.1.5 - Internal Filler Material Process Development

A design analysis is being prepared in response to a request from Waste Acceptance Storage and Transportation Design (CRWMS M&O, in prep.). The analysis first examines access requirements (both to remove/replace spent nuclear fuel and to add filler materials) as

established by the Multi-Purpose Canister Subsystem Design Procurement Specification. The analysis concludes that to add filler to the multi-purpose canister, the canister would be opened at the Mined Geologic Disposal System by cutting through the cylindrical shell in the vicinity of the shield plug, and the top end and shield plug would be removed, thereby providing access to the entire cross section of the multi-purpose canister. Furthermore, the basket and internals must be designed to provide access to all void spaces within the multi-purpose canister, including void spaces within any flux trap baskets. The void access requirement derives from the criticality control aspect of filler materials.

Forecast: Work on cost estimation and integration of process development with multi-purpose canister design will continue.

5.6 WASTE PACKAGE PERFORMANCE (SCP SECTION 8.3.5.9)

Waste package container designs, as described in the Controlled Design Assumptions Document, currently focus on a multiple barrier approach and 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 (SNL, 1987). Discussions of the progress made on evaluating these "alternate materials" are found under Activity 1.4.2.4 (Section 5.6.6), rather than Activities 1.4.2.2 (Section 5.6.4) and 1.4.2.3 (Section 5.6.5), and Activity 1.4.3.3 (Section 5.6.9) rather than Activities 1.4.3.1 (Section 5.6.7) and 1.4.3.2 (Section 5.6.8). The only option of these "alternate materials" currently being pursued is the "Bimetallic/Single Metal," which is the multiple barrier design.

5.6.1 Activity 1.4.1.1 - Integrate Design and Materials Information (Metal Container)

The current waste package container designs focus on a multiple-barrier approach for both spent nuclear fuel packages and for vitrified high-level waste packages. These designs are "robust" in the sense that (a) multiple barriers provide reinforcement to the containment function, (b) thick sections are used for some of the barrier materials, and (c) some of the barrier materials are very highly corrosion resistant to a wide range of environmental conditions. Materials of construction for the waste package are grouped into three categories according to their projected performance. Configurations of the waste package depend on the thermal load designed for the repository.

Highly Corrosion Resistant Materials

Multiple candidates are presented as corrosion resistant materials that could be used as an inner barrier of a multiple barrier waste package. This group of materials is itself divided into three groups:

1. Nickel-rich Stainless Alloys. These materials are viewed as transition alloys falling between stainless steels and nickel-base alloys. These materials contain 40 to 50 percent nickel plus chromium. They also contain iron, molybdenum and other alloying elements. Candidate materials in this group are Alloy 825 and Alloy G-3.

2. Nickel-base Alloys. These materials can be viewed as an extension of the previous group, in which nickel has replaced iron in the composition. These alloys contain 60 percent or more nickel. Candidate materials in this group are Alloy C-4 and Alloy C-22.

3. Titanium. This group of candidate materials includes Ti Grade 12, which is a "lean" titanium-base alloy containing small additions of nickel and molybdenum, and Ti Grade 16, which contains a small addition of palladium.

Corrosion Allowance Materials

These are materials that are expected to oxidize or corrode at a predictable rate. If these degradation rates are within acceptable limits, the barrier can be made sufficiently thick so that a rather lengthy service lifetime can be obtained. Economical iron-base materials have generally been considered corrosion allowance materials for nuclear waste containers, not only because of their comparatively low cost but also because they can be readily formed and welded in thick sections. Candidate materials in this group are wrought carbon steel, cast carbon steel, and low chromium-molybdenum alloy steel.

Intermediate Materials

A third group of materials was identified, which are referred to as "intermediate" between the corrosion resistant and corrosion allowance groups, because they have some performance characteristics of both groups. Candidate materials are Alloy 400 (UNS N04400) and 70/30 copper-nickel (UNS C71500).

A more complete discussion of these candidate materials, their properties, and their projected performance under a range of possible repository emplacement conditions is presented in a draft report (McCright, in prep.). This draft has been reviewed and is being revised.

A report on engineered materials characterization (Van Konynenburg et al., in prep.) was in DOE review. The report was prepared in three volumes. The first volume describes the engineered materials effort for the YMP, defines terms and outlines the history of selection and characterization of these materials, and summarizes the recent Engineered Barrier System materials characterization workshop. The second volume tabulates design data for engineered materials, and the third volume provides corrosion data, radiation effects on corrosion, and corrosion modeling. The second and third volumes will be evolving documents, with new data added as they become available from additional studies. Initially, volume 3 is devoted to information currently available for environments most similar to those expected in the potential Yucca Mountain repository. This report tabulates existing data (from non-Project

sources) on mechanical and physical properties of the candidate materials, but no additional Project data on these properties was acquired during this period. The existing data were added to the Reference Information Base.

The Metallic Barrier Scientific Investigation Plan (DOE, 1995) was revised, updated, and issued as a controlled document on January 31, 1995. The update is consistent with the current waste package design for a multiple barrier container. The plan describes many technical activities that will be performed in the next several years to support the selection of materials to be used in fabricating the waste package container and to support the performance analysis of the selected materials. The activities can be grouped into four categories: (1) degradation mode surveys and information bases, (2) corrosion testing and physical evaluation, (3) modeling of performance behavior, and (4) materials recommendations. This plan explains how interfaces between the metallic barriers task and other programmatic elements function; it also shows the sequencing of individual activities and how results from the different activities support one another. The preface discusses how the waste package design changes and candidate material evaluations have proceeded through the various revisions of the plan.

Forecast: Integration between the materials evaluation efforts and other aspects of the waste package design effort continue to be emphasized. The Metallic Barrier Scientific Investigation Plan is the main document that will guide the materials evaluation effort for the next several years, and in the coming year this plan will become fully implemented. As new data become available from the testing and modeling activities the Engineered Materials Characterization Report will be periodically updated.

5.6.2 Activity 1.4.1.2 - Integrate Design and Materials Information (Alternate Barriers Investigation)

The purpose of the nonmetallic barriers task is to characterize the behavior of nonmetallic materials, such as ceramics, and to determine degradation rates and mechanisms. One of the barriers of the disposal container may be fabricated from a nonmetallic material. A primary objective of this task is determination of the feasibility of making a nonmetallic barrier as part of a waste package.

Work on alternative barrier approaches to waste package container design ceased at the end of FY 1994. A report (Wilfinger, in prep) on the survey of ceramic materials and processes for fabricating and joining them, either as stand-alone barriers or as thick coatings applied to metal surfaces, was prepared and is currently in review.

There is currently no on-going work on subactivities in this section. If work resumes, progress will be reported accordingly.

Subactivity 1.4.1.2.1 - Survey of alternative barrier designs, materials, and processes to determine feasibility of fabricating a satisfactory waste package. No progress was made during this reporting period; this was an unfunded subactivity.

Subactivity 1.4.1.2.2. - Mechanical properties. No progress was made during this reporting period; this was an unfunded subactivity.

Subactivity 1.4.1.2.3. - Microstructural properties. No progress was made during this reporting period; this was an unfunded subactivity.

Subactivity 1.4.1.2.4 - Thermophysical properties. No progress was made during this reporting period; this was an unfunded subactivity.

Subactivity 1.4.1.2.5 - Nondestructive characterization of the alternate barrier investigations waste package container. No progress was made during this reporting period; this was an unfunded subactivity.

Forecast: When approved, the survey report will be issued. Additional FY 1995 funding is being considered.

5.6.3 Activity 1.4.2.1 - Selection of the Container Material for the License Application Design

Subactivity 1.4.2.1.1 - Establishment of selection criteria and their weighting factors. Criteria and weighting factors for each criterion were selected for the SCP-Conceptual Design materials in the 1987-88 period.

Subactivity 1.4.2.1.2 - Material selection. A quantitative scale for evaluating candidate materials for each criterion was developed for the SCP-Conceptual Design materials in the 1987-88 period.

The results of these activities are being re-evaluated for the candidate materials being considered for multiple barrier waste package containers. Most of the criteria will probably stay the same, but different weighting factors will probably be used to evaluate materials for multiple barriered designs.

Forecast: A draft report on any recommended changes in the selection criteria and weighting factors will be prepared.

5.6.4 Activity 1.4.2.2 - Degradation Modes Affecting Candidate Copper-Based Container Materials

The Controlled Design Assumptions focus entirely on multiple barrier waste package container configurations; therefore, degradation mode activities are reported under Activity 1.4.2.4. The only option currently being pursued under the controlled design assumptions is the "Bimetallic/Single Metal," which is the multiple barrier design. See the discussion in Section 5.6.

5.6.5 Activity 1.4.2.3 - Degradation Modes Affecting Candidate Austenitic Materials

The Controlled Design Assumptions focus entirely on multiple barrier waste package container configurations; therefore, degradation mode activities are reported under Activity 1.4.2.4. See the discussion in Section 5.6.

5.6.6 Activity 1.4.2.4 - Degradation Modes Affecting Ceramic-Metal, Bimetallic/Single Metal, or Coatings and Filler Systems

All the work discussed below is applicable to the bimetallic/single metal case for design alternatives discussed in the SCP (DOE, 1988). See the discussion in Section 5.6.

Subactivity 1.4.2.4.1 - Assessment of degradation modes affecting ceramic-metal systems. No progress was made during the reporting period; this was an unfunded activity.

Subactivity 1.4.2.4.2 - Laboratory test plan for ceramic-metal systems of the alternate barriers investigations. No progress was made during the reporting period; this was an unfunded activity.

Subactivity 1.4.2.4.3 - Assessment of degradation modes affecting bimetallic/single metal systems. The objectives of degradation mode surveys are to (a) compile relevant previously published information about a candidate material and its performance in a number of environments and (b) interpret this body of information in the context of a potential repository in Yucca Mountain. In many instances, the degradation mode survey indicates the ways in which a material can degrade and serves to indicate the rate and kind of degradation in environments that have some similarity to what a metal barrier may experience in the Yucca Mountain setting. In other instances, the lack of information suggests what work will be required to determine the behavior of the candidate material in Yucca Mountain environmental conditions.

Titanium and its alloys are considered for waste package containers because of their excellent corrosion resistance in most aqueous environments. A draft survey report on the degradation modes of titanium (Gdowski, in prep.) was completed in January 1995. The survey included commercially pure titanium, and several "lean" Ti-base alloys, containing less than 1 percent alloying elements.

The degradation mode survey concludes that of the materials reviewed, commercially pure Ti Grade 2 is the most susceptible to crevice corrosion, however, several Ti alloys are likely to be very resistant to crevice corrosion under the expected Yucca Mountain repository conditions.

Hydride-induced cracking of titanium is a possibility, and therefore, further investigation of this phenomenon under credible repository conditions is warranted. One disadvantage of titanium and its alloys is that their strengths decrease rather rapidly with temperature. This is because of the strong temperature dependence of interstitial solute strengthening mechanisms.

The survey recommended that Ti Grades 12 and 16 be considered as candidate materials for one of the barriers in the multiple barrier design for the waste packages in the YMP program.

Forecast: After review and approval, the Titanium Degradation Mode Survey will be published as part of the series on candidate materials. Previous surveys have dealt with copper-base alloys, "austenitic" alloys (stainless steel and Alloy 825), high nickel-chromium-molybdenum alloys (including Alloy C-4 and C-22), and carbon steels, alloy steels, and cast irons as corrosion allowance materials. Additional volumes are planned for Alloy 400 (a nickel-copper alloy) and other nickel-base alloys that have not been previously covered. These are planned for completion in FY 1995. In addition, a Degradation Mode Survey on weldments of high performance materials (nickel-base and titanium-base) is being planned.

Subactivity 1.4.2.4.4 - Laboratory test plan for bimetallic/single metal material systems.

Long-Term Corrosion Studies

The objective of this activity is to determine comprehensive corrosion properties of metallic alloys being considered for waste package structural materials. Three classes of materials are to be addressed: corrosion resistant, corrosion allowance, and intermediate materials (see discussion under Activity 1.4.1.1 in Section 5.6.1). Corrosion properties to be assessed are general corrosion, pitting corrosion, crevice corrosion, intergranular corrosion, stress corrosion cracking, hydrogen embrittlement, and galvanic corrosion. This activity will provide kinetic and mechanistic information about the corrosion degradation of candidate materials. This information will help in materials selection, performance analysis, and model development. Tests are conducted in "bounding environments" to capture the range of environmental conditions and water chemistries that are projected to develop near the container surface over long periods of time. This comprehensive corrosion test is planned for a five-year period (or longer), with periodic removal and inspection of test specimens to measure corrosion degradation as a function of exposure time.

Four bounding water chemistry environments were identified in which these long-term corrosion tests are conducted. The rationale for their use was discussed in the Engineered Materials Characterization Report and the Metallic Barrier Scientific Investigation Plan (discussed in Activity 1.4.1.1). Briefly, the four environments are laboratory-simulated UE-25 J#13 well water, the same simulated UE-25 J#13 well water but with solutes concentrated 20 to 100 times (to simulate water characteristic of the unsaturated zone), the "concentrated" UE-25 J#13 water acidified to pH 2, and the "concentrated" UE-25 J#13 water alkalized to pH 12. The acidified condition represents a "worst case" environment that could arise from microbial activity and possibly the interaction of diesel fuel or other hydrocarbons with steam to form various carboxylic acids. The alkaline condition could result from the reaction of water with concretes, grouts, and other cementitious materials expected to be widely used in the repository construction. Test specimens are exposed to these four water chemistries and the saturated vapor space above the liquid. Some species in the water are expected to volatilize and concentrate in the vapor space. Tests are conducted at 60° and 90°C; these temperatures were selected because previous work in the published literature has

indicated that localized corrosion effects are particularly severe in this temperature range for many materials.

Test specimens, fabricated from all the candidate materials discussed under Activity 1.4.1.1, are configured in flat coupons, coupons with crevices, U-bend stressed specimens, and galvanically coupled specimens. Several thousand specimens are required for the matrix of test conditions. Welded specimens are sometimes used. The activity plan for the long-term corrosion studies gives greater experimental detail on the specimens, environments, and test procedures to be used.

Forecast: The long-term corrosion study is a keystone activity for many of the investigations of the metallic barriers planned for the next several years. Several companion studies will be performed, including tests conducted with measurements of the corrosion potential and determinations of critical potentials for the initiation of different forms of localized corrosion and forms of environmentally assisted cracking. These companion studies are described in the Metallic Barriers Scientific Investigation Plan. The long-term corrosion test specimens are expected to begin exposure before the end of FY 1995.

Thermogravimetric Analysis Studies

The objective of this work is to determine the conditions under which aqueous corrosion processes occur after emplacement of the waste package. These conditions have special significance in an unsaturated zone repository, because the extent of degradation of the candidate material becomes much greater when aqueous corrosion processes begin. The key parameters appear to be humidity, temperature, and surface conditions; the experimental work aims to determine the interrelationship among these parameters. Thermogravimetric analysis is a particularly sensitive technique for using a micro-analytical balance to measure very small changes in weight gain as a material reacts with the environment.

The Cahn 131 unit, which is the apparatus purchased for this investigation, has required several modifications to achieve the uniform humidity control required for these experiments. Subsequent studies on the apparatus have detected thin water films on metal surfaces, and the reversibility of film formation and evaporation as temperatures and humidities change. This preliminary experimental work has been confined to carbon steel and copper specimens, but specimens of other materials have been ordered.

Forecast: The thermogravimetric analysis studies are used to establish the approximate boundaries of the oxidation/corrosion transition and to establish the critical parameters for this transition. An activity plan will be prepared for the work. Planning for longer term oxidation and corrosion studies in controlled humidity chambers will progress as results from the thermogravimetric analysis work are obtained.

Crack Growth Tests

The objectives of this study are to (a) determine the susceptibility of candidate waste package materials to stress corrosion cracking under a variety of environmental, metallurgical,

and mechanical stress conditions relevant to the repository, and (b) provide the experimental data base for predictive models for stress corrosion cracking in the waste package environment. These tests are equally valid for determining the hydrogen embrittlement susceptibility of susceptible materials, if that degradation phenomenon is operating. Stress corrosion cracking and hydrogen embrittlement are important degradation modes that can affect corrosion resistant and corrosion allowance materials. A sensitive crack growth measurement apparatus, which operates under the principle of measuring minute changes in the electrical resistance of the test specimen as a crack propagates, is being used to measure crack growth on pre-cracked compact tension fracture mechanics type of specimens.

Research activities deal with crack growth rate determinations on Alloy 825, Ti Grade 12, Alloy C-4, and Alloy C-22. Crack growth rate tests using standard compact tension fracture mechanics specimens have been conducted on Alloy 825 in an earlier phase of the program. Additional tests began on the other candidate materials and on a new heat of Alloy 825 in FY 1994. These tests are conducted in a simulated UE-25 J#13 well water environment, maintained at 93°C. The specimens have been fatigue cracked in air at room temperature for a pre-crack length of 1.9 mm under a cyclic load with a triangular load shape, load ratio of R = 0.1 to 0.25 (the load ratio R is the maximum stress/minimum stress) and loading frequency of 1 Hz to introduce a sharp starter crack before commencing the crack growth rate tests in the simulated UE-25 J#13 well water environment.

Preliminary data show that the crack propagates faster in the Ti Grade 12 specimen than in both the "Alloy C" specimens by an order of magnitude, under a 0.5-Hz cyclic load and triangular load shape, load ratio of R = 0.5 and stress intensity range of 26 to 28 MPa-$m^{1/2}$ in UE-25 J#13 well water. Growth rates of 1.1 x 10^{-7}, 0.90 x 10^{-8}, and 1.1 x 10^{-8} m/s were observed for the Ti Grade 12, Alloy C-22, and Alloy C-4 specimens, respectively. Because of the inherently faster crack growth rate for the Ti Grade 12 as compared with the nickel-base Alloy C-22 and C-4 specimens, the growing crack is longer in the titanium specimen. The significance of this observation is being analyzed.

Forecast: The crack growth test will be continued for longer time periods at higher stress intensities, and subsequently different R values. Because these would be more aggressive conditions, the crack growth rates should increase. Work is also planned at a second laboratory, using a similar apparatus, to conduct similar types of tests but at different environmental conditions to complement the work currently under way. The second apparatus will undergo preliminary testing to ensure that its operating characteristics are satisfactory.

Microbiologically Influenced Corrosion Studies

The objective of microbiologically influenced corrosion studies is to determine if corrosion is enhanced by the presence and propagation of microorganisms, particularly bacterial species. Metabolism products from these microorganisms can alter the chemical environment significantly, and this effect can occur on a localized level or over a wide area of the container surface. Different types of microorganisms attack different kinds of metal and alloys because of the chemical specificy of the corrosion process. Much of the work proposed for studying microbiologically influenced corrosion effects will be performed by organizations

and personnel having the specialized knowledge and facilities for conducting these kinds of studies. Topics to be addressed include the following:

1. Electrochemical detection of microbiologically influenced corrosion – This part involves developing test procedures to determine microbiologically influenced corrosion susceptibility of steel in water samples ultimately to be taken during exploratory and construction phase of repository operations.

2. Electrochemical stimulation of corrosion by bacterial growth – This part involves determining electrochemical interactions between corrosion and bacterial growth, including cause and mechanism of localized microbiologically influenced corrosion at weld joints.

3. Effects of elevated temperature and nutrient availability on bacterial growth and subsequent microbiologically influenced corrosion – This part involves studying the ability of microbial cultures from Rainier Mesa and Yucca Mountain to revive, grow, and cause corrosion at elevated temperatures.

Forecast: Work will begin on the proposed microbiologically influenced corrosion studies, as indicated in the above discussion.

Subactivity 1.4.2.4.5 - Assessment of degradation modes in coatings and filler systems. No progress was made during the reporting period; this was an unfunded activity.

Subactivity 1.4.2.4.6 - Laboratory test plan for coatings and filler systems of the alternate barriers investigations. No progress was made during the reporting period; this was an unfunded activity.

Forecast: No work is planned in FY 1995 for Subactivities 1.4.2.4.5 and 1.4.2.4.6.

5.6.7 Activity 1.4.3.1 - Models for Copper and Copper Alloy Degradation

The Controlled Design Assumptions focus entirely on multibarrier waste package container configurations; therefore modeling activities are reported under Activity 1.4.3.3. See the discussion in Section 5.6.

5.6.8 Activity 1.4.3.2 - Models for Austenitic Material Degradation

The Controlled Design Assumptions focus entirely on multibarrier waste package container configurations; therefore, modeling activities are reported under Activity 1.4.3.3. See the discussion in Section 5.6.

5.6.9 Activity 1.4.3.3 - Models for Degradation of Ceramic-Metal, Bimetallic/Single Metal, and Coatings and Filler Alternative Systems

The modeling work discussed below applies to the bimetallic/single metal design alternative. See the discussion in Section 5.6.

Pitting Corrosion Model

The objective of the model development activity is to derive predictive tools that will enable using experimental data and analyses to draw long-term assessments of the performance of candidate materials under Yucca Mountain conditions. This work will ultimately describe the performance of the multiple-barrier waste package container, but as a first step in that direction the modeling work has focused on the pitting corrosion of a corrosion resistant barrier, such as one of the nickel-base or titanium-base alloys. While pitting is usually governed by electrochemical, chemical, and occasionally metallurgical parameters, an important aspect of pitting is "stochastic." Much of the modeling work is aimed at developing the stochastic aspect of pitting within the electrochemical and chemical parameters.

A pitting initiation and growth stochastic model has been developed. The most recent work focused on the new capability of the pitting initiation and growth stochastic model to simulate the permanent cessation of growth for "stable" (e.g., macroscopic) pits by including a new stochastic variable η describing the probability that stable pits permanently halt their growth. There are two possible ways to view pit growth with cessation: (1) pit growth is fundamentally stochastic and includes the possibility that pits may permanently stop growing; and (2) pit growth is fundamentally deterministic and continuous, but individual pits may stop growing at different times during exposure. For instance, the kinetics of surface electrochemical reactions may change with time due to small chemical changes in the area surrounding the pit. This can result in the reduction of the electrochemical current so that pit growth can no longer be sustained. The focus of efforts has been on the first possibility, which can be explored using $0 < \eta < 1$, and a pit growth probability γ less than one. The investigation of how permanent pit growth cessation affects the damage function (e.g., the distribution of pit depths) continued by extending previous calculations. Several numerical experiments were performed using different pit growth cessation probabilities for different exposure steps. A nearly static distribution was reached following 4,000 steps of exposure. This distribution exhibits a gradual exponential-type decay in the number of pits vs. their depth, although there is a large variability from one pit depth to the next.

The previous discussion suggests that the ultimate pit distribution is a large number of relatively shallow pits with a smaller number of pits that grow to attain much greater depth. The experimental data suggest that the pit depth distribution following long exposure times is more complex than this; typically, it contains a significant intermediate peak. Of course, a wider combination of γ (and other input) values must be explored to confirm these general observations. Calculations are continuing, using the "deterministic pit growth" option of $\gamma = 1$ (with $0 < \eta < 1$). Again, the major goal is to determine if distributions similar to those observed experimentally can be simulated using this approach.

These results (Henshall, in prep.) were presented at the Materials Research Society XVIII International Symposium on the Scientific Basis for Nuclear Waste Management. The paper will appear in the proceedings of that conference, slated for publication in 1995.

Forecast: Work will continue to refine the pitting corrosion model. Work is under way in the testing and evaluation area that will provide experimental data and, hence, deterministic factors (such as pH, electrochemical potential, temperature, and solution chemistry) for the model. Many of the stochastic features of the pitting model can be successfully applied to models of other degradation modes. As outlined in the Metallic Barrier Scientific Investigation Plan, work on models for the other degradation modes will begin as experimental information on the significant chemical, physical, metallurgical, and, in some instances, mechanical parameters becomes available from the testing activities.

5.6.10 Activity 1.4.4.1 - Estimates of the Rates and Mechanisms of Container Degradation in the Repository Environment for Anticipated and Unanticipated Processes and Events, and Calculation of Container Failure Rate as a Function of Time

The YMIM model (Gansemer and Lamont, 1995) was used to compare the effects of varied repository areal mass densities on containment performance (Gansemer and Lamont, in prep.). The areal mass density, through its heat energy deposited over time, affects the repository temperature and relative humidity fields (Buscheck et al., 1994). In turn, the temperature and humidity affect the corrosion and hence the containment performance of the waste packages. Pitting corrosion of a corrosion-resistant container was examined, by varying the key parameters of the pitting process over a broad range. A higher initial heat loading (110 kW/acre) provides a greater time delay between the decline of repository-ambient temperatures and the return of high relative humidity than the lower initial heat loading (55 kW/acre). Over most of the likely range of pitting process parameters, the temperature-humidity relationship of the 110 kW/acre design is effective in preventing loss of containment function to pitting for most of the repository for over 100,000 yr. This is not true for the 55 kW/acre design. If the uncertainty in the range of the pitting parameters can be halved, this will substantially improve the predicted performance of the 110 kW/acre design.

Forecast: See Section 5.3.10.

5.6.11 Activity 1.4.5.1 - Determination of Whether the Substantially Complete Containment Requirement is Satisfied

No progress was made during this reporting period; this was an unfunded activity. Information pertaining to a predecessor activity is provided under Section 5.3.10.

Forecast: No activity is planned for FY 1995. See Section 5.3.10.

5.6.12 Activity 1.5.5.2 - Radionuclide Transport Modeling in the Near-Field Waste Package Environment

Although originally planned as an out-year activity, considerable progress has been made on this topic in the past six months within the International Program. Simple, semi-analytic bounding models have been developed (Chesnut, 1994a) for estimating the effect of heterogeneity on the transport of radionuclides from a nuclear waste repository to the accessible environment. These simple models provide useful complements to more complex calculations based on detailed mechanistic descriptions of flow and transport, because they can be performed extremely rapidly, and the parameters can possibly be determined by analysis of the cosmogenic isotope data already being obtained as part of site characterization.

The common approach underlying these semi-analytic models is a numerical convolution of a source term function with a ground-water transport function. The source term provides the rate of release of radionuclides from the Engineered Barrier System to the hydrogeologic barrier system, and the ground-water transport function gives the radionuclide breakthrough at the accessible environment as a function of time following the release of a unit pulse from the Engineered Barrier System at time zero. The result of this convolution is a function giving the rate of release to the accessible environment as a function of time. This can be integrated numerically to obtain the cumulative radioactivity released to the accessible environment at any time after emplacement. It can also be used to calculate hypothetical dose rates, when combined with assumptions for the delivery of the dose.

For reasons documented elsewhere (Chesnut, 1994b), the ground-water transport function is believed to be a log-normal function, requiring only three parameters:

t_w, the mean ground-water travel time

σ, a measure of heterogeneity, equal to the standard deviation of the natural logarithm of the travel time

R_F, the retardation factor.

When $\sigma = 0$, transport is completely homogeneous (one-dimensional piston-like displacement). As σ increases, the system becomes progressively more heterogeneous, and transport is dominated by a small number of "fast flow paths." Note that this distribution is in principle deterministic. For a specific system, single values of t_w and σ will bound the travel time distribution that could be measured by a conservative tracer breakthrough curve. Retardation factors must be estimated for each species of interest (only the product $R_F \cdot t_w$ appears in the transport equation).

A "regulatory Engineered Barrier System" is used to illustrate the method–the source term is assumed to follow exactly the NRC subsystem requirements:

- Substantially complete containment of radionuclides for a time t_{cc}, equal to 1,000 yr

- Thereafter, controlled release of each radionuclide at an annual rate, f_I, not to exceed 1 part in 10^5 of its remaining inventory.

This particularly simple source term is a step function for each radionuclide, starting at t_{cc} and continuing until its inventory is exhausted at time t_e. For long-lived radionuclides, t_e is 100,000 + t_{cc}; for short-lived species, t_e is less because some of the inventory decays before it can be released.

Figure 5-1 shows the sensitivity of the normalized accessible environment release to the mean ground-water travel time, for values of σ shown in the legend. For the EPA sum to remain below 1.0 for an infiltration of 1.4 mm/yr, the heterogeneity parameter must be less than about 1.9. In other words, there must be credit for the saturated zone, less heterogeneity than is indicated by the Calico Hills pump test data, a smaller average infiltration rate than is suggested by the current site data, or an Engineered Barrier System that performs better than the existing subsystem requirement, to show compliance with the total system requirement.

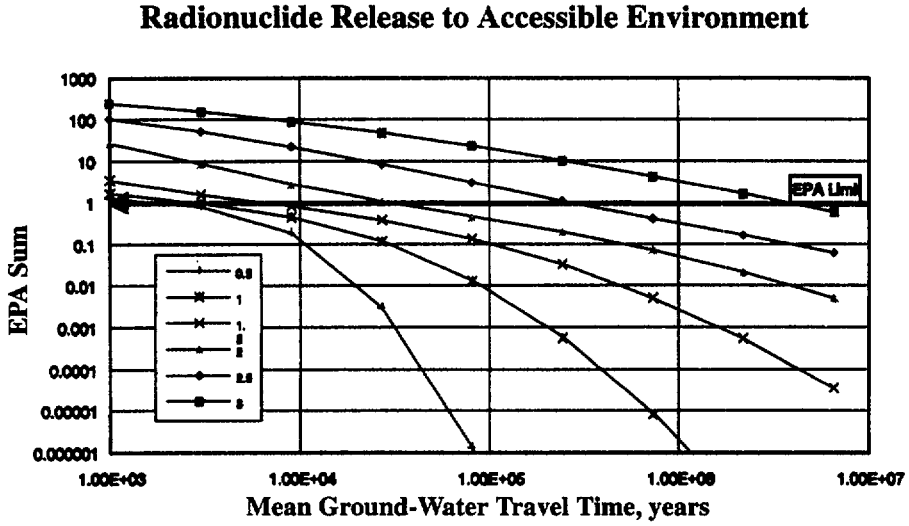

Figure 5-1. Normalized radionuclide release to the accessible environment from convolution of a "regulatory Engineered Barrier System" with a log-normal ground-water transport function. Values of the heterogeneity parameter, σ, are shown in the legend: 0.5 corresponds to a homogeneous soil, 1.6 describes the ground-water flux distribution at Stripa, and 2.2 fits the Calico Hills saturated zone permeability data.

Ultimately, the location of radionuclides as a function of time after emplacement must be determined. That is,

How much of the initial inventory has decayed (the safest fraction)?

How much is still contained within the waste packages (the next safest fraction)?

How much is moving through the geologic control volume?

How much remains in the accessible environment?

The conceptual model described above can be used to answer these questions.

Figure 5-2 shows the distribution of total radionuclides, normalized on the EPA limits for each of the 29 species in the reference inventory. Parameters are chosen to give an EPA sum slightly less than 1.0 for 10,000 yr. The upper curve represents the total normalized radioactivity, taking primary decay into account but ignoring daughters. At emplacement, the total normalized inventory is more than 65,000 (times the EPA release). About 7.4 billion years is required for decay alone to reduce this to 1.0.

The second curve is the total normalized radioactivity minus the normalized radioactivity remaining within the Engineered Barrier System. The region between the two curves represents the portion of the total inventory contained within the Engineered Barrier System.

Finally, the third curve gives the normalized radioactivity that has reached the accessible environment, again allowing for primary decay. The region between the second and third curves represents the inventory contained within the geologic control volume. Note that after 1,000,000 yr, almost all the remaining total radionuclide inventory has reached the accessible environment. Sensitivity studies, exploring order of magnitude changes in the mean ground-water travel time and controlled release fraction, indicate the magnitude of the peak radionuclide inventory remaining in the accessible environment is very insensitive to these model parameter variations.

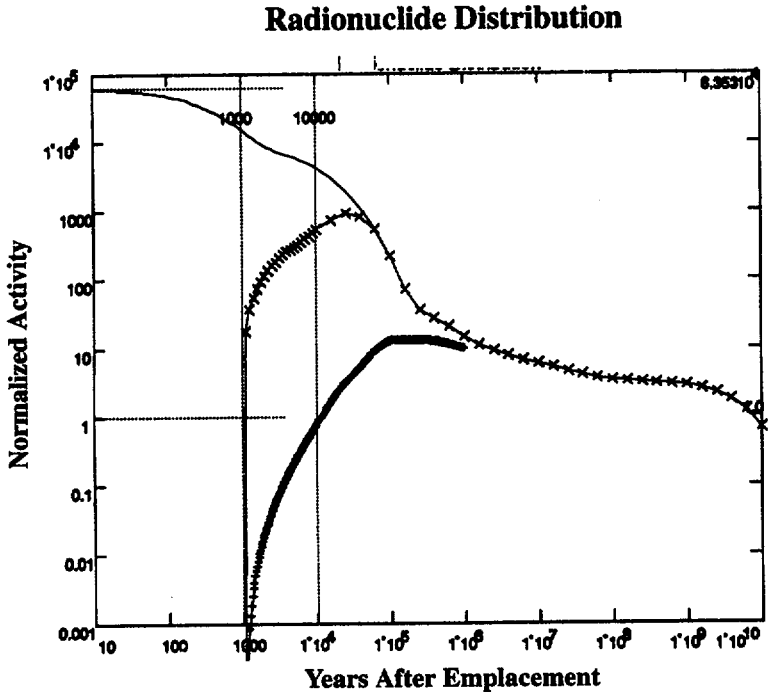

Figure 5-2. Distribution of total radionuclide inventory for the base parameter values. The upper curve is the total, the middle curve is the total minus the Engineered Barrier System inventory, and the lower curve gives the total radionuclide content of the accessible environment.

Related International Work. See Section 5.2.7 for related work (under the heading Effects of Grouting around an Excavation) performed under the auspices of the OCRWM international program.

Forecast: Other Engineered Barrier System release rate functions and ground-water transport functions will be used in the model, and dose rates will be calculated in addition to the EPA sum.

CHAPTER 6 - PERFORMANCE ASSESSMENT

Performance assessment is the set of activities needed for quantitative evaluations of repository system performance to evaluate the suitability of a site, to assess compliance with regulations, and to support the development of a geologic repository. Performance assessment conducts investigations and develops models to examine the performance of the Mined Geologic Disposal System in the preclosure and postclosure phases by using total system and subsystem assessments. Performance assessment verifies, benchmarks, and documents computer codes for assessing the performance of the system's overall waste isolation.

Related International Work. See Section 6.12 for related work [under the heading, Performance Assessment Technology (Verification of SYVAC code)] performed under the auspices of the OCRWM international program.

6.1 WASTE RETRIEVABILITY (SCP SECTION 8.3.5.2)

Section 8.3.5.2 of the SCP, Waste Retrievability, addresses whether the repository be designed, constructed, operated, closed, and decommissioned so that the option of waste retrieval will be preserved as required by 10 CFR 60.111.

A systems study report (CRWMS M&O, 1994i) was written to address the advantages and disadvantages of longer retrievability periods and reported in Progress Report #11 (DOE, 1995m). No further work on this issue was done during the reporting period.

Forecast: No activity is planned for FY 1995.

6.2 PUBLIC RADIOLOGICAL EXPOSURE - NORMAL CONDITIONS (SCP SECTION 8.3.5.3)

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

Forecast: The Technical Basis Report for Preclosure Radiation Safety will be started in the next period. The magnitude of the routine radionuclide releases from the operational waste package handling facility will be estimated. This estimate will be made for all operations from multi-purpose canister arrival at the surface facility to final waste package drift emplacement.

6.3 WORKER RADIOLOGICAL SAFETY - NORMAL CONDITIONS (SCP SECTION 8.3.5.4)

The fully coupled neutron-gamma ray transport code MCNP has been procured and installed on a 486 IBM personal computing platform. The installed code has been exercised with the complete set of test problems which covered a spectrum of criticality and radiation

shielding problems of importance to preclosure radiation safety. Since the procurement of the code began, an updated and more accurate cross section data set for MCNP has been released. This new data has been acquired.

Forecast: The most recent cross section data will be loaded for use with the code. The code will be loaded on a second computer as soon as an already procured large capacity hard drive is installed.

Activities outlined in the forecast under Section 6.2 will be extended to cover worker exposure under normal operating conditions at the facility. For worker radiological safety, both direct ionizing radiation and radionuclide exposure will be assessed.

6.4 ACCIDENTAL RADIOLOGICAL RELEASE (SCP SECTION 8.3.5.5)

A simple model has been developed to predict the deformation of robust waste containers from energetic events such as drops and collisions. A relatively simple spreadsheet model is necessary to perform the multiple realizations required by the probabilistic risk assessment approach to preclosure radiation safety.

Planning was conducted to comply with the accelerated schedule for the technical basis report for Preclosure Radiation Safety. An initial outline was drafted and circulated for comment, and is currently being revised.

Forecast: In support of the Technical Basis Report for Preclosure Radiological Safety, evaluation of dose consequences to the maximally exposed individual and the regional population caused by accidental radionuclide releases will begin.

6.5 GROUND-WATER TRAVEL TIME (SCP SECTION 8.3.5.12)

The DOE developed an approach to calculating ground-water travel time that was presented to NRC in a November-December Technical Exchange and was modified based on staff comments made at that exchange. The modified approach was presented at the DOE Technical Program Review in February and to NRC in a Technical Exchange in March 1995. The NRC staff clarified their suggestions made at the previous exchange. The DOE will present the modified approach to the Advisory Committee on Nuclear Waste in April 1995, and will continue to work with the NRC staff to refine the approach. (For additional information on the DOE approach see Chapter 2, Section 2.2.3.2, Issue Resolution. The results of implementation of that approach are discussed below.)

The 1994 ground-water travel time calculations were completed and documented (Arnold et al., in prep). The report describes the development of the geostatistical model domain, the code for modeling unsaturated-zone ground-water flow, and the particle tracker used to evaluate travel times. The emphasis of this work was on simulating the creation of zones of local ground-water saturation in the unsaturated zone based on plausible assumptions

of model parameters and boundary conditions. In addition to baseline analyses on nine realizations of the model domain, sensitivity studies on the effects of variations in model parameters and the domain were made.

The current investigations, the 1995 iteration of ground-water travel time calculations, emphasize the development of alternative conceptual and numerical models (e.g., the dual-permeability model) for unsaturated-zone flow. This work will include both unsaturated- and saturated-zone analyses by the end of FY 1995.

Improvements in the model domain for use in the calculation were implemented during the first half of FY 1995 and continue to be an area of active research. The unsaturated-model domain is being evaluated using (a) information from deterministic geologic models and (b) geostatistical simulation methods. The saturated-zone model domain is being evaluated based on alternative geologic models. Information on the spatial distribution of relevant hydrologic parameters is necessary to perform flow simulations for the travel-time calculation.

A strategy was developed to incorporate uncertainty into the spatial distribution of properties in the unsaturated zone by using multiple realizations of the model domain. Borehole data were used to co-simulate the distributions of matrix porosity and matrix saturated hydraulic conductivity along cross sections use in the flow modeling. The simulations are based on geostatistical analysis of the spatial correlation of matrix porosity. Because borehole data are sparse, a link between the simulation technique and a digital geologic model has been developed to constrain the simulations in regions of higher uncertainty. The spatial distribution of fracture hydraulic properties will be independently simulated. Statistical relationships among parameters defining relative permeability-moisture retention functions and porosity have been derived. These relationships will be used to define the unsaturated-flow parameters in the model domain.

Methods were developed for the upscaling and averaging of hydraulic parameters in the unsaturated-zone model domain for use in the flow simulation. Because hydraulic properties are measured at the laboratory scale and numerical simulations of ground-water flow are necessarily performed at a much larger scale, upscaling relationships are required. A strategy has been developed in which properties are first upscaled to the intermediate, geostatistical-simulation scale and then averaged to derive effective properties at the flow-modeling scale.

Two-dimensional heterogeneous domains are currently being assessed using the equivalent-continuum and dual-permeability models. In addition, equivalent-continuum and dual-permeability models of the region near the unsaturated UE-25 UZ#16 well are being assessed to compare these models with field data and to bound the range of possible infiltration rates.

A comparison has been documented of equivalent continuum and dual permeability models of one-dimensional infiltration through an unsaturated, fractured, heterogeneous domain. Results showed the potential existence of significant flow in fractures in the dual-permeability model, even when the matrix sustained low saturations (Ho, in prep.).

6.5.1 Activity 1.6.2.1 - Model Development

Calculational models for ground-water travel time must address the initiation and propagation of ground-water flow along fast pathways to the accessible environment. The initial model development has investigated the conditions that might lead to initiation of these fast paths. In addition, some of the details concerning how the results of the calculations will be interpreted have also been studied.

The model domain for the saturated zone used in the analysis is much larger than the domain for the unsaturated zone, and fewer data are available at the depth of the saturated zone. For these reasons, the saturated zone model domain is based on deterministic geologic conceptualizations. Alternative geologic models have been evaluated and the travel-time analysis will be based on two alternative geologic model domains. Reinterpretation of the saturated-zone model domain, as presented in Total System Performance Assessment - 1993, has been performed and will be incorporated in flow simulations. The model domain as defined in the digital geologic model will also be used in flow simulations.

Subactivity 1.6.2.1.1 - Development of a theoretical framework for calculational models. No progress was made during the reporting period; this was an unfunded activity.

Related International Work. See Section 5.2.7 for related work (under the heading, Design and Analysis of Disturbed Zone Experiments) performed under the auspices of the OCRWM international program.

Subactivity 1.6.2.1.2 - Development of calculational models. No progress was made during the reporting period; this was an unfunded activity.

Forecast: Alternative conceptual models will be developed; specifically, the dual-permeability model. This will allow comparison of the effects on unsaturated-zone flow of the different conceptual models.

6.5.2 Activity 1.6.2.2 - Verification and Validation

Laboratory-scale and field-scale studies are progressing to obtain process-level information appropriate for verifying and validating numerical representations of natural processes used in ground-water travel time and total system performance assessment calculations.

Subactivity 1.6.2.2.1 - Verification of codes.

Develop and Verify Continuum Joint Model and Code

Continuum models appear to be an efficient technique for modeling jointed rock masses. These models allow the nonlinear closure and sliding behavior of a joint to be combined in an average sense with the behavior of intact rock. Work is under way to

develop models and codes using continuum models of jointed rock masses. A joint model report (Jung and Thorne, in prep.) was approved by DOE. The step-size dependent errors in the F-T algorithm used in the code JAS3D can be eliminated by using a polar decomposition algorithm. Additionally, the damping calculations for the dynamic relaxation method have been modified. A new joint model version of JAS3D uses damping based on the elastic intact material with the optimum (rather than minimum) damping as default. This version converges on all test problems and requires about the same amount of computer time as the conjugate gradient method. Before the joint model is made standard in JAS3D this version of the dynamic relaxation method will be a standard option.

Forecast: Benchmark calculations on the Large Block Test are planned for the second half of FY 1995.

Subactivity 1.6.2.2.2 - Validation of models.

Flow in Discrete Fractures

Development of adequate conceptual models for flow and transport through fractured rock is an essential component of calculation of ground-water travel time, Total System Performance Assessment, and Technical Site Suitability. To support the development of such models, the focus is currently on three areas: (1) understanding the effects of gravity on relative permeability, (2) measuring the relative permeability in cast replicas of natural fractures, and (3) reducing the data obtained from the flow visualization test performed at Fran Ridge during FY 1994.

Work continued on the flow visualization test performed at Fran Ridge in FY 1994. In this test, three dye-tracer experiments were conducted before excavating the country rock surrounding the Large Block Test. During excavation, the flow paths of the tracer were mapped. Excavation, and hence mapping activities, at the site ceased in the fall of 1994. Efforts continued to extract data from the pavement maps acquired during excavation. One of the experiments was run to test the utility of electrical resistance tomography to delineate moisture within fractured rock. Preliminary cross-sections of the fracture network across two planes perpendicular to the electrical resistance tomography probes were prepared and supplied for comparison with their geophysical results.

No new experimental results were obtained in this time period. Laboratory capabilities were refined significantly as a result of the relocation for casting natural fractures (casting in clear epoxy allows visualization of two-phase flow in the fracture). Method improvement efforts have focused on casting and replication of a fracture in a block of Bandelier Tuff, which will be completed during FY 1995. Once casting is completed, aperture characterization can be compared by (a) transport measurements, (b) surface profilometry, (c) thin casts of the aperture field, and (d) casts of the fracture surfaces. During the flow visualization experiments at Fran Ridge, several boulders (Topopah Spring Tuff) containing natural fractures were obtained. Those samples were transported to Beatty, Nevada, and currently await cutting.

Fracture-Matrix Interaction

The absorption of water from a flowing fracture by an unsaturated matrix may play an important role in buffering ground-water travel times. To investigate this issue, a series of physical and numerical experiments are scheduled. The basic goal of this work is to evaluate when and how best to model this imbibition process.

Laboratory facilities were relocated during this period, and following the move, efforts focused on setting up for experiments to be conducted in the second half of FY 1995. An x-ray visualization laboratory for conducting such studies was recently completed and approved for use at the new facilities. The new laboratory will greatly facilitate experimentation, as well as improve control over the experiment.

Significant progress was made toward analyzing a suite of fracture-matrix interaction data collected this past summer. These experiments involved x-ray imaging of matrix imbibition from a vertically oriented slot fracture. In these experiments, the influence of matrix heterogeneity and presence of barrier fractures on imbibition behavior was investigated. To date, staff have completed digitizing the x-ray films and have nearly completed reduction of the data to matrix saturation fields.

Predicting fluid flow and transport behavior in unsaturated, fractured rock is greatly simplified where matrix imbibition can be modeled as a linear function of the square root of time; however, such a treatment implicitly assumes homogenous matrix properties. To investigate matrix heterogeneity, data were analyzed from a simple experiment in which x-ray imaging was used to monitor the imbibition of water from a single slot fracture into a slab of volcanic tuff. The results are currently being documented (Tidwell et al., in prep.). Experimental results show that matrix imbibition follows a linear relationship with the square root of time even though the saturated hydraulic conductivity of the tuff varies by over four orders of magnitude. This result suggests the fracture-matrix interaction terms based on sorptivity will be less sensitive to matrix heterogeneity than originally expected.

Effective Media Property Scaling in Heterogeneous Systems

One of the difficult issues pertaining to the characterization and modeling of rock property characteristics at Yucca Mountain is that measurements are made at scales much smaller than those of the grid blocks used in performance assessment modeling. As such, scaling models are required to transform data from the scale of measurement to the scale at which analysis is being conducted. The goal of this study is to test the current upscaling models through systematic physical experimentation.

Experimental studies were precluded between October 1994 and January 1995 because of the move of the Subsurface Flow and Contaminant Transport Laboratory to new facilities. In February and March 1995, however, the gas permeameter, which is used to acquire multiscale gas permeability data for testing upscaling models, was re-assembled and tested. Additionally, a number of modifications have been made to the permeameter that will

expedite and improve measurement precision. Construction has also begun on a new large tip seal capable of measuring block-scale permeability (blocks are approximately 1 m^3).

Preliminary efforts began for comparing measured up-scaling behavior with various analytic and numerical upscaling models. An extensive literature review was completed and a list of alternative models for testing was compiled. Computer algorithms for many of these models were developed in support of Study 8.3.1.4.3.2, "Three-Dimensional Rock Characteristics Models" (Chapter 3, Section 3.3.7). Strategies are being finalized for implementing comparison studies between measured and modeled upscaling behavior. Preliminary results will be presented at the 1995 High-Level Waste Conference (McKenna and Tidwell, 1995).

Results of these studies are being integrated into performance assessment calculations. Meetings between the staff responsible for testing and travel-time calculations have resulted in a strategy for upscaling rock properties for use in ground-water travel-time calculations. This strategy is currently being documented.

Conduct Nonisothermal Flow Model Development and Validation

Minimal activity has been performed on this task to date. Efforts will begin in late May or June.

Develop/Validate Reactive Transport Model

Final batch adsorption and column experiments to provide data needed to model the caisson experiments were performed. The experiments showed that the adsorption properties of the sand are dominated by two trace components. The extent and rate of nickel adsorption by the sand are pH-dependent; nickel adsorption occurs primarily on the iron oxyhydroxide coatings on the sand, on sites where lithium does not compete. Some of the nickel adsorbs to kaolinite, and competes with lithium for adsorption sites on that mineral. Lithium adsorbs irreversibly, suggesting that kaolinite is the only important phase in the sand with respect to lithium adsorption. Breakthrough curves for nickel and lithium transport in bench-scale columns were consistent with the batch sorption data. Nickel elution profiles from several samplers within the caisson were obtained.

The final report for studies in support of the caisson experiments was completed and was in management review (Siegel et al., in prep.). The studies described in this report should provide a basis for understanding the transport of nickel, lithium, and bromine through porous media similar to the reference sand. Techniques were developed for obtaining parameter values for surface complexation and kinetic adsorption models for rocks and minerals. These should be useful for characterizing other natural materials in support of coupled hydrogeochemical transport calculations.

Integration of Basic Process Understanding Into Performance Assessment Modeling

Approaches to integrating the understanding developed in this laboratory program into performance assessment calculations are being developed through bimonthly meetings with performance assessment and laboratory staff. In addition, an annotated outline was developed for a report of the implications with respect to performance assessment modeling. In particular, the outline provides examples of how recent advances in understanding of small-scale processes in discrete fractures, fracture networks, between fractures and the matrix, and between ensembles of matrix blocks influence formulation of effective permeabilities. Also explored in the outline are how these same small-scale processes could influence large-scale system response in a manner that presently cannot be simulated by classical continuum modeling. The outline was submitted for approval (Glass et al., in prep.).

In line with the integrative effort, it was suggested that the performance assessment group consider using the infiltration experiment performed at Fran Ridge as a test problem in the proposed follow-up to the INTRAVAL program. A draft test problem was prepared and is being considered.

Significance of Short Ground-Water Travel Times

The ground-water travel time regulation was intended to be a simple measure of the geologic quality of a repository site, independent of total system performance. Unfortunately, it is neither independent nor simple.

The standard is not independent because the travel time reflects the distribution of ground-water flux among all pathways connecting the repository to the accessible environment. Since liquid water is believed to be the principal medium for the transport of radionuclides, the radionuclide flux entering the accessible environment will be closely related to the amount and spatial distribution of water flowing from the repository, as well as depending upon the sorption coefficients and solubilities of the radionuclide species released from the Engineered Barrier System.

The ground-water travel time distribution does not represent just the uncertainty in understanding of the geologic system. It is an intrinsic effect of spatial heterogeneity. The travel time issue can be stated as follows: in a heterogeneous system, a non-zero fraction of the total ground-water flow, F(1000), will have a travel time less than or equal to 1,000 yr.

- At Yucca Mountain, observations of tritium from atmospheric weapons testing in the Calico Hills, along with C1-36 data from such testing, strongly suggest that an unknown fraction of water infiltrating from the surface reaches the water table in a few decades.

- Although water reaching the water table still has to travel about 5 km to reach the accessible environment, it is increasingly difficult to argue convincingly that no water will reach the accessible environment in less than 1,000 yr under pre-emplacement conditions.

- Given that F(1000) > 0, how large can the "fast fraction" be and still allow reasonable assurance of meeting total system performance requirements?

The use of total system performance analysis to evaluate the significance of travel times less than 1,000 yr can be used to address this question. There is no simple way, with large complex models, to separate the contributions of the barrier system and the hydrogeologic system in controlling the release of radionuclides to the accessible environment. However, a "validation" of this separation of Engineered Barrier System and geosphere contributions using performance assessment models was provided with the aid of a simple analytic model for bounding the release of radionuclides to the accessible environment (see Section 5.6.12). The travel-time distribution is assumed to be log-normal (Chesnut, 1994b), with natural log standard deviation, σ, and arithmetic mean, t_w.

The significance of "fast pathways" was assessed by assuming exact compliance with the Engineered Barrier System subsystem requirements (substantially complete containment and controlled release). Release to the accessible environment, normalized by their respective EPA limits, was calculated for a reference inventory of 29 radionuclides using minimum K_d values tabulated. Combinations of the travel-time distribution parameters were chosen so that the EPA sum was exactly 1; other combinations were chosen so that the EPA sum was exactly 10.

Results are shown as the upper and lower curves, respectively, in Figure 6-1. Above the upper curve, the EPA sum is less than 1; regulations require reasonable assurance that the probability is 0.9 or greater that this is true. Compliance also requires reasonable assurance that the probability is at least 0.999 that parameters will lie in the region above the lower curve. Note that for $\sigma \approx 0$ (a completely homogeneous system), a travel time of 1057 yr is sufficient to assure compliance with the total system performance requirement. As the system becomes increasingly heterogeneous (i.e., σ increases), a longer mean travel time is required.

A heterogeneity parameter of $\sigma = 1.6$ fits the inflow flux distribution at Stripa (Neretnieks, 1987), and a value of about 2.2 fits the distribution of hydraulic conductivity obtained from pump tests of the Calico Hills in the saturated zone (Loeven, 1993). A mean ground-water travel time of about 70,000 yr is required to make the EPA sum equal to 1.0 when the heterogeneity parameter is equal to 2.2. Since transport through the unsaturated zone at Yucca Mountain is through the Calico Hills, this degree of heterogeneity should be used in performance calculations until other data become available.

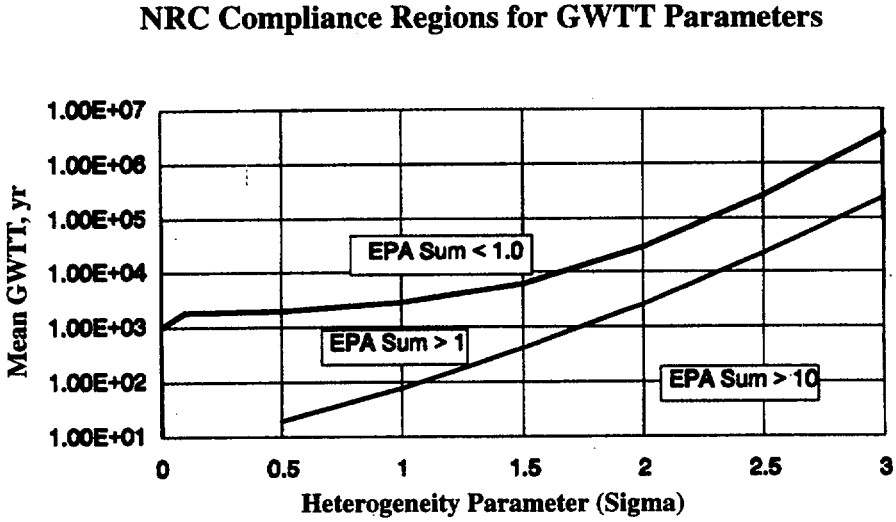

Figure 6-1 Ground-water travel time distribution parameters corresponding to compliance and non-compliance with total system release standards. Along the upper curve the EPA sum is equal to 1.0, and along the lower curve, it is equal to 10.0.

If the infiltration rate is 0.1 mm/yr, as often assumed, the mean travel time from the repository to the water table is 250,000 yr, and there would be no difficulty showing, in the context of this bounding calculation, that the total release standard would be met for σ up to about 2.5. On the other hand, at 1 mm/yr, it must be shown that the system is much more homogeneous, with a σ less than about 1.8. Finally, at 10 mm/yr (a value which cannot be excluded based on available data), the mean travel time would be only 2,500 yr, and it must be shown that σ is less than about 0.8 for total system compliance. A σ value much less than 1.5 seems very unlikely if fractures contribute to the flow and transport in the unsaturated zone below the repository.

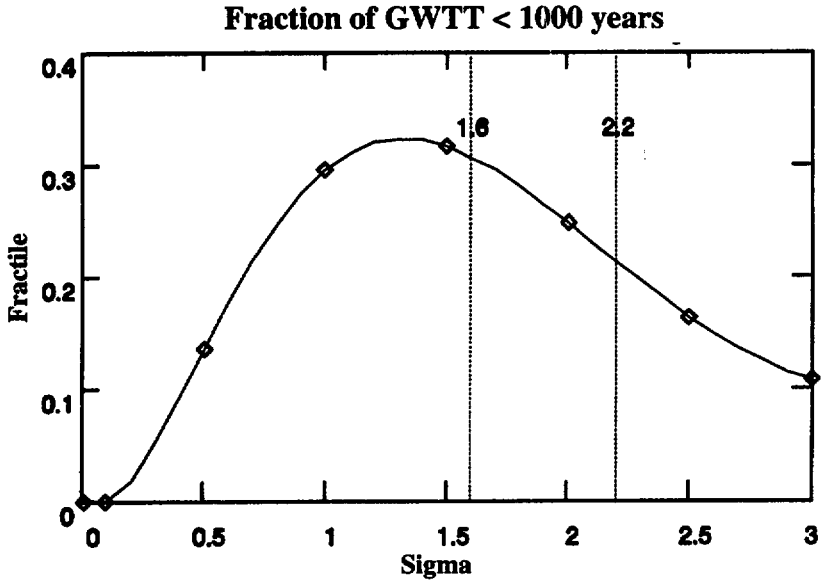

Figure 6-2. The fraction of ground-water flow with a travel time less than or equal to 1,000 years for combinations of t_w and σ given in Figure 6-1.

The question asked above can now be considered: how large can the "fast fraction" be and still allow reasonable assurance of meeting total system performance requirements? Figure 6-2 is a plot of the fraction of ground water having a travel time less than 1,000 yr for the combinations of t_w and σ that result in a value of the EPA sum of 1.0 (from the upper curve in Figure 6-1).

This plot shows that up to about 30 percent of the ground water could have a travel time less than 1,000 yr from the repository to the accessible environment and still permit a demonstration of compliance with the total system release standards. The maximum in this plot indicates that the greatest tolerance to "fast paths" would be obtained for a σ of about 1.3.

These calculations suggest that, in a strongly heterogeneous system with a large mean travel time, a rather large fraction of the total ground-water flux could have a travel time much less than 1,000 yr and still allow satisfactory containment of radionuclides within the geologic control volume.

The observation of bomb-pulse isotopes over most of the depth of the unsaturated zone must be accommodated in any satisfactory analysis of site-scale transport. These observations indicate some transport from the surface essentially to the water table in 40 yr or less. What are the total system performance implications of this rapid transport?

Figure 6-3 shows the fraction of infiltrating water having a travel time less than 40 yr for the same combinations of t_w and σ used above. Note that for σ greater than about 2, more than 1% of the total ground-water infiltration would have a travel time less than 40 yr. For σ less than 1, a negligible fraction would have a travel time less than 40 yr. In other words, to simultaneously account for the observed frequency of occurrence of bomb-pulse material at depth and to demonstrate compliance, the system must not be too homogeneous.

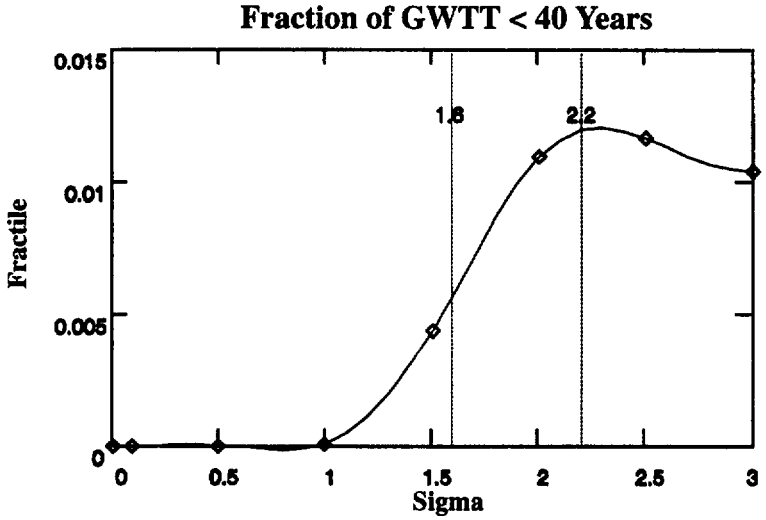

Figure 6-3. The fraction of ground-water flow with a travel time less than or equal to 40 years for combinations of t_w and σ used in Figure 6-1.

Since bomb pulse isotopes have been observed at depth, these calculations suggest that σ is likely to be closer to 2 than to 1, or, alternatively, that the mean ground-water travel time is much shorter than the value required to bound the total system release within the regulatory requirement.

Forecast: Efforts will continue among Project participants to extract fracture network data from the pavement maps obtained from Fran Ridge. That data will be then be made available to both performance assessment and site characterization groups. Experiments investigating the effects of gravity on relative permeability are scheduled to begin in May, with measurement of relative permeability in the fractures scheduled for June. Fracture-matrix studies will focus on analyzing saturation images for the heterogeneous matrix and barrier fracture experiments. Efforts will also be made to perform a new experiment in a tuff slab system cut by a network of rough walled fractures. All work completed under the discrete fracture task will be assimilated and reported under a single report. The primary goal of this report is to document results of laboratory experimentation and, more importantly, to discuss their implications relative to performance assessment modeling. Consistent with these ends, efforts will also be made to assist in implementing discrete-fracture and fracture-matrix flow findings into FY 1995 ground-water travel time calculations.

A series of permeability-sealing experiments on blocks of Yucca Mountain tuff will be completed followed by data analysis. Measured upscaling behavior will be compared with various upscale models, the ultimate goal being to set bounds on the upscale behavior of matrix permeability for tuffs at Yucca Mountain. The results of this effort and the ground-water travel time upscale strategy will be documented in the next six months.

To test many of the assumptions implicit in modeling of nonisothermal flow, physical experiments are to be performed in FY 1996. A series of numerical simulations will be performed to assist in the design and planning of these experiments, including determination of key experimental parameters (e.g., saturations, fracture density, tuff permeability, heater output, and heater placement). Results of these analyses will be documented and submitted.

The final report will be published after comment resolution.

Future work with the log-normal transport function approach will use cosmogenic radiotracer (C-14 and Cl-36) data from the Yucca Mountain site to bound the mean ground-water travel time and heterogeneity parameter.

6.5.3 Activity 1.6.3.1 - Analysis of Unsaturated Flow System

The objective of this activity is to determine which flow paths or sets of flow paths of likely radionuclide travel in the unsaturated zone will be used in ground-water travel time calculations.

Subactivity 1.6.3.1.1 - Unsaturated zone flow analysis. The objective of this subactivity is to determine pre-waste-emplacement unsaturated flow paths from the disturbed zone to the water table. The flow paths will be described in conjunction with Activity 8.3.1.2.2.9.5 and the fastest path of likely radionuclide travel through the unsaturated zone will be identified.

Geohydrologic Data Development

Interactions with field-data investigators and properties-scaling investigators are continuing. Hydrologic properties and other data have been compiled into a local data base in formats that are useful for performance assessment and ground-water travel time modelers. The formats include a local ACCESS data base (primarily hydrologic properties data that represent about 20 percent of all the data that were contained in the old Site and Engineering Properties Data Base with some additions from USGS publications). The remaining 80 percent of the old Site and Engineering Properties Data Base data and additional USGS data (geochemistry, mineralogy, seismology, etc.) have been recovered as ASCII files in a directory format that makes access relatively straightforward but not as convenient as for the data in the ACCESS database.

Subactivity 1.6.3.1.2 - Saturated zone flow analysis. The objective of this subactivity is to determine which flow paths or set of paths of likely radionuclide travel in the saturated zone will be used in ground-water travel time calculations.

No progress was made during the reporting period; this was planned for the second half of FY 1995.

Forecast: The unsaturated zone work should culminate in a data structure that is very convenient for use by performance-assessment and ground-water travel time modelers. Work improving the representation of the saturated zone will be accomplished in conjunction with the ground-water travel time activity reported in Section 6.5.

6.5.4 Activity 1.6.4.1 - Calculation of Pre-Waste-Emplacement Ground-Water Travel Time

Subactivity 1.6.4.1.1 - Performance allocation for Issue 1.6. No progress was made during the reporting period; this was an out-year activity.

Subactivity 1.6.4.1.2 - Sensitivity and uncertainty analyses of ground-water travel time. Sensitivity and uncertainty analyses were conducted as part of Ground-Water Travel Time-94 (Section 6.5) and are documented in Arnold et al. (in prep.).

Subactivity 1.6.4.1.3 - Determination of the pre-waste-emplacement ground-water travel time. The activity described in Section 6.5 is the first step toward making a determination. This was an out-year activity.

Forecast: Additional analyses will be conducted during the remainder of FY 1995.

6.5.5 Activity 1.6.5.1 - Ground-Water Travel Time After Repository Construction and Waste Emplacement

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

Forecast: No activity is planned for FY 1995.

6.5.6 Activity 1.6.5.2 - Definition of the Disturbed Zone

Near-field thermomechanical analyses

The thermomechanical code DDA is being applied to the fractured rock near a heated drift to estimate the change in fracture apertures caused by the thermal pulse. When completed, these results will be used to estimate the near-field change in hydraulic

conductivity, which will help define the near-field disturbed zone attributed to thermomechanical effects.

Forecast: This activity will be completed and reported in FY 1995.

6.6 TOTAL SYSTEM PERFORMANCE (SCP SECTION 8.3.5.13)

A revised strategy for waste isolation and containment was formulated during this reporting period. This strategy was developed on the basis of the experiences gained during Total System Performance Assessment - 1991 (Barnard et al., 1992; Intera, Inc., 1993; Eslinger et al., 1993) and Total System Performance Assessment - 1993 (Andrews et al., 1994; Wilson et al., 1994) and the associated sensitivity analyses, included in these analyses as well as the "mini-total system performance assessments" conducted in FY 1994 which were reported in Progress Report #11. The developed strategy was presented to the Nuclear Waste Technical Review Board in September 1994 and January 1995, and was also presented to NRC and their Advisory Committee on Nuclear Waste. The strategy is also described in the Executive Summary of Volume 2 of the Program Plan (DOE, 1994a).

The strategy places primary importance on five key elements of the total system:

1. A favorable environment for the waste package provided by the unsaturated rock mass

2. Robust waste packages to address near-field uncertainties

3. A limited mobilization of the radionuclides within the waste package

4. The slow release of radionuclides through the engineered barriers

5. The slow migration of radionuclides in the geosphere.

Each of these elements is incorporated in the assessment of total system performance.

The key elements of the containment and isolation strategy just described rely on the natural setting to provide a hydrologic environment that limits the contact of water with the waste package materials, therefore extending the life of these engineered materials. In addition, the limited availability of water within the engineered drifts places constraints on the mobilization of radionuclides because of the limited contact of water with the spent fuel once the containment has been breached, as well as limiting the release of radionuclides through the Engineered Barrier System. The strategy therefore relies on the entire system to work in concert, with the natural system providing a favorable environment in which the engineered barriers may perform optimally. The natural system also plays the conventional role as a barrier in limiting the transport of radionuclides released from the engineered barriers to the accessible environment.

The total work effort within the total system performance assessment area during this reporting period can be divided into two components (1) sensitivity analyses, using as a starting point the Total System Performance Assessment - 1993 conceptual models and parameters, to evaluate the significance of different fracture-matrix transport models on the postclosure performance and (2) process modeling and model abstraction for use in Total System Performance Assessment - 1995. The first activity was performed to evaluate the potential effect of various assumptions regarding the relative importance of the Calico Hills hydrostratigraphic unit in limiting radionuclide transport to the accessible environment in support of the Calico Hills Systems Study. The second activity is a necessary precursor to Total System Performance Assessment - 1995. The status of the work performed under these two activities is presented in the following.

Sensitivity Analyses of Alternative Transport Models in the Calico Hills

The Calico Hills hydrostratigraphic unit has frequently been mentioned as the primary geosphere barrier inhibiting the transport of radionuclides in the unsaturated zone from reaching the water table. To test the significance of the Calico Hills as such a barrier, a series of sensitivity analyses have been performed. These analyses started with the base-case conceptual models embodied in Total System Performance Assessment - 1993. Three different types of analyses were conducted. In the first set of analyses, the transport properties of the Calico Hills were fixed at the 10th, 50th, and 90th percentile of the probability density function and all other parameters were sampled from their respective probability density functions. In these analyses, the conceptual models for flow and transport in the Calico Hills (as well as the other hydrostratigraphic units in the unsaturated zone) were treated as an equivalent continuum. In the second set of analyses, the transport models for all unsaturated and saturated zone hydrostratigraphic units were sequentially modified to allow varying degrees of fracture transport in the different welded and nonwelded units. As before, the conceptual representation and parameterization for the waste package and Engineered Barrier System components of the total system were fixed at those assumed in Total System Performance Assessment - 1993. Finally, the third set of analyses varied the degree of fracture-matrix transport coupling (as defined by the effective matrix diffusion coefficient). The results and relevant conclusions based on these analyses will be presented in the final systems study document on the Calico Hills.

Process Modeling and Model Abstraction for Total System Performance Assessment - 1995

The third iteration of total system performance assessment was initiated during the current reporting period. Although the results of Total System Performance Assessment - 1995 are not expected to be available until the next reporting period (see Forecast), the overall objectives of this total system performance assessment iteration as well as the status of the detailed process-level modeling that will feed into the total system performance assessment calculations are presented below.

The general objectives of Total System Performance Assessment - 1995 can be broadly classified into three major categories: (1) incorporate more representative results, and the corresponding uncertainty, from process models into the abstracted models used in total

system performance assessment, (2) test the significance of a range of conservative assumptions incorporated into previous total system performance assessment iterations, with special emphasis on Waste Package/Engineered Barrier System conceptual models, and (3) evaluate a range of potential system and subsystem postclosure performance measures. Each of these objectives is discussed below with the status achieved during the present reporting period.

The direct link between the detailed process model results and the abstracted model inputs required for total system performance assessment was transparent in Total System Performance Assessment - 1993 for a few processes, including the advective thermally driven gaseous flux and C-14 travel times in the unsaturated zone and the saturated zone ground-water velocity and travel times. In Total System Performance Assessment - 1995, the goal is to provide more representative process model inputs derived from the unsaturated zone flow model, a drift-scale thermal hydrology model, and a model for the initiation and rate of humid air and aqueous corrosion of reference waste package designs. In addition to enhancing the representativeness of the process models, the goal is to evaluate the impact of uncertainties in the process model parameters on the predicted behavior of the system, and ultimately to incorporate the effect of this uncertainty on the postclosure performance consequences.

The basis for the unsaturated zone flow model used to abstract results for Total System Performance Assessment - 1995 is a representative cross-section through the three-dimensional flow model described in Wittwer et al. (1995). The two-dimensional model has been tested over a range of possible infiltrations rates, equivalent continuum hydrologic properties, and the definition of the satiated matrix saturation to determine the following:

1. The range in ambient percolation fluxes at the repository horizon

2. The percentage of the total percolation flux likely to be in fractures

3. The advective velocity of the ground water within both the matrix and fractures of each hydrostratigraphic unit.

The results are highly correlated with the applied infiltration rate at the surface and the spatial distribution of that infiltration rate. These results, and the corresponding uncertainty or variability, will be directly incorporated into the Total System Performance Assessment - 1995 analyses. The results from the unsaturated zone flow model will affect both the advective flux through the Waste Package/Engineered Barrier System, as well as the advective velocity through the unsaturated zone. The level of analyses will not allow for distinguishing between uncertainty and variability, and so these factors will be combined in the Total System Performance Assessment - 1995 analyses.

The basis for the drift-scale thermal hydrology model is also a two-dimensional vertical slice through the unsaturated zone flow model, with the thermal hydrologic properties of the hydrostratigraphic units being similar to those used by Buscheck and Nitao (1993). Sensitivity analyses will be conducted with two areal mass loadings (25 and 83 MTU/acre) and two backfill designs, as well as a range of uncertain/variable parameters including the

percolation flux, the hydrologic properties of the Topopah Spring welded tuff, and the vapor diffusion coefficient. These analyses will be similar to those conducted by Lingineni et al. (1995). Multiple deterministic calculations are planned to evaluate the impact of these uncertain and/or variable properties on the transient humidity and temperature adjacent to the waste packages and the water content and aqueous flux within the drift materials. These results, and the corresponding uncertainty/variability, will be directly incorporated into the Total System Performance Assessment - 1995 analyses. The results from the drift-scale thermal hydrology model will affect the initiation and rate of aqueous corrosion of the waste package, the water contact with the waste form, and the advective/diffusive transport through the waste package and other engineered material in the drift.

The model describing the initiation and rate of humid air and aqueous corrosion of candidate waste package designs to be used in Total System Performance Assessment - 1995 has been based on empirical fits, including the corresponding uncertainty in the functional relationships, to observed data from similar materials in similar environments. Specific laboratory testing of candidate materials under actual environments likely to exist in potential repository drifts at Yucca Mountain have not been completed to date. In the absence of such testing, literature data are all that are available. While these data are extensive for corrosion-allowance materials such as mild steel, there is a lack of information on corrosion-resistant materials. Therefore, the model for pitting corrosion of corrosion allowance material used in Total System Performance Assessment - 1995 will be the same as that used in Total System Performance Assessment - 1993. Using the corrosion initiation and rate empirical models, the stochastic pit growth can be calculated and the cumulative distribution of pits penetrating the waste package as a function of time can be determined. From these results, the distribution of initial pits that penetrate each package can be defined. The cumulative area of pits through each waste package also can be defined assuming a nominal pit size of 1 mm^2. These results, and the corresponding uncertainty/variability will be directly incorporated into the Total System Performance Assessment - 1995 analyses. The results from the corrosion initiation and rate models will affect the time the waste packages are breached, as well as the effective waste package surface area through which any dissolved radionuclides can be transported.

In addition to the direct incorporation of more representative results from process models into the Total System Performance Assessment - 1995 analyses, sensitivity analyses will be conducted on a number of assumptions that have been included in previous Total System Performance Assessment iterations. For example, in previous Total System Performance Assessment analyses it was assumed that once the waste package had been breached by the first pit, that (a) the entire waste package surface area was available for release, (b) the entire cladding surface was breached and the entire waste form surface exposed, and (c) the entire waste form surface was covered by a thin liquid film. All these assumptions will be tested in Total System Performance Assessment - 1995. The degraded waste package surface area will be allowed to vary with time due to the cumulative pit penetration distribution. The cladding performance will be incorporated as a sensitivity analysis. The amount of water in contact with the waste form will be assumed to depend on the water content within the waste package. Additional sensitivity analyses will evaluate the potential significance of natural colloids on enhancing the mobility and transport of some

insoluble actinides, and on the significance of a range of fracture-matrix transport representations.

One of the primary benefits of Total System Performance Assessment is the evaluation of the significance of uncertain and/or variable conceptual models and parameters on the predicted performance. This performance may be defined with respect to system or subsystem performance. In Total System Performance Assessment - 1995, a range of performance measures will be evaluated. These include the mean time to waste package breach, the peak release rate from the Engineered Barrier System, the cumulative release of radionuclides at the accessible environment over different time periods (10,000 and 100,000 yr), and the peak individual dose at the accessible environment over different time periods (10,000, 100,000, and 1,000,000 yr). The correlation between the different performance measures can yield insights into the controlling elements of the waste isolation and containment strategy that most significantly affect the overall performance of the system.

Performance Assessment Integration Activities

Efforts continued at a low level to define frameworks for effective and efficient integration of experimental and process-level modeling work into performance assessment work. Integrating the data from process-level work into realistic performance assessments will require significant investigation of coupling among the processes, as well as accounting for changes in scale between relatively homogeneous laboratory systems and the heterogeneous systems expected to exist in actual geological structures. Ongoing laboratory and field experiments are providing useful and important information on aqueous flow through fractures and scaling effects. Studies of nonisothermal effects and site geochemistry were not funded for FY 1995. Work on integration has been delayed because of higher-priority work elsewhere (e.g., the Calico Hills performance assessment calculations).

Forecast: The detailed process models that will be abstracted for input to Total System Performance Assessment - 1995 will be completed in the next reporting period. Following this, the abstracted model results, and the corresponding uncertainty, will be input into the Total System Performance Assessment code RIP. A range of sensitivity and uncertainty analyses will be performed with RIP to evaluate the system and subsystem performance measures. This work will be documented toward the end of the next reporting period.

6.6.1 Performance Assessment Activity 1.1.2.1 - Preliminary Identification of Potentially Significant Release Scenario Classes

Subactivity 1.1.2.1.1 - Preliminary identification of potentially significant sequences of events and processes at the Yucca Mountain repository site. No progress was made during the reporting period; this was an out-year activity.

Subactivity 1.1.2.1.2 - Preliminary identification of potentially significant release scenario classes. The release scenarios reported in Barr et al. (1995) are being screened to develop a

short list of scenarios describing the expected behavior of flow and transport in Yucca Mountain. This list will be used as a baseline for initial performance calculations and later comparison with other scenarios. The screening is essentially complete, and the necessary documentation needs to be written.

Interactions between performance assessment analysts and site investigators have begun in order to develop a Total System Performance Assessment module on the effects of seismic events on repository performance.

Forecast: The reference hydrological cases should be reported in a document to be published during the next few months. In addition, scenarios will be constructed for tectonic processes and human intrusion at Yucca Mountain. Conceptual model development on the tectonic subsystem will be completed early in the third quarter. The models will then be implemented in a numerical form and run as part of Total System Performance Assessment-1995 to assess effects on repository performance. Results will be presented at the FOCUS '95 conference.

6.6.2 Performance Assessment Activity 1.1.2.2 - Final Selection of Significant Release Scenario Classes to be Used in Licensing Assessments

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

Forecast: No activity is planned for FY 1995.

6.6.3 Performance Assessment Activity 1.1.3.1 - Development of Mathematical Models of the Scenario Classes

Subactivity 1.1.3.1.1 - Development of models for releases along the water pathways. No progress was made during the reporting period; this was an out-year activity.

Subactivity 1.1.3.1.2 - Development of a model for gas-phase releases. No progress was made during the reporting period; this was an unfunded activity.

Subactivity 1.1.3.1.3 - Development of a model of releases through basaltic volcanism. No progress was made during the reporting period; this was an out-year activity.

Subactivity 1.1.3.1.4 - Development of a model of releases through human intrusion. No progress was made during the reporting period; this was an out-year activity.

Forecast: No activity is planned for FY 1995.

6.6.4 Performance Assessment Activity 1.1.4.1 - The Screening of Potentially Significant Scenario Classes Against the Criterion of Relative Consequences

No progress was made during the reporting period; this was an unfunded activity.

Forecast: No activity is planned for FY 1995.

6.6.5 Performance Assessment Activity 1.1.4.2 - The Provision of Simplified, Computationally Efficient Models of the Final Scenario Classes Representing the Significant Processes and Events Mentioned in Proposed 10 CFR 60.112 and 60.115

No progress was made during the reporting period; this was an unfunded activity.

Forecast: No activity is planned for FY 1995.

6.6.6 Performance Assessment Activity 1.1.5.1 - Calculation of an Empirical Complementary Cumulative Distribution Function

No progress was made during the reporting period; this was an unfunded activity.

Forecast: No activity is planned for FY 1995.

6.7 INDIVIDUAL PROTECTION (SCP SECTION 8.3.5.14)

6.7.1 Activity 1.2.1.1 - Calculation of Doses Through the Ground-Water Pathway

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

Forecast: No activity is planned for FY 1995.

6.7.2 Activity 1.2.2.1 - Calculation of Transport of Gaseous Carbon-14 Dioxide Through the Overburden

No progress was made during the reporting period; this was an unfunded activity.

Forecast: No activity is planned for FY 1995.

6.7.3 Activity 1.2.2.2 - Calculation of Land-Surface Dose and Dose to the Public in the Accessible Environment Through the Gaseous Pathway of Carbon-14

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

Forecast: No activity is planned for FY 1995.

6.8 GROUND-WATER PROTECTION (SCP SECTION 8.3.5.15)

6.8.1 Analysis 1.3.1.1 - Determine Whether Any Aquifers Near the Site Meet the Class I or Special Source Criteria

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

Forecast: No activity is planned for FY 1995.

6.8.2 Analysis 1.3.2.1 - Determine the Concentrations of Waste Products in any Special Source of Ground Water During the First 1,000 Years After Disposal

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

Forecast: No activity is planned for FY 1995.

6.9 PERFORMANCE CONFIRMATION (SCP SECTION 8.3.5.16)

No progress was made during the reporting period; this was an unfunded activity.

Forecast: No activity is planned for FY 1995.

6.10 U.S. NUCLEAR REGULATORY COMMISSION SITING CRITERIA (SCP SECTION 8.3.5.17)

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

Forecast: No activity is planned for FY 1995.

6.11 HIGHER-LEVEL FINDINGS–POSTCLOSURE SYSTEM AND TECHNICAL GUIDELINES (SCP SECTION 8.3.5.18)

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

Forecast: No activity is planned for FY 1995.

6.12 RELATED INTERNATIONAL PERFORMANCE ASSESSMENT WORK

Performance Assessment Technology (Verification of SYVAC code)

The following is work, related to Program 8.3.5 (Chapter 6), conducted cooperatively with Canada under the auspices of the OCRWM international program.

During the previous reporting period, the verification effort for the total system performance assessment code, SYVAC, continued to demonstrate the value of having the entire code development process reviewed externally in depth. The review led to numerous improvements, including the correction of both relatively important errors and a few of significant impact, which had not yet been tested by Atomic Energy of Canada Limited. Kersch and Oliver (1994) provide details of the pilot phase of this task. The same tools developed for the Atomic Energy of Canada Limited work can be used directly for other codes, including models used by the Yucca Mountain Site Characterization Project.

During this reporting period, twenty subroutines of the geosphere model and four of the biosphere model were reviewed. Eight subroutines still need review to complete the current scope of work. Work continued on the documentation requirements of SYVAC3-CC3 and its associated development and support tools, including a users manual for the CC3 model. The CC3 programmers manual was begun. Considerable progress was made on the documentation of support programs that generate input files using data from the CC3 data base. Review of the vault model unit tests was initiated.

Forecast: The review of eight remaining SYVAC subroutines, two of which are large, should be completed. Preliminary results of the vault testing will be presented at the Summer Computer Simulation Conference. The United States involvement in the project will be completed in FY 1996.

CHAPTER 7 - EXPLORATORY STUDIES FACILITY DESIGN AND CONSTRUCTION

Section 8.4.2 of the SCP, presented the rationale for planned testing and described surface testing and the underground test facility. In the SCP underground testing was to be conducted by means of an "Exploratory Shaft Facility." The change to a ramp and drift "Exploratory Studies Facility" means the following description of progress does not closely parallel the SCP structure, and as a result there are not as many references to SCP sections as there are elsewhere in this report.

Throughout this section various design packages are referenced. Table 7-1 identifies and describes the package and shows the status at the end of the reporting period. Figure 7-1 shows the locations of the design packages. Table 7-1 and Figure 7-1 have been updated to reflect the ESF configuration contained in the Civilian Radioactive Waste Management Program Plan (DOE, 1994a). In Table 7-1 the design package numerical identifications have been eliminated beyond Package 2 because of the initiative to streamline the design process and to align the remaining design packages with the ESF configuration contained in the Program Plan.

7.1 EXPLORATORY STUDIES FACILITY DESIGN

Minor modifications were made to the contents of Packages 1E and 2B from those shown in Progress Report #11 (DOE, 1995m). Initiatives were developed and implemented to streamline the design and construction process and align the remaining design packages with the ESF configuration contained in the Program Plan. A value engineering study was completed on the communication system for the ESF pad and the Field Operations Center that will result in a significant cost savings.

Ongoing modifications in the form of Field Change Requests and Change Requests continue to be made against Design Package 1A to support construction. Package 1A consists of the following elements:

- North Portal pad
- Topsoil storage area
- ESF access road
- Sewage collection and treatment system
- North Portal pad water supply system (including the Booster Pump Station)
- Tunnel boring machine starter tunnel
- Rock storage area
- Switchgear building
- North Portal pad power distribution system (partial)

Table 7-1. Design Package Identification and Description

Design Package	Design Package Description	Status
1	North Portal site preparation and surface facilities	
1A	Pad, rock and top soil storage, access road, sewage system, water supply, starter tunnel, switchgear building, power distribution system	Issued
1B	Change house, shop, sewage system, power and water distribution, road grading and paving, site grounding, pad drainage and surface rail modifications, pad grading and paving plan	Issued
1C	Compressed air system, stand-by power, site lighting and grounding	Issued
1D	Site lighting and grounding, muck storage, conveyor access road, fuel storage, equipment foundations, compressed air condensate collection system	Issued
1E	Stand-by power, site grounding, electrical distribution, fuel storage modifications	FY 1995
IDCS	Integrated Data and Control System	Issued
2	North Ramp excavation - starter tunnel to Topopah Spring level	
2A	Conveyor, switchgear, transformers, power centers, subsurface transportation	Issued
2B	Utilities, tunnel ventilation, rail haulage system, mapping platform, control system, safety monitoring and warning system	Issued
2C	Excavation layouts, ground support, utilities, electrical power, site lighting, site grounding, alcoves	FY 1995
	Topopah Spring Level Main Drift	FY 1995
	Ghost Dance Fault Accesses at Topopah Spring Level	Out year
	North Ramp Extension	Out year
	Thermal Test Areas	Out year
	Topopah Spring Level South Ramp	Out year
	South Portal Pad and Facilities	Out year
	Calico Hills Level North Ramp	Out year
	Calico Hills Level Main and Cross Drifts	Out year

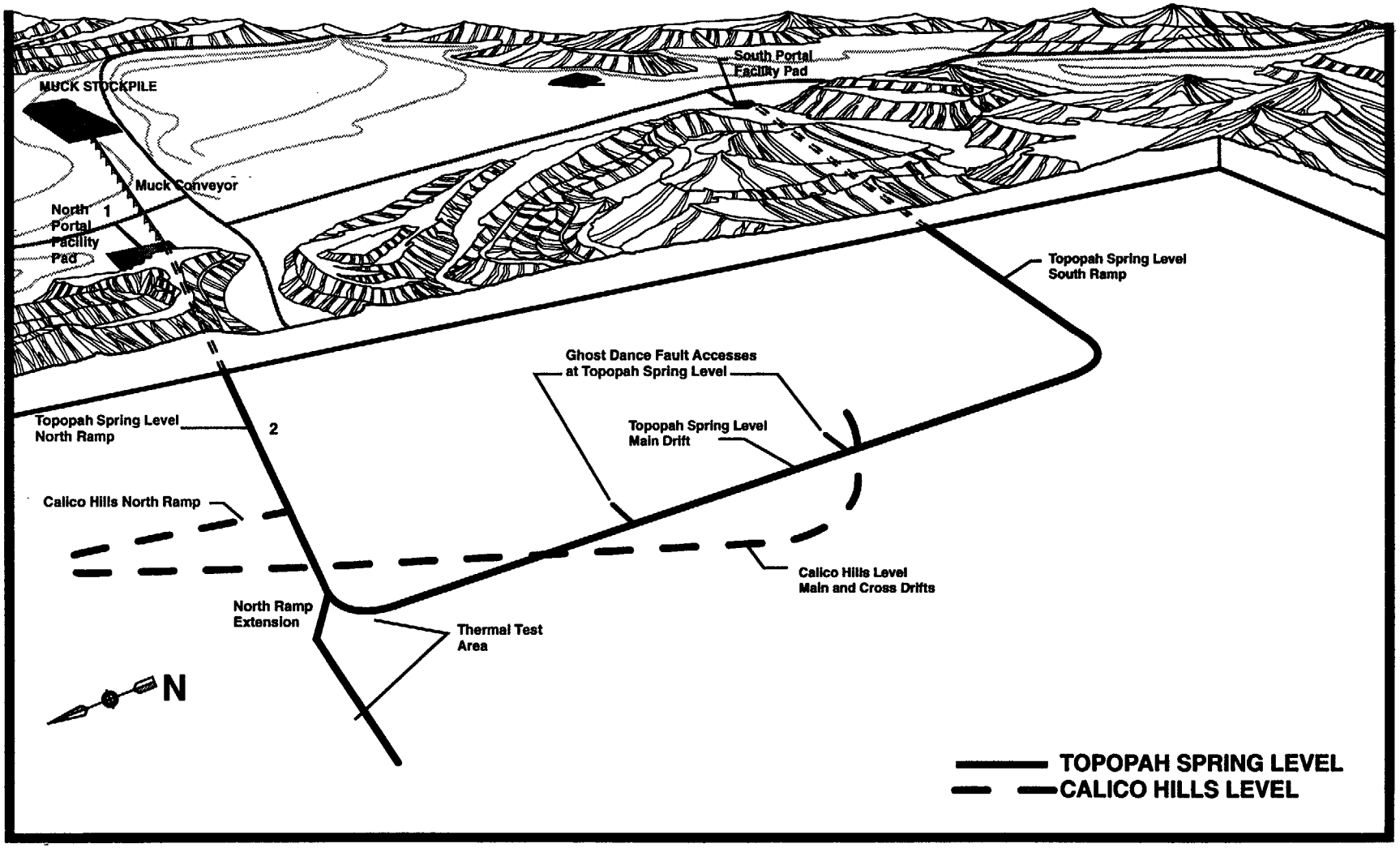

Figure 7-1. Exploratory Studies Facility Design Package Locations

Ongoing modifications in the form of Field Change Requests and Change Requests continue to be made against Design Package 1B to support construction. Design Package 1B consists of the following elements:

- Change house building (contains other services to support portal control)
- Shop building
- Sanitary sewer system
- Power distribution
- Water distribution system
- Subsurface wastewater system
- H-road, site grading, and paving
- Explosive storage area (deleted)
- Site grounding
- Redesign North Portal pad drainage
- Reconfigure North Portal pad for surface rail
- Finish grading and paving plan and surface rail (added by Change Request).

Ongoing modifications in the form of Field Baseline Change Proposals and Baseline Change Proposals continue to be made against Design Package 1C to support construction. Design Package 1C consists of the following elements:

- Compressed air system
- Stand-by power
- Site lighting (partial)
- Site grounding (partial).

Design Package 1D, which was baselined and issued for construction during this period, consists of the following elements:

- Site grounding (continuation)
- Muck storage area
- Conveyor maintenance access road
- Fuel storage system
- Site lighting (continuation)
- Equipment foundations
- Compressed air system condensate collection system.

Design Package 1E, which completed design during this period, consists of the following elements:

- Stand-by/auxiliary power
- Site grounding (continuation)
- ESF electrical distribution (continuation)
- Revised fuel storage system.

The Integrated Data and Control System Design Package, which underwent a 90% Design Review and was baselined and issued for procurement during this period, consists of the following elements:

- Procurement specification for the complete Integrated Data and Control System
- Fiber Distributed Data Interface for the first phase.

A decision was made to use the M&O, through one or more of its team members, as the Integrated Data and Control System Systems Integrator. Discussions are currently under way to implement this decision. This will enhance the Project's ability to accept change to the system in a more timely manner and to minimize costs resulting from change orders to the purchase order with the hardware and software vendors.

Subsurface Design Package 2 for the North Ramp, consisting of Design Packages 2A, 2B, and 2C, was continued and is nearly complete. At this time only the alcove drill and blast specification remains to be completed. Ongoing modifications in the form of Field Change Requests and Change Requests continue to be made against Design Package 2A. Package 2A consists of the following elements:

- Surface and subsurface conveyor
- Electrical switchgear, transformers, and power center
- Subsurface transportation alternatives.

Ongoing modifications in the form of Field Baseline Change Proposals and Baseline Change Proposals continue to be made against Design Package 2B as tunneling progress continues. The control system design was removed from this package and integrated into the Integrated Data and Control System Design Package. Design Package 2B, which was baselined and issued for procurement during this period, consists of the following elements:

- Utility systems
- Tunnel ventilation specification and drawings
- Rail haulage system
- Mapping platform procurement specification
- Excavation, ventilation, and muck storage trade studies
- Control system specification and drawings (now included as part of Integrated Data and Control System Package)
- Life safety monitoring and warning system specifications.

This package contains the appropriate procurement information for these elements.

A value engineering study was completed on the communication system for the ESF pad and the Field Operations Center. The study results included recommendations for a significantly reduced system on the ESF pad based on current needs. The original plan for a fiber optic network to link the ESF pad and Field Operations Center has been modified. The current approach is to use existing microwave capability and existing switching equipment to meet the ESF pad communication needs for the next five years. The value engineering study recommendations are being reviewed by the Architect/Engineer to determine which will be included in a revision to the current ESF pad communications design contained in Design Package 2B. Incorporating the value engineering study recommendations is projected to save approximately $1,000,000.

Design Package 2C, which underwent a 90% Design Review during this period, was issued as segments to support the procurement and construction schedule for the initial phase of tunnel boring machine operations. Three additional segments, which cover tunnel boring machine excavation to the end of the North Ramp, were baselined and issued during this period. Ongoing modifications in the form of Field Baseline Change Proposals and Baseline Change Proposals continue to be made against Design Package 2C as tunneling progresses. Design Package 2C consists of the following elements:

- 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.

This package primarily contains construction and installation details for these elements, as well as the elements in Design Packages 2A and 2B.

During this reporting period, an alternative approach for designing and installing ESF construction utilities was proposed based on discussions between the Architect/Engineer, DOE, the Construction Management Organization, and the Constructor. The objective of the proposal was to enhance tunnel boring machine productivity by installing construction utilities only and to defer costs associated with procuring and installing of Architect/Engineer designed permanent systems. Pending final approval of this approach by DOE, the Architect/Engineer is proceeding with the design package for the Topopah Spring Level Main Drift (formerly labeled 8A). This package covers primarily the excavation layouts for the remainder of the Topopah Spring loop and will use ground control, drilling and blasting, and other standard drawings and specifications from Design Package 2C. To improve overall efficiency of the design/construction approach, the Constructor has been given responsibility for planning the construction utility systems, including compressed air, water, waste water, electric power and control systems, and ventilation. The construction systems will comply with all construction controls imposed by Architect/Engineer specifications. The construction utilities will be designed to support both construction and site characterization testing needs, and on completion of the construction phase will be upgraded or replaced to meet standards of the Architect/Engineer designed permanent systems. The Design Package 2C electrical and mechanical systems designs will be reviewed and if necessary reconfigured to support the Program Plan.

Design for the Topopah Spring Level Main Drift Package is continuing and currently consists of the following elements:

- Topopah Spring level main drift excavation layouts and ground support
- Associated operational support alcoves
- Conveyor system support structures.

The Topopah Spring Level Main Drift Package design details are being developed with input from the Constructor, Test Coordination Office (Los Alamos) and USGS. The Architect/ Engineer interfaces with SNL and USGS in planning for future design validation activities.

During this reporting period, an initiative was started to streamline the design process. The bulk of the design for the underground portion of the ESF was performed as part of the design of the North Ramp (Design Package 2). This included analyses of the various systems and preparation of standard specifications and drawings. The remaining portions of the underground facility will use these analyses and standard specifications and drawings. In addition, specific general arrangement and detail drawings and specifications for each portion of the underground facility will be developed as required.

Because the bulk of the underground design was reviewed during the development of the North Ramp design, the 50% and 90% Design Reviews have been eliminated. They will be replaced with one external review for each of the design packages for the remaining portions of the underground facility. This process will shorten the development time for releasing designs for the remaining portions of the facility, but will not sacrifice the quality of the products. Organizations such as NRC, Nuclear Waste Technical Review Board, State of Nevada, and Affected Counties will be invited to observe the external reviews.

As part of this initiative, we will no longer refer to design packages by number. Design packages will be referred to by the physical scope of the design package. For example, Design Package 8A will simply be referred to as the Topopah Spring Level Main Drift Design Package. This will eliminate confusion over the contents of a particular design package. The design packages that remain to be released for construction are as follows:

- Topopah Spring Level Main Drift (formerly Design Package 8A)
- Ghost Dance Fault Accesses at Topopah Spring Level (formerly part of Design Package 8)
- North Ramp Extension (formerly part of Design Package 8)
- Thermal Test Areas (formerly part of Design Package 9)
- Topopah Spring Level South Ramp (formerly Design Package 4)
- South Portal Pad and Facilities (formerly Design Package 3)

- Calico Hills Level North Ramp (formerly Design Package 5)
- Calico Hills Level Main and Cross Drifts (formerly Design Package 7).

The Topopah Spring Level Main Test Area (formerly Design Package 9) no longer exists as a defined area. The tests that were to have been performed in this area have been relocated to various locations along the Topopah Spring Level Main Drift and North Ramp Extension. The Optional Shaft (formerly Design Package 10) is no longer part of the Program Plan.

The 69 kV temporary power system upgrades were completed. The remaining design work for breaker addition and replacement at Canyon and North Portal substations is nearing completion. The design is scheduled to be released the end of April 1995. After the release, the breaker addition and replacement will be initiated, with planned completion in FY 1995.

One item originally planned for FY 1995, which will slip into FY 1996, is the voltage correction capacitors at Stockade Wash substation. Because of funding constraints DOE/ Nevada Test Site has canceled the Stockade Wash substation upgrade. The location of the voltage correction capacitor banks will be changed to Valley substation, which is a better location technically. This requires a design for Valley substation to accommodate the capacitors. Raytheon Services Nevada has begun preparing a schedule and cost estimate for this design for DOE approval. The capital funds for the capacitor banks will be reallocated to purchase a replacement transformer for the one on loan from Nevada Power Company at the North Portal substation. The current transformer is scheduled for return to Nevada Power Company September 30, 1995.

Forecast: Design Package 1E is scheduled to undergo a design review, be baselined, and issued for construction early in the fourth quarter of FY 1995. The Architect/Engineer will support procurement, which is scheduled to begin on the first portions of the Integrated Data and Control System Package in the third quarter of FY 1995. The initial Integrated Data and Control System procurement will consist of a surface work station, ethernet, and the first five Data Acquisition Stations to support the SNL construction monitoring activities and the USGS alcove work. Design of the following additional Design Package 1 and 2 items will be completed, baselined, and issued for construction by Change Request in the third quarter of FY 1995:

- Local controls for water and Compressed Air System
- North Portal pad perimeter fencing
- North Portal lightning protection
- Modifications to switchgear building for Integrated Data and Control System
- Sanitary sewage treatment.

The remaining segment of Design Package 2C, design of alcoves and alcove utilities, is scheduled to be baselined and issued for construction early in the third quarter of FY 1995. Design Package 2B utility systems and life safety monitoring and warning system drawings and specifications, which were initially issued for procurement only, are scheduled to be issued for construction during the second half of FY 1995.

A revision to the Design Package 2B communications design for the ESF pad and Field Operations Center is scheduled to begin in the third quarter of FY 1995 to incorporate accepted value engineering study recommendations.

The Topopah Spring Level Main Drift Design Package is scheduled for design completion in the third quarter of FY 1995 and external review and issue for construction in the fourth quarter of FY 1995. The Ghost Dance Fault Accesses at Topopah Spring Level Design Package is scheduled to begin design in the third quarter of FY 1995.

Design will begin in the third quarter of FY 1995 to incorporate voltage correction capacitors at the Valley substation as part of the Nevada Test Site power system upgrades to the ESF site. The design is scheduled to be completed in the first quarter of FY 1996, which will result in the procurement and installation of the capacitors in the second quarter of FY 1996.

7.2 Exploratory Studies Facility Seismic Design

A technical assessment of the ESF seismic design inputs began in FY 1993. No work was performed on this task during the reporting period. The technical assessment examined the seismic design basis for the ESF using a two-phase approach. First, the assessment team was to review the Exploratory Shaft Seismic Design Basis Working Group Report (Subramanian et al., 1990) to determine if the proposed seismic design basis was still appropriate given the current configuration of the ESF and the current understanding of seismic hazards at Yucca Mountain. Second, if the proposed basis could no longer be supported, the team was to recommend a new seismic design basis.

A review of Subramanian et al. (1990) resulted in three main comments:

1. Assumptions related to the configuration of the ESF are now inappropriate given the new configuration involving ramps and drifts.

2. Conclusions based on geologic data available at the time of the report need to be revised using new information gathered since that time.

3. The multiple levels of conservatism recommended in the report are inappropriate.

On the basis of this evaluation, the assessment team concluded that the proposed seismic design basis could no longer be supported. Hence, the technical assessment team implemented the second phase of its charter: to recommend seismic design inputs appropriate for design of the ESF at Yucca Mountain.

As part of the process to develop these inputs, a probabilistic assessment of vibratory ground motion hazard at Yucca Mountain was performed (DOE, 1994g). The results of the probabilistic assessment yield values of peak horizontal acceleration and velocity as a function of their annual probability of being exceeded. The results also provide the information

needed to determine a design basis earthquake and associated response spectrum. This approach incorporates the time dependence of earthquake occurrence, allows uncertainties in assessment inputs to be explicitly incorporated in the analysis, and evaluates hazard from potential sources of future seismicity.

The resulting values of mean peak horizontal acceleration with various annual probabilities of being exceeded are as follows:

Annual Probability of Being Exceeded	Mean Peak Horizontal Acceleration (g)	Average Return Period (yr)
2×10^{-3}	0.19	500
1×10^{-3}	0.27	1,000
5×10^{-4}	0.37	2,000
1×10^{-4}	0.66	10,000

Because the purpose of the ESF is to facilitate underground exploration and testing to support a site suitability evaluation for Yucca Mountain, the technical assessment team recommended that seismic design loading for the facility should be based on a hazard with a 90% probability of not being exceeded in 50 yr (or a return period of roughly 500 yr). Seismic design inputs, therefore, were developed for the hazard with an annual probability of being exceeded of 2×10^{-3}.

Disaggregation of the probabilistic seismic hazard assessment indicates that for annual exceedance probabilities greater than about 1×10^{-4} (return periods of less than 10,000 yr), the primary source of ground motion hazard at the site is a background earthquake. At an exceedance level of 2×10^{-3}, the mean magnitude and distance of contributing earthquakes is M 5.7 at a source-to-site distance of 9 km. Response spectra were developed for such an earthquake using three approaches: (1) probabilistic equal-hazard, (2) empirical deterministic, and (3) stochastic deterministic. The recommended design response spectrum envelops the three approaches.

Peak velocity for design was determined using the band-limited white noise approach and random vibration theory. The velocity was derived to be consistent with the recommended design spectrum. For the 2×10^{-3} exceedance probability level, the design peak velocity is 12 cm/sec.

The technical assessment team also evaluated the effect on ground motion caused by depth of burial below the surface. Both stochastic and empirical approaches were used. For design, a step-function that envelops the results of the two approaches was recommended.

To evaluate the need for seismic design inputs for surface fault displacement, a simpler analysis was performed. The recurrence intervals for surface displacement on faults within

and near the site were compared with the approximately 50- to 100-yr expected life of the ESF. Because the recurrence intervals for surface fault displacement are large, the technical assessment team concluded that design did not need to accommodate fault displacement.

On the basis of the recommendation of the technical assessment team, and considering other information, the ESF Design group developed a graded approach for seismic design of temporary and permanent items. This approach uses the philosophy in DOE Standard 1020 in which structures, systems, and components with larger adverse consequences of failure are designed more conservatively. This approach is often referred to as the performance goal-based approach.

Seismic design within a performance goal-based framework requires that structures, systems, and components be classified into performance categories. Items within a single performance category have a similar target for performance that is established on the basis of the adverse consequences of their failure. The target is expressed as an annual probability of failure that the design should not exceed. Performance categories established in DOE Standard 1021 range from performance category-0, for which the structures, systems, and components are unimportant from safety, mission, and cost perspectives and for which seismic design is not required, to performance category-4, for which the structures, systems, and components performs a safety function in a highly hazardous facility and for which seismic design should provide an annual probability of failure that does not exceed 1×10^{-5}.

Temporary ESF items are evaluated as equivalent to performance category-1 items within the DOE Standard 1021 framework. The ESF surface and subsurface items are only planned to be functional during the ESF maintainable service life of 25 yr, and thus are not important to radiological safety or waste isolation. Temporary items are only considered important to worker safety. Within the DOE Standard 1021 framework, items in performance category-1 are designed for a ground motion with a 2×10^{-3} annual probability of being exceeded to achieve a performance goal of 1×10^{-3}. The value of mean horizontal acceleration determined from the probabilistic hazard assessment for this annual probability of exceedance is 0.19g. Design for the controlling earthquake associated with this ground motion level would be reasonable for temporary ESF items.

Although the value of 0.19g is derived from a site-specific analysis, ESF designers decided to design temporary ESF items more conservatively. The Nevada Test Site is classified as Uniform Building Code Zone 3 in Appendix C of DOE Standard 1020. Because Yucca Mountain is located on the boundary of the Nevada Test Site, ESF temporary items will be designed conservatively for a mean horizontal acceleration of 0.30g consistent with Uniform Building Code Zone 3.

Depth reduction factors from the ESF Seismic Design Inputs Report are considered to directly apply to the selection of appropriate subsurface ground motions. These factors are multipliers used to reduce the surface acceleration values for subsurface design. The ground motion reduction factors for acceleration are summarized as follows:

	Peak Acceleration	
Depth (m)	Horizontal	Vertical
0-100	1.00	1.00
100-200	0.60	0.70
200-400	0.50	0.60
>400	0.50	0.50

The design response spectrum for temporary ESF items is based on the one developed in the ESF Seismic Design Inputs Report. The response spectrum presented in that report for a mean horizontal ground acceleration with an annual probability of exceedance of 2×10^{-3} (0.19g) was normalized and scaled to the selected design acceleration value of 0.30 g.

Permanent ESF items could potentially be incorporated within the repository if one is built at Yucca Mountain. A methodology for seismic design of a repository at Yucca Mountain is being developed as the second in a series of topical reports addressing seismic hazard assessment and seismic design issues (see Section 3.13). Pending development and implementation of that methodology, a preliminary evaluation of ESF permanent items has classified them as, at most, equivalent to performance category-3 within the DOE Standard 1020 framework. Damage to ESF permanent items (openings, ground support, linings, and operational seals) from a seismic event poses only low risk of radiation exposure to the public during the preclosure period. This risk is judged to be lower than that from damage to a reactor hot cell and its filtered ventilation system. Specific considerations include the following:

- There will be no direct handling of radioactive materials underground
- Storage of radioactive materials will be in dedicated emplacement drifts
- During transport underground, there will be no direct handling or storage of radioactive materials
- Radioactive waste will always be contained within protective waste packages that will be designed to survive severe drift damage.

Also, the repository facility will not need to be continuously operated. Following a seismic event, operations could be suspended while crews inspect the openings and complete minor maintenance and repair to ground support systems. Ground support systems will, nonetheless, be designed to withstand the design-basis earthquake without either disrupting operations or causing rockfalls that may damage equipment or expose personnel to bodily injury. This evaluation of ESF permanent items is consistent with earlier evaluations which suggest that repository structures, systems, and components are likely to be, at most, equivalent to performance category-2 or performance category-3. In addition, ESF permanent items are being designed such that items can be upgraded, if appropriate, for repository seismic design.

Mean horizontal ground accelerations, based on the analysis supporting the ESF Seismic Design Inputs Report for annual probabilities of exceedance equivalent to those for performance category-2 and performance category-3 within the DOE Standard 1020 framework are 0.27g and 0.37g, respectively. Depth reduction factors to take into account the attenuation of ground motion with depth are again considered appropriate for determining seismic design values.

ESF design based on the described approach has been analyzed using input ground motion values corresponding to an acceleration of 0.4g. For example, ESF Design Package 2C was analyzed using inputs at all depths based on maximum horizontal and vertical ground accelerations of 0.40g. For quasi-static analyses of the North Ramp, ground motion inputs were an acceleration of 0.40g and a velocity of 40 cm/sec. Also for the North Ramp, dynamic analyses were performed consisting of a P-wave analysis and a combined P-wave and S-wave analysis. Unsupported and rock-bolt supported openings were analyzed. Combined loadings included in situ, thermal (where appropriate), and seismic. These analyses add an additional conservatism to the ESF seismic design.

Forecast: The assessment of Subramanian et al. (1990) and the ESF Seismic Design Inputs Report will be combined to form the review record of the technical assessment. The completed review record will be submitted.

7.3 EXPLORATORY STUDIES FACILITY CONSTRUCTION

This reporting period marked significant progress in ESF construction. The tunnel boring machine continued excavating late in the last period of FY 1994 and has achieved many key milestones. Construction began on several key surface facilities, and several key items related to construction were procured.

The Phase I (initial test excavation) operations, which began in September 1994, were completed in October 1995. This phase consisted of a 12.2-m (40-ft) trial excavation to test the operation of the tunnel boring machine under low load conditions. Phase II (shakedown) operations began after Phase I operations concluded and were completed in late December 1994. In this phase, the tunnel boring machine was operated under increasing load to shake down the system under sustained operating conditions. Also in this phase the tunnel was mapped without a mapping platform. At the end of Phase II the mapping platform was assembled, installed, and checked out in the tunnel boring machine trailing gear. Phase III (limited operations) operations began in December 1994 and continued throughout the period. This phase added a fully operational mapping platform. The tunnel muck was handled using locomotives and muck cars and ground support, consisting of steel sets and lagging or rock bolts and welded wire fabric was required by ground conditions and safety considerations. Phase III will end with the installation and checkout of the surface/subsurface conveyor system. Progress slowed significantly during excavation through the Bow Ridge Fault in late January and early February 1995. This was caused by loose, blocky ground and the requirement to implement special construction methods to fill the voids resulting from excavation in these ground conditions. In spite of the slow progress through the fault zone,

the tunnel boring machine was 34-m (111.8 ft) ahead of schedule at Station 5+49.4-m (18+02.5 ft) at the end of March 1995.

The following two milestones were achieved during the first half of FY 1995:

1. Excavation of 30-m (98.7 ft) of the North Ramp by tunnel boring machine - Level 2 Project milestone (late November 1994)

2. Excavation of North Ramp to Station 3+75-m (12+33.6 ft) - Level 3 Project milestone (early March 1995)

Surface construction began on the following surface facilities during this reporting period:

- Conveyor service road
- Subsurface power center
- Perimeter security fencing
- Electrical duct banks
- Booster pump station
- Water storage tanks (on top of Exile Hill)
- Water line from UE-25 J#13 to the booster pump station
- Change house building
- Surface conveyor.

Surface construction continued on the following surface facilities during this reporting period:

- Water line from the water storage tanks on top of Exile Hill to the North Portal pad
- Water line from the booster pump station to tanks on top of Exile Hill
- Sanitary sewer system
- Switchgear building
- Booster pump station.

The following major procurements were made during this reporting period to support surface and subsurface construction:

- Surface/subsurface conveyor
- Steel sets and lagging
- Shell and heating ventilation and air condition system for the change house building
- Transformers to support surface facilities and the conveyor system.

Forecast: Installation and checkout of the surface/subsurface conveyor system is scheduled for completion in the third quarter of FY 1995. Phase IV (full operations) tunnel boring machine operations will begin after the checkout of the conveyor system. This operation consists of tunneling with the muck being handled using the conveyor system and should significantly increase the daily advance rates to the 20-30-m (65-100 ft) per day range

depending on ground conditions. Alcove No. 2 (Bow Ridge Fault Test Alcove) at Station 1+68.2-m (5+53.3 ft) is scheduled for completion late in the third quarter of FY 1995. Alcove No. 3 presently planned at Station 8+86-m (29+14.5 ft) is scheduled for completion late in the fourth quarter of FY 1995. Excavation on Alcove No. 4, presently planned at Station 10+61-m (34+90.1 ft), is scheduled to begin the end of the fourth quarter of FY 1995. All alcove excavation is planned to use drilling and blasting.

Alcove No. 2 construction and conveyor installation will be performed concurrent with tunnel boring machine tunneling operations. Because of this coordinated effort construction schedules will be maintained for the remainder of FY 1995.

Because excavation progress is projected to remain ahead of schedule through the remainder of FY 1995, the initiatives, discussed in Section 7.1 of this document, for an alternative approach for design and installation of ESF construction utilities, and streamlining the design process were implemented during the reporting period and will continue to assure timely delivery of the design packages to support subsurface construction.

The initial portions of the Integrated Data and Control System, which are currently being procured, are scheduled for delivery and installation at the end of the fourth quarter of FY 1995.

The following surface construction items are scheduled to be completed in the second half of FY 1995:

- Muck storage area
- Conveyor service road
- Perimeter security fencing
- Electrical duct banks
- Subsurface waste water
- Sanitary sewer system
- Water line from UE-25 J#13 to the booster pump station
- Water line from the booster pump station to tanks on the top of Exile Hill
- Water line from the water storage tanks on top of Exile Hill to the North Portal pad.

This will complete a significant portion of the surface construction at the ESF North Portal pad.

7.4 RELATED INTERNATIONAL EXPLORATORY STUDIES FACILITY CONSTRUCTION WORK

Development of Capability for Integration of Construction and Testing Related to the Exploratory Studies Facility

The following is work conducted cooperatively with Sweden under the auspices of the OCRWM international program.

This task provides for exchanges of ideas regarding interaction between construction management strategies and test controls, application of test design, performance of instruments, test progress reporting, and QA process in the underground environment that are jointly beneficial.

Two technical exchange visits by YMP participants were coordinated with DOE, one with USGS participation. The first visit was a workshop on tunnel boring machine operations sponsored by the Swedish Nuclear Fuel and Waste Management Company. The second visit allowed direct viewing and technical information exchanges of the Swedish underground facilities and experiments at the Hard Rock Laboratory, the Central Interim Storage Facility for Spent Nuclear Fuel, and the Forsmark site for final repository for radiogenic operational waste. The Swiss Grimsel experimental site and proposed Wellenberg site for intermediate and low level radioactive waste storage were also visited.

Product exchanges for the period included illustrations and drawings that demonstrate test and construction progress and measurement results of the field deployment of a Laser-Induced Breakdown Spectroscopy system that provides real-time elemental analysis of the tunnel wall and drilling cuttings.

Forecast: Several instrumentation systems unique to the United States program will be deployed and evaluated, which will allow their value to both programs to be assessed. These efforts include additional Laser-Induced Breakdown Spectroscopy measurement of dust particles produced during aircoring, muck produced by the tunnel boring machine, and coming off tunnel walls. This will allow real time identification of elements and will identify changes in the rock compositions and fracture filling. A RAMAN LIDAR measurement system to detect gases and water vapor as they escape from fractures and openings in either the underground or surface environment will be deployed and evaluated. Continued review of Swedish Nuclear Fuel and Waste Management Company reports, and comparison with other international program reports and correspondence, will provide valuable information on underground operations construction and testing interfaces.