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Nevada
Nuclear
Waste
Storage
Investigations

A U.S. DOE PROJECT

BIBLIOGRAPHY OF THE PUBLISHED REPORTS, PAPERS, AND ARTICLES ON THE NEVADA NUCLEAR WASTE STORAGE INVESTIGATIONS

JANUARY 1985

UNITED STATES DEPARTMENT OF ENERGY
NEVADA OPERATIONS OFFICE
LAS VEGAS, NEVADA

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PREFACE

This document is a bibliography of the published reports, papers, and articles on the Nevada Nuclear Waste Storage Investigations (NNWSI). A brief history is included to familiarize the reader with the general direction and activity highlights of the NNWSI and to give the reader some insight into the kinds of bibliographic references to be found in this document. The bibliography is categorized by principal NNWSI participant organizations. Participant-sponsored subcontractor reports, papers, and articles are included in the sponsoring organization's bibliography list. The principal participant bibliography listings are arranged in chronological order by title. An author index is provided after the bibliography.

Technical reports on the NNWSI are on display in special open files at the Nevada State Library in Carson City; the Washoe County Library and the University of Nevada Library in Reno; the Tonopah Public Library in Tonopah; the Amargosa Valley Community Library in Amargosa Valley; the Beatty Community Library in Beatty; and the Clark County Library in Las Vegas. Technical reports on the NNWSI are also on display in the Public Document Room of the Department of Energy, Nevada Operations Office, in Las Vegas. Further information about the NNWSI may be obtained from the following offices:

Mr. Chris L. West
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Post Office Box 14100
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Dr. Donald L. Vieth
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Copies of most NNWSI reports and other documents published by the DOE and the principal participant organizations are available at nominal cost from:

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

Requests for copies of published reports and documents not available from the National Technical Information Service should be directed to the publisher, which in most cases is the principal participant organization. For your convenience, the addresses of the principal NNWSI participants are given after the author index.

Jerry J. Lorenz
Compiler

TABLE OF CONTENTS

FOREWORD

The purpose of the U.S. Department of Energy's (DOE) Civilian Radioactive Waste Management (CRWM) Program, formerly the National Waste Terminal Storage (NWTS) program, is to safely dispose of the growing quantities of nuclear waste being accumulated at nuclear power plants in an environmentally acceptable manner. Regardless of what the future holds for the commercial nuclear power industry, the substantial accumulations of highly radioactive wastes that already exist need to be permanently isolated from the biosphere. The DOE has determined that the safest and most feasible method currently available to ultimately dispose of such wastes is by storing them in mined geologic repositories. Mined repositories can be inspected and monitored--even waste retrieval is possible if that should become advisable.

The Nevada Nuclear Waste Storage Investigations (NNWSI) Project, which is part of the CRWM Program, is currently conducting investigations of Yucca Mountain, Nevada, and its regional setting to further evaluate the suitability of the Yucca Mountain site as a potential location for a commercial nuclear waste repository. In addition, the NNWSI Project is supporting other aspects of the CRWM Program by using the unique resources available at the Nevada Test Site (NTS) to help in developing and demonstrating the capability to safely handle and store spent fuel and high-level waste. The NNWSI Project is managed by the DOE Nevada Operations Office. Scientists and engineers from many fields and organizations are involved in these investigations. The principal organizations participating in the NNWSI are: Sandia National Laboratories (SNL), Los Alamos National Laboratory (LANL), Lawrence Livermore National Laboratory (LLNL), U.S. Geological Survey (USGS), Westinghouse Electric Corporation (WEC), and Science Applications International Corporation (SAIC).

On January 7, 1983, President Reagan signed into law the Nuclear Waste Policy Act of 1982 (Public Law 97-425). This Act reflects a decision by the President and the Congress to develop geologic repositories for the disposal of high-level radioactive waste and spent nuclear reactor fuel. Title I of the Act spells out the procedures by which potentially acceptable repository sites will be nominated, characterized, and recommended for development as repository sites.

For several years, the DOE has been conducting investigations of potentially suitable repository sites in various parts of the nation. In accordance with the Nuclear Waste Policy Act, the Secretary of Energy nominated five sites, including a site in Nevada, suitable for further evaluation as repository sites. On December 20, 1984, Energy Secretary Hodel recommended to the President, three of the nominated sites for detailed characterization as candidate repository sites. These sites were the (1) Yucca Mountain Site in Nevada, (2) Deaf Smith County Site in Texas, and (3) Hanford Site in Washington.

Site characterization represents an intensification of activities that include the mining of a relatively large diameter shaft which will allow scientists and engineers to descend into the geologic formations of interest for detailed exploration and in situ testing. By March 1987, the three sites will have been evaluated and one will be selected for recommendation to the President as the proposed location of the nation's first geologic high-level radioactive waste repository.

The Nuclear Waste Policy Act requires the President to submit to Congress by March 31, 1987, his recommendation for the site of the first repository and by March 31, 1990, his recommendation for the site of the second repository. To mitigate the social and economic impacts resulting from these decisions, the Act further requires that impact assistance payments be made by the DOE to affected State and local governments.

By a letter dated February 2, 1983, the Governor of the State of Nevada was informed that the Secretary of Energy believes Nevada has a potentially acceptable site for a nuclear waste repository. The site is on and adjacent to the NTS in Nye County about 100 miles northwest of Las Vegas at a location known as Yucca Mountain. The mountain is a long narrow ridge generally running north and south with a steep western slope and a gentler eastern slope. The ridge stands from about 1,000 to 1,200 feet above the surrounding alluvial flats.

One of the characteristics that makes Yucca Mountain attractive is the presence of a potentially suitable repository host rock known as tuff; tuff is a highly sorptive rock composed of solidified and welded volcanic ash and detritus (rock fragments and other loose materials). Tuff has good physical, mechanical, and chemical characteristics for nuclear waste containment and for preventing waste from reaching the biosphere. Each layer of tuff was formed separately millions of years ago by volcanic activity.

Yucca Mountain also has an extremely deep static water table--more than 1,700 feet below land surface. This feature makes it possible to choose the most favorable repository horizon in the unsaturated zone where water would not be expected to fill a repository because of very low water infiltration rates. The horizon selected for detailed at-depth characterization is a unit of the Topopah Spring tuff about 1,200 feet below land surface and about 500 feet above the static water table.

The NNWSI participant organizations are currently conducting investigations to further establish the geohydrologic conditions and history of Yucca Mountain and its regional setting. They are also developing engineering criteria for designing and assessing the performance of waste package and repository systems suitable for the conditions present at Yucca Mountain. Furthermore, they are addressing the impacts a repository would have on the surface environment as well as the socioeconomic and institutional aspects of siting a repository at this location. Through these investigations, the NNWSI Project is obtaining the detailed site-specific, regional, engineering, and other information needed for sound decision making in regard to the suitability of Yucca Mountain for a nuclear waste repository. If a repository is constructed at Yucca Mountain, it will be licensed by the U.S. Nuclear Regulatory Commission.

NNWSI HISTORY

The DOE originally selected the NTS for investigation as a potentially favorable site for a nuclear waste repository for three main reasons: (1) favorable overall geologic and hydrologic conditions, (2) prior land use for national nuclear programs, and (3) the capability to carry out the required work. This decision resulted in the establishment of the NNWSI in April 1977. Shortly thereafter, a growing variety of site-exploration and regional geologic, geophysical, hydrologic, tectonic, seismic, and volcanic investigations were begun to augment existing knowledge which has primarily resulted from over three decades of geohydrologic investigation of the NTS area by the U.S. Geological Survey in support of the weapons testing program.

Early site-exploration investigations at the NTS concentrated on evaluating the suitability of two locations: (1) the Climax granite formation, which was accessible using the underground access facilities constructed for two previous nuclear weapons tests, and (2) the exposed Eleana argillite formation at Syncline Ridge. Other investigations were conducted to locate potentially suitable granitic rocks in the Twinridge Hill and Timber Mountain areas. Early regional investigations concentrated on developing a comprehensive regional hydrologic model and on determining whether disruptive events were likely to occur in the near and distant future.

Early investigations also included developmental work on the safe handling, encapsulation, and storage of spent fuel (nuclear reactor fuel assemblies that have served their useful lives) in preparation for both surface and underground spent fuel storage tests at the NTS. This work was accomplished using some of the unique equipment and facilities constructed in the 1960s at Jackass Flats in the southwestern NTS for the Nuclear Rocket Development Program. The equipment and facilities include what is believed to be the world's largest highly radioactive materials handling facility (known as the E-MAD Facility) and a small onsite railroad (known as the Jackass and Western Railroad); both of these resources were modified for their new use.

The following subsections present some historical highlights of NNWSI activities for each fiscal year (October 1 through September 30; e.g., FY 1978 began October 1, 1977). More detailed information is available in NNWSI technical reports which are published and distributed to the Nuclear Waste Management Distribution List (UC-70) of the DOE Technical Information Center and are available through the National Technical Information Service (see Preface).

FY 1978

In FY 1978, some of the first work was done to determine whether a nuclear waste repository would be compatible with present and future nuclear weapons testing activities at the NTS. Ground motion monitoring stations were installed at surface and underground locations. Monitoring data showed that nuclear weapons testing would not pose a problem providing the distance from the detonation sites was sufficient and normal safety precautions were taken during tests. In addition, the NNWSI established a network of seismic monitoring stations to measure natural seismicity and to map tectonic activity at the NTS and for an area of about 100 miles in radius around the NTS.

In mid-1978, the DOE determined that a nuclear waste repository located in the southwestern portion of the NTS would not interfere with present or future nuclear weapons testing activities. Consequently, the exploratory investigations began focusing on the rock units available in that 245 square-mile area and investigations of the Twinridge Hill and Timber Mountain granites and Eleana argillite were brought to a close. Although in the weapons testing area, work continued on developing a test facility in the Climax granite to determine the generic suitability of granite as a repository host rock. In the southwestern NTS, exploratory work concentrated on two potential granite sites, Wahmonie and Calico Hills-Topopah Wash, and one tuff site, Yucca Mountain. Two exploratory holes were drilled and cored to depths of about 2,500 feet at Calico Hills and Yucca Mountain; geophysical logs were obtained in both holes and samples of the drill core were shipped to participating laboratories for analysis. In addition, a variety of geologic, geophysical, and hydrologic studies were initiated or intensified during FY 1978.

The properties of four potential emplacement media at the NTS were studied. Consideration of one medium, alluvium, was deferred because of its low thermal conductivity. Studies of the three other potential media, granite, argillite, and tuff, continued into FY 1979. The results of laboratory studies and an underground heater experiment in granite indicated that this medium should be able to withstand the thermal load imposed by spent fuel. Exploratory fieldwork and the conceptual design were completed for a spent fuel test to be conducted deep within an underground granitic unit of the Climax Stock. The exposed granitic rock masses in southern Nevada were inventoried. Analytical and inventory work was begun on shale, argillite, and tuff rock masses. Surface preparation and site development were accomplished for the Eleana argillite heater test which was begun in FY 1978. A program of laboratory sorption and permeability studies was begun to determine the extent to which the radioactive species associated with spent reactor fuel are immobilized by various geologic media.

FY 1979

During FY 1979, the underground facility for testing the storage of spent reactor fuel in Climax granite (Spent Fuel Test--Climax) was constructed about 1,400 feet below the surface of the NTS. A vertical access hole connecting the surface to the underground emplacement drift was drilled and most of the various handling, encapsulation, and emplacement systems were designed and manufactured. Twenty-foot-deep storage holes were drilled in the granite floor of the facility and special steel liners were installed in preparation for the emplacement of the eleven canisters containing spent reactor fuel assemblies and six electrical simulators. Major objectives of the test were to demonstrate a capability to transport, encapsulate, and emplace spent reactor fuel in a mined facility and to provide data on the in situ behavior of granite subjected to continuous heat and radiation output over a period of several years.

The Eleana full-scale heater test was completed and axisymmetric thermal and mechanical modeling of the test results was accomplished. Posttest gas transmissivity measurements showed that the transmissivity of the argillite increased by three orders of magnitude within 4 feet of the main heater hole during the course of the test. Increases of about one order of magnitude were evident to distances as great as 11 feet.

Several hydrologic studies were conducted to determine the distribution and movement of groundwater in the NTS region. These studies included field mapping of discharge areas, monitoring of static water levels in available wells, and sampling of groundwater for chemical analyses and isotopic dating. Construction of a two-dimensional model of an area 100 miles in radius around the NTS was also in progress during FY 1979 and a sensitivity analysis of the resulting regional groundwater transport model was initiated. A major conclusion reached in the paleohydrologic study was that the water table of the NTS was never more than about 200 feet above its present position during the Pleistocene (glacial) Epoch.

A study of past volcanic activity resulted in a preliminary determination of the probability of a recurrence of basaltic volcanism in the southwestern NTS area. The Black Mountain volcanic center, the youngest major silicic eruptive center in the NTS area, is about 7 to 9 million years old. A basalt from above the Timber Mountain tuff and below a huge tectonic slide block of Paleozoic rocks near the south end of Crater Flat next to the NTS was dated at 10.4 million years, which is near the end of major volcanic and tectonic activity in the southern Timber Mountain caldera area.

After reviewing the geologic, geophysical, and hydrologic data for the Wahmonie, Yucca Mountain, and Calico Hills/Topopah Wash locations, the USGS recommended that exploration be focused on the most promising potential repository host rock and location, the tuffaceous rock of Yucca Mountain. Consequently, the NNWSI decided in mid-1979 to concentrate exploration and characterization efforts on the thick layers of tuff underlying Yucca Mountain and no new studies of other host rocks or locations were initiated. Laboratory efforts focused on determining the physical, mechanical, and chemical characteristics of rock samples taken primarily from exploratory drill holes. An in situ water migration/heater experiment was designed and site preparations were made for the experiment in the welded Grouse Canyon tuff accessible in the G-Tunnel complex at the NTS.

A formal site evaluation activity was initiated to ensure that the evaluation of potential respository sites on the NTS occurs on a timely basis and is coordinated with the National Waste Terminal Storage Program schedule. The Site Evaluation Steering Committee was formed to establish a Site Evaluation Working Group of scientific and technical experts. The Working Group was chartered to develop repository location evaluation criteria, evaluate and screen potential repository locations, and make location recommendations to the Steering Committee.

A comprehensive review of the Quality Assurance Program Plans of participating organizations was conducted and several new quality assurance procedures were implemented by participating organizations. An overall Quality Assurance Plan for the NNWSI was in review at the end of FY 1979.

Four scientific peer reviews were conducted to permit external experts to assess the adequacy of ongoing host-rock media, geohydrologic, and tectonic investigations and the Spent Fuel Test--Climax. As a result of the Spent Fuel Test--Climax review, another meeting among the peer reviewers, the Office of Nuclear Waste Isolation (ONWI), and the DOE Office of Nuclear Waste Management (ONWM) resulted in an agreement to augment the experimental design of the Spent Fuel Test--Climax to obtain additional rock mechanics and radiation dosimetric data during the test. Another recommendation of the peer reviewers was that the development of a separate or adjoining underground rock mechanics experimental facility in the Climax granite should be considered as a means for obtaining further data on the thermal behavior of potential host-rock media. The evaluation of a plan for designing an in situ rock mechanics testing laboratory was begun.

FY 1980

During FY 1980, preparations for the Spent Fuel Test--Climax were completed and the test was begun. The spent reactor fuel assemblies for the test were received and encapsulated in experimental canisters at the E-MAD Facility on the NTS. Construction of the surface and underground facilities and equipment for the test was completed. During April and May, 11 spent fuel canisters were transported from the E-MAD Facility to the surface access hole at the Climax site in a special transport cask and lowered 1,400 feet into the underground test facility. A remotely controlled vehicle received the 11 canisters and emplaced them in predesignated storage holes, and the corresponding electrical simulators were turned on to begin the test.

A small-scale underground water migration/heater experiment was conducted in welded tuff in the G-Tunnel complex at the NTS. During FY 1980, facility construction was completed and instrumentation was installed to measure intrarock temperature changes, reconfigurations, and fluid migration. After the test was completed, the posttest cool-down behavior of welded tuff was monitored and the rock involved in the test was evaluated.

Early in the year, a status report on the NNWSI evaluation of the suitability of the NTS for a repository was prepared and submitted to the DOE/HQ. The general conclusion of this report was that nothing has been found in the area of interest or its regional setting which would preclude the siting of a repository at the NTS, although a specific location for a suitable site had not as yet been identified.

The NNWSI focused its investigations on a block of tuffaceous strata underlying Yucca Mountain. A major stratigraphic drill hole (USW G-1) was drilled, cored, logged, and hydrologically tested to 6,000 feet in depth. The tuffs encountered in the depth range of interest at the time were partially welded and moderately welded. These tuffs were competent rock with few fractures, and most of the fractures were healed. In September, drilling began on a major hydrologic hole (USW H-1) to further characterize the block of interest.

Maps were compiled and data were gathered to establish, dimensionalize, and analyze the geohydrology and the geohydrologic setting of the NTS in the Great Basin. A major achievement was the compilation of a geologic base map of the southwest quadrant of the NTS at a scale of one inch equals 4,000 feet. The alluvial deposits in the region around Yucca Mountain were also mapped. Groundwater recharge from area to area was investigated and precipitation data were assessed for use in the sensitivity studies of parameters of the regional hydrologic model.

As a result of a study of erosion rates in the Great Basin, a simplified computer program and a mathematical model were devised to relate erosion and slopes to the rate of tectonic uplift. A geomorphic contour map of the Great Basin derived from the altitudes of valley-range intersections was prepared for use in quantifying Quaternary tectonic activity.

Geophysical techniques and data were used to remotely investigate subsurface conditions at and in the vicinity of Yucca Mountain. During FY 1980, all electrical traverse data obtained around Yucca Mountain were integrated with the mapped geology to produce a map of inferred faulting in the area of interest. Induced polarization lines of varying dipole spacing and length were completed over the potential repository block at Yucca Mountain. Ground magnetic traverses were also made in Crater Flat across several possible locations of future drill sites to explore the volcanic stratigraphy.

Work continued in developing a paleoclimatic scenario from which estimates of past precipitation levels were made for the hydrologic studies. Rat midden fossil assemblages of middle Wisconsin through Holocene age were collected, dated, and analyzed to determine the altitudinal ranges of glacial and interglacial climatic changes at the NTS. The rat midden samples were collected at low, intermediate, and high elevations.

Two working groups were formed to define, study, and evaluate the parameters involved in site evaluation and mine design. The Site Evaluation Working Group was formed and began to develop site evaluation criteria and a plan for screening potential repository locations in the NTS area. The Mine Design Study Working Group was formed and began to study the parameters affecting the design of an underground repository in tuffaceous rock.

An interim status report on the suitability of tuffs as media for a high-level nuclear waste repository was prepared and published. This report was given to the National Academy of Sciences, Committee on Radioactive Waste Management, for review.

Preparatory work for two new tasks was begun during the spring of 1980. The objective of the rock mechanics task is to perform studies to determine the in situ response of tuffaceous and granitic rocks to anticipated and elevated stresses that have a bearing on the design of a permanent high-level nuclear waste repository. The objective of the radionuclide migration task is to perform studies to develop field testing techniques and to determine radionuclide migration in underground tuffaceous and granitic environments under natural and induced conditions. The detailed program plans for the radionuclide migration program were subjected to external peer review in August.

The overall NNWSI Quality Assurance Plan was reviewed, finalized, and published. The quality assurance activities of participant organizations were incorporated into the NNWSI logic network charts. The Quality Assurance Program Plan of each participant organization was reviewed and approved.

FY 1981

The Commercial Waste and Spent Fuel Packaging Program (CWSFP) was merged with the NNWSI on October 1, 1980. CWSFP objectives have included maintaining and operating the E-MAD Facility at the NTS, designing and evaluating spent fuel canisters, developing and exercising waste handling and encapsulation techniques, conducting surface and near-surface waste storage tests, and providing engineering and technical support to the NNWSI. The E-MAD Facility was modified and updated to handle additional waste forms and to remotely cut open waste canisters. Several near-surface storage tests were completed this fiscal year and support was provided for the first exchange of spent fuel canisters in the ongoing Spent Fuel Test--Climax.

An oral presentation on tuffaceous media was made to the Committee on Radioactive Waste Management of the National Academy of Sciences. The presentation was made in October 1980 by the SNL and LANL Technical Project Officers who are directing the investigations of specific tuffaceous rock masses on or adjoining the NTS for their technical suitability as host rocks for a nuclear waste repository.

The Site Evaluation Working Group developed, evaluated, and began exercising a method for screening the southwest NTS and contiguous lands for nuclear waste repository locations. The relatively homogeneous lithologic units in the depth range of interest that are available in the screening area were reviewed and mapped. Technical experts in various fields were consulted to identify and document the pivotal physical and environmental attributes, assumptions, and rationale for assessing location suitability. These experts also rated the favorability and relative importance of the attributes they selected for screening locations within the southwest NTS screening area. The computer algorithm for rating the individual quarter-section grid elements and the computerized data base to be used in the screening were completed. Preliminary results were obtained which confirmed that Yucca Mountain is one of the better locations in the screening area.

The NNWSI continued to concentrate on evaluating the technical acceptability of Yucca Mountain as a potential repository location. Geologic, geophysical, geochemical, hydrologic, volcanic, seismic, and environmental investigations continued to yield data which further characterized Yucca Mountain and its regional setting. In mid-FY 1981, the drilling program was accelerated to meet the new Administration's decision-making schedule. A major hydrologic hole (USW H-1) was drilled, cored, logged, and tested to 6,000 feet in depth near the center of the block of interest at Yucca Mountain.

Detailed mineralogic and petrographic characterizations were completed of drill-core samples from USW G-1, with emphasis on the potential target horizons. These characterizations showed that the tuffs, which generally are variably welded ash flows, can be recrystallized to a variety of minerals. The important alteration products are zeolites, smectite clays, and alkali feldspar.

At the end of FY 1981, a second major stratigraphic hole (USW G-2) was in the process of being completed and logged to 6,000 feet in depth at the north end of the block of interest at Yucca Mountain. Several other holes were completed during FY 1981, including a volcanic-hydrologic drillhole (USW VH-1) which explored the subsurface environment of Crater Flat just west of Yucca Mountain.

All fieldwork and mapping for the regional volcanism studies were completed by late FY 1981. Sampling was completed of all basalt occurrences within the NTS region. Basalt centers in the NTS region were formed predominantly by Strombolian eruptions. Major products of the eruptions are small-to-moderate sized cinder cones and relatively short lava flows. The evolution of basaltic volcanism has been traced from generation at mantle depth through ascent and eruption at the surface. Data have been examined for each step in this evolution and possible repository disruption consequences have been evaluated. A draft report on the consequences of volcanic disruption to a repository was prepared and the probability calculations for volcanic risk were completed.

Five trenches were dug in the south and southeastern areas of Crater Flat next to Yucca Mountain. Two trenches were dug in an ancient spring area to expose the relationships between fine-grained sediments, alluvium, and ancient spring deposits. The other three trenches were dug on two faults to refine the age of the faults by exposing relationships between faulting and the alluvium.

The spring area trenches revealed an intertonguing of gravelly alluvium and playa-type deposits with associated ancient spring deposits. Some of the spring deposits are younger than the sediments. All deposits and sediments appear to be overlain in most places by alluvium of intermediate age (probably about 100,000 years old). However, a date on the tufa deposits suggests some activity there until about 25,000 years ago.

Trenches on the faults revealed that the faults have been inactive since about middle-Quaternary time. Intermediate-age alluvium appears to overlap the faults and the basaltic ash found in one of the faults is probably from the 1.1-million-year-old Red Cone-Black Cone volcanic centers. Therefore, Quaternary faulting, fissuring, and basaltic eruptions probably occurred simultaneously in Crater Flat.

Studies to identify and understand the dominant radionuclide retardation processes that occur in each of the hydrostratigraphic units which would be encountered along pathways from potential repository units in Yucca Mountain have shown, both experimentally and theoretically, that diffusion into the matrix of fractured porous tuff could be a very significant factor in retarding the migration of radionuclides--independent of sorption processes. This means that even the migration of nonsorbing tracers may be appreciably retarded by diffusion alone into the surrounding rock mass. Preliminary characterization of the retardation properties as a function of depth in USW G-1 was completed as part of the information needed to select a repository horizon. Details of the retardation mechanisms have been investigated.and put into radionuclide transport models.

Initial development of a three-dimensional constitutive model for the mechanical response of a jointed rock mass to thermal loadings was completed. The model is capable of handling discrete displacements along and across joints and will allow mesh-independent treatment of joint spacings, orientations, and apertures.

A new task, waste package development, was added to the NNWSI. Task studies are providing information to the NWTS program on rock-type and other geologic constraints for waste package design for tuffs indigenous to the NTS area. These activities, in conjunction with other NWTS program activities, are developing a waste package that will contain and retard the movement of nuclear waste from a repository environment. Initial work was begun to determine the engineering performance criteria needed for designing an underground repository in specific tuff strata. In addition, a close-in seismic net was established at Yucca Mountain to more precisely define the seismic behavior of the area of interest and its implications for repository and waste package design and performance.

The NNWSI Quality Assurance Plan and the NNWSI Management and Overview Quality Assurance Program Plan were updated. A Project Record Center was established for NNWSI quality assurance records at the NTS. The NNWSI Quality Assurance Program and the Quality Assurance Plans for each Project participant were fully in effect.

Work was begun on researching or anticipating the documentation requirements of the U.S. Environmental Protection Agency, U.S. Nuclear Regulatory Commission, and U.S. Department of Energy and in preparing the documentation required by the National Environmental Policy Act. Preliminary design work was also begun in preparation for an Exploratory Shaft at Yucca Mountain to further characterize potential repository horizons.

In August 1981, a five-day peer review was conducted of the entire NNWSI Project pertaining to potential repository siting in the NTS area. The peer review was divided into three sessions: geology/hydrology, geotechnical/geoengineering, and environmental. Twenty peer reviewers and 183 attendees participated in this review.

The Spent Fuel Test--Climax continued to provide data on the in situ behavior of granite subjected to continuous heat and radiation output. One spent fuel canister from the test facility was exchanged in January with another from the E-MAD Facility for periodic systems evaluation. The Spent Fuel Test--Climax has continued to operate as anticipated and has demonstrated the capability to safely transport, encapsulate, and emplace spent reactor fuel in a mined facility. However, no funding was received for conducting the generic rock mechanics field tests in the Climax granite.

FY 1982

During FY 1982, six major geologic and hydrologic drill holes (USW G-2, G-3, GU-3, H-3, H-4, and H-5) were completed and three more (USW H-6 and G-4 and UE-25p#1) were begun. These drill holes were bored into Yucca Mountain along the perimeter of the block of interest with the exception of the Principal Borehole (USW G-4) which was located to verify the suitability of the site selected for the Exploratory Shaft and the paleozoic hole (UE-25p#1) which was located to penetrate the pre-Tertiary basement rock at the shallowest depth. All of the drill holes were extensively cored, logged, and hydrologically tested. The groundwater was sampled and characterized and representative samples of the drill core were analyzed and subjected to laboratory testing to determine their physical, mechanical, and chemical attributes. Geochemistry, mineralogy, petrology, and rock physics studies of the core samples were also conducted to characterize the nature, history, and suitability of the rock strata underlying Yucca Mountain.

Laboratory and field data resulting from the exploratory drilling program was used to define a three-dimensional stratigraphy of the lateral variability within the block of interest under Yucca Mountain. The relationships between the major functional zones and lithologic stratigraphy and the thermal conductivities and bulk properties for the major thermal zones were defined. Work was begun on models that describe the chemical, geochemical, and hydraulic processes dominant in the various hydrostratigraphic units. These models will ultimately be incorporated in regional and repository-site transport models. The data obtained from 60 wells in and around the NTS, including 16 in the Yucca Mountain area, show that variations in temperature with depth which are used in calculating heat flow are attributable primarily to hydrologic processes. These data also show a general downward movement of water at the rate of a few milliliters per year.

In mid-1982, the numerous rock strata or horizons at Yucca Mountain were narrowed to one located at a depth of about 1,200 feet and about 550 feet above the static water table. Repository performance, safety, and economic considerations were all taken into account in selecting the most promising horizon for further investigation. The horizon selected lies deep within the Topopah Spring Member of the Paintbrush Tuff. The Topopah Spring Member appears to be at least 1,000 feet thick throughout the block of interest. Major zones of the Topopah Spring Member include the lower zeolitized zone, the upper and lower vitric (glassy) zones, and the thick interior zone of crystallized, devitrified tuff. The position of these major mineralogical zones is controlled by the degree of welding, unit thickness, and vapor-phase alteration. The Topopah Spring Member is underlain by the highly sorptive and zeolitized Calico Hills Tuff (also known as the Tuffaceous Beds of Calico Hills).

Detailed mapping of the area of interest at Yucca Mountain was completed and the data were compiled on a topographic base map. The mapping has identified a number of minor faults within the southern one-third of the area of interest as currently defined. Trenching of alluvium near faults on the east side of Yucca Mountain was subsequently completed and the trenches were mapped. No displacement of alluvium was found. The volcanic and alluvial deposits of the Big Dune 15-minute quadrangle, which are generally located between southern Crater Flat and the Funeral Mountain, were also mapped. No faulting of definite Quaternary age was found in this area.

Early in FY 1982, a computerized earthquake monitoring and recording system that is more efficient at detecting and locating earthquakes was made operational. Although the epicenters of natural earthquakes have not yet been detected at Yucca Mountain, very accurate locations will be identified if earthquakes do occur in the future. However, two earthquakes of particular interest (magnitude 3.5) did occur about 35 miles to the west of Yucca Mountain at Death Valley in an area of youthful deformation where Quaternary gravels are folded and tilted. These moderate-sized earthquakes are typical of those occurring, not on the major Death Valley-Furnace Creek system, but on subsidiary faults in the Salt Creek Hills.

Bounding calculations for water velocity and travel time from the unsaturated units at Yucca Mountain to the water table have been completed. Scoping studies have begun to shed light on the analyses which need to be performed. Initial results indicate that the travel time of water from the surface to the water table through a repository hypothetically located in the middle of the Topopah Spring Member is much longer than the Chapter 10, Code of Federal Regulations, Part 60 (10CFR60) requirement. The results of this effort indicate that the techniques are available for quantitatively assessing the impact of climatic changes on travel time through a repository located in the unsaturated zone.

Analytical results from the ongoing geochronology studies indicate that the source for the oxygen in NTS calcites is meteoric water. The source for the carbon in nearby Amargosa Desert samples was found to be dissolved atmospheric carbon dioxide and Precambrian carbonates as reflected by the near-zero values of their carbon isotopic compositions. Field work for a related study was begun in mid-1982; the objective of this study is to gather some of the data needed for better defining the hydrogeology of the deep paleozoic acquifers in the Yucca Mountain area and for developing a model of the pre-Tertiary tectonic history of the NTS region.

In the area-to-location screening activity, a series of 53 baseline assumption sets were defined for the analysis of their effects on screening results. The baseline assumption sets represent relative weightings placed on repository performance objectives. Computer algorithms were completed for assessing the effects of statistical variance resulting from attribute weightings. These algorithms were used to perform a quantitative systems analysis which was used to formally and systematically screen the southwestern NTS area for the best places to explore for potentially suitable repository locations. A summary of the results and conclusions (DOE/NV Report NVO-247) was published and distributed nationally. As anticipated, Yucca Mountain was ranked as the most favorable location to look for a repository site because it rated highest in the overall conditions which would promote successful long-term waste containment and isolation. The detailed supporting documents for the summary report were also prepared for publication.

Microprobe studies in conjunction with whole-rock chemical analyses were completed for the basalts of Dome Mountain, Kiwi Mesa, and Silent Canyon and the basalts and xenoliths of Nye Canyon. Potassium-argon dates on rock samples from the Yucca Mountain area gave an indication of the age of volcanic activity in the area. An ash bed sample obtained near the south end of Yucca Mountain was age-dated at 3.2 million years. An age of 3.6 million years was obtained on a basalt core sample from the volcanic/hydrologic drillhole (USW VH-1) in Crater Flat about four miles southwest of Yucca Mountain; this age was close to the ages obtained on samples from similar flows on the surface. Although no new volcanic units were found as a result of investigations in Crater Flat (including the USW VH-1 exploratory hole), important evidence was obtained on the structure and possible Miocene caldera locations just west of Yucca Mountain.

The Hawaiite-type lavas which erupted next to Yucca Mountain at Crater Flat were found to form an alkalic series in which the less evolved basalts plot near the olivine-diopside divide and the more evolved basalts project into the hypersthene or nepheline fields. The rise rates of basaltic magma for the strombolian volcanic centers in Crater Flat were in the low range of typical basaltic rise rates based on ratios of cone volume to lava volume and short lava flows. Potential dispersal pathways of radioactive waste incorporated and dispersed through stromblian eruptions were traced to predict the consequences of such an eventuality. After detailed computer modeling, researchers concluded that the radiological consequences of basaltic volcanism intercepting a repository at Yucca Mountain would be small.

In FY 1982, three major new tasks were begun. The first task is the waste package development studies. The studies are to design and to test waste package components for compatibility with the physical and chemical environment of the candidate repository horizon to assure successful waste containment and isolation. The second task is the repository conceptual design studies. These studies are analyzing the effects of heat generation on tuff and developing an optimal repository conceptual design to assure that the best mix of economic and safety criteria are used in designing a repository for Yucca Mountain. The third task is the repository performance assessment studies. These studies are developing the computer models and codes for assessing the performance of individual and overall repository systems working together to assure that a repository at Yucca Mountain would scientifically and systematically accomplish its mission both throughout its relatively short operational phase and very long decommissioned phase.

The waste package development task was outlined and a program of materials testing to support the task was developed and initiated. Tentative criteria for waste package design were developed largely on the basis of the requirements outlined in the draft regulations proposed by the Nuclear Regulatory Commission. Studies of the effects of various waste forms on waste package design were begun. Preliminary waste package designs were developed.

Tuff-water interaction experiments were formulated and undertaken to determine the composition of groundwater in contact with waste packages in a repository and also to validate existing geochemical models. Waste package corrosion tests were also carried out on carbon and alloy steels. The effect of oxygen on the corrosion rate is being investigated at temperatures which simulate expected conditions in a waste repository. The effects of water and radiation are also being addressed in these investigations. Studies of tuff waste package backfill materials were also started. Initial work is being directed at exploring the possibility of using crushed and fabricated tuffaceous rock as the basis for backfill material in a repository sited in tuff.

A comprehensive work breakdown structure for repository design was prepared. This structure has five major categories: waste, site, operations, special equipment, and systems. Each of these categories was developed and expanded to include four to five levels of detail. At each appropriate level, the following information will be provided: design objectives, design output (deliverables), data and information, codes and standards, design criteria and requirements, and references. This work breakdown structure was developed for use in addressing repository conceptual design and DOE Procurement Regulations, Title I and Title II requirements.

Preliminary studies of topography, shaft locations, ventilation schemes, repository surface layouts, and repository underground layouts were started early in FY 1982. A study of ventilation for a repository under Yucca Mountain was completed; this study concluded that natural ventilation should be used in conjunction with mechanical ventilation in an operating repository. A preliminary physiological parameters study was initiated to establish repository air quality control standards during mining and underground waste operations. This information will ultimately form the basic design criteria to be used in the air conditioning and mechanical utility systems for the control of gaseous, liquid, and particulate contaminants, including radioactive materials.

The topography of the potential repository block at Yucca Mountain was digitized in 20-foot contour intervals and stored in a computer graphics system. A preliminary repository surface layout for Yucca Mountain was prepared. The buildings were sited to take advantage of the natural terrain. Five preliminary repository underground layouts were also prepared and their relative advantages and disadvantages were assessed. All of the layouts were stored in a computer system that enables geometric modifications and the restructuring of graphic displays as repository conceptual design work progresses. The thermal and mechanical stratigraphies of drill holes at Yucca Mountain were correlated. The contacts between the stratigraphic zones were correlated on the basis of mineralogical results, lithologic logs, downhole geophysical logs, and bulk properties. These contacts were entered into the computer graphics system for modeling and assessing repository performance at Yucca Mountain. In addition, a two-dimensional finite-element computer code was developed for modeling groundwater flow in both saturated and unsaturated rock strata.

The Program Evaluation and Review Technique (PERT) for repository performance assessment was completed. This PERT will be used for analyses and documentation in support of repository licensing. The performance assessment network analysis work is directed at analyzing the interrelationships and relative importance of repository subsystems as they affect repository performance which, in turn, will help define the documentation needed for repository licensing. Since the validation of the models used in the overall performance assessment of repository containment and isolation systems is essential for site characterization and licensing, a validation program was initiated for the NNWSI. The goals of the validation program are adequate documentation, code verification, and model validation. A primary task of the validation program is to define performance targets for the computer modeling codes which correspond to the relative sensitivities of the specific processes addressed by the codes for the containment and isolation systems. The performance assessment validation process will demonstrate model validity through successful prediction of the results of laboratory tests, field data, and natural analogs. A survey of the computer modeling code requirements for repository systems performance assessment was completed and a code library was established to provide a central location for documentation of repository performance assessment codes. A quality assurance program plan with detailed activity plans and instructions for each activity in the performance assessment work breakdown structure was developed.

A three-year program plan was developed for studying the stability of promising candidate materials for shaft and borehole sealing. A workscope was prepared for the investigation of the permeability of the seal-rock interface, the properties of specific seals, characterization of the rock-concrete/grout interface zone of selected plugs prepared for containing underground nuclear weapons explosions, documentation of the NTS experience and capability to produce specific physical and chemical properties in concrete and grout mixtures, and documentation of the NTS experience in emplacing concrete and grout seals. A testing program was established for studying the possible interactions of previously developed inorganic cements and grouts in combination with a tuff filler and the tuff units of interest at Yucca Mountain. The incorporation of geologic materials removed during repository construction as fillers in the sealant mixture appears particularly attractive from geochemical compatibility, availability, and cost standpoints. The formulation and testing of rock-grout/concrete sealing materials began in the second quarter of FY 1982.

A program plan for nuclide migration field experiments in tuff was developed. This plan includes matrix diffusion and fracture-flow experiments which would provide data for developing three-dimensional transport models that would calculate, for example, the progress of water infiltration into tuffaceous rock from a fracture and the affects of several key parameters on nuclide migration/retardation. Various substances and microorganisms were evaluated for their suitability as tracers. Laboratory experiments were performed on rocks containing both natural and artificial fractures. However, field experiments have been deferred until facilities in the Exploratory Shaft are available and appropriate experiments have been designed. The generic granite radionuclide migration experiments were cancelled during the first quarter; a termination plan was developed and implemented to allow the technical community to take advantage of the research conducted. The engineering test plan for these experiments was peer reviewed.

A plan view of the G-Tunnel rock mechanics complex in the Grouse Canyon tuff, which is similar to Yucca Mountain tuff, was prepared and the experimental facilities were mined. Several experiments will be conducted in this complex. A small diameter heater experiment was completed in unsaturated (about 85 percent saturated) welded tuff to study groundwater migration in response to localized heat. The results support the interpretation that groundwater does initially migrate toward the heater hole and then vaporizes; no water collected in the bottom of the hole during cool-down. A small diameter heater experiment in unsaturated (about 90 percent saturated) nonwelded tuff was in progress at the end of FY 1982 to study heat transfer and dewatering phenomena.

Development work on the design of an Exploratory Shaft (ES) was under way during FY 1982. An Ad Hoc Working Group was established in April to make Figure of Merit evaluations on two key ES alternatives. The first working group evaluation resulted in the recommendation of the preferred ES construction method, conventional mining rather than large-hole drilling. The second evaluation narrowed five possible sites for the ES to the most desirable one, a site on the east side of Yucca Mountain in Coyote Wash. Work on the Title I ES design and drilling of the Principal Borehole (USW G-4) for the ES was begun during the last quarter of FY 1982.

The preparation of several major documents was begun in FY 1982. These documents included the Environmental Assessment for the Exploratory Shaft, Site Characterization Report, Test Plan for the Exploratory Shaft, and Siting Recommendation Report for a nuclear waste repository at Yucca Mountain. In addition, a land protection plan was prepared to secure the availability of the necessary land should a commercial nuclear waste repository be sited on the DOE's NTS and/or contiguous U.S. Air Force and Bureau of Land Management land.

The Spent Fuel Test--Climax operated in accordance with established plans. About 4,700 people, including many public officials and scientists from around the world, have visited the Climax test since it began in the Spring of 1980. During FY 1982, the second and third spent fuel canister exchanges were successfully conducted in October and August, respectively. As in the first exchange, all operations were executed in a safe and efficient manner. During the third exchange, a canister which had been exposed to boiling groundwater for eight months was removed and examined for corrosion; none was found. The spent fuel exchanges were conducted to maintain and demonstrate the retrieval capabilities of the handling systems. The Climax test environment caused two types of geotechnical instruments to malfunction; the malfunctioning instruments were replaced and other instruments were augmented with additional temperature sensors to enhance the quality of acquired data. Ventilation effects tests were also conducted to provide data for improving existing models of convection and ventilation processes. In addition, a laboratory study of the effects of a massive dose of radiation on the Climax granite was completed.

The Surface Storage Cask (SSC) was moved into the E-MAD Hot Bay, the spent fuel canister was removed and placed in the Lag Storage Pit and the SSC was returned to the pad. This event terminated a four-year demonstration of dry interim storage of a sealed canister containing spent nuclear fuel in an aboveground reinforced concrete cask. In October 1982, the canister will be cut open and the fuel assembly will be removed from the canister. After the physical condition of the assembly is determined by visual observation, complete video scan, and numerous still photographs, the assembly will be installed in the fuel temperature test apparatus and will be tested for approximately one year.

In support of the Dry Storage Fuel Integrity Demonstration Program, gas samples were acquired from the seven drywell test canisters containing spent fuel assemblies. The samples were analyzed for the presence of krypton-85, which would indicate fuel pin leakage; none was detected. Equipment was designed and fabricated for handling canisters during fuel assembly/canister contamination examinations and for holding and vibrating canisters to remove loose debris for analysis in preparation for FY 1983 Program activities.

FY 1983

During FY 1983, the Principal Borehole (USW G-4) for the Exploratory Shaft was completed in Coyote Wash (dry) on the east side of Yucca Mountain. Results from USW G-4, which was drilled with air-foam to a depth of 3,000 feet near the proposed shaft site, confirmed the geologic and hydrologic suitability of the location. A major hydrologic hole (USW H-6) was also completed to 4,000 feet in depth around the edge of the area of interest at Yucca Mountain. About six miles west of Yucca Mountain, a major exploratory hole (USW VH-2) was drilled, cored, and tested to 4,000 feet in depth in Crater Flat to further define the nature and age of ancient volcanism in the area.

Downgrade to the east of Yucca Mountain, Paleozoic drill hole UE-25p#1 reached the carbonate pre-Tertiary basement rock at about 4,100 feet in depth at a location where gravity and other data indicated that basement rock could be reached at the shallowest depth. Elsewhere around the area of interest at Yucca Mountain, exploratory holes did not encounter basement rock at depths of up to 6,000 feet. UE-25p#1 revealed the nature of the acquifer in the Palezoic basement rock and the complete sequence of volcanic rocks underlying the Yucca Mountain area, including some older tuffs not seen in other holes. This hole also made possible the evaluation of total groundwater production and the identification of water production in all producing zones throughout the complete sequence of volcanic rocks.

The regional hydrologic studies were expanded to include an additional objective while past efforts, which concentrated on developing models of groundwater flow in the unsaturated zone, were continued. The new objective was aimed at understanding the movement of groundwater and dissolved chemicals through fractured rock using tracers. To provide supplemental data for the continuing studies, a number of limited-purpose holes were drilled to further define the hydrology around Yucca Mountain. During FY 1983, the drilling program included eleven of a series of water table holes which were drilled to establish the static water level and to collect water samples around the entire block of interest. The water table elevations suggest that the fault of Solitario Canyon, which is just west of the main ridge of Yucca Mountain, may be retarding the eastward movement of groundwater. Chemical analysis revealed that sodium is the most abundant cation and bicarbonate is the most abundant anion in all of the groundwater samples obtained. In support of the new objective, the first of a series of 3,000-foot-deep holes that will be used for measuring groundwater flow rates down-hydraulic-gradient from Yucca Mountain neared completion at the end of FY 1983. In addition, horizontal drilling into the Topopah Spring Tuff exposed at Fran Ridge near Yucca Mountain also neared completion. This test hole was drilled with air to obtain data on groundwater movement in tuff in the unsaturated zone without the introduction of water and foreign material such as drilling mud.

By the end of FY 1983, detailed geologic mapping (scale 1:12,000) of intra-cooling units within the Tiva Canyon and Topopah Spring Members had progressed outward from the central block to include the western and northern blocks and outcrops as far to the east as Fran Ridge. Results suggest a slight increase in the density of faults in all areas surrounding the central block. Efforts were also focused on the detailed characterization of the geologic setting in the vicinity of the proposed Exploratory Shaft. Studies included detailed surface fracture analysis along ridges surrounding the site and analyses of cores collected from drill hole USW G-4.

A study was begun to develop a model to predict the lateral continuity of stratigraphic units and their mineralization between drill holes in the Yucca Mountain area. The distribution of sorptive zeolites and other minerals which would retard waste element migration or produce thermomechanical effects under repository conditions are of particular interest. Related studies will provide information on the composition and geologic history of the rocks between the block of interest and the accessible environment. Geochemical experiments continued to relate radionuclide sorption capacity to the sorptive mineral content of different tuff strata. The data and models resulting from these efforts will be used for developing repository and waste package design criteria and in calculating the effectiveness of natural retardation barriers within the host rock and contiguous geologic units along the flow path to the accessible environment. During FY 1983, the kinetics of cation adsorption within Yucca Moutain tuff was shown to be consistent with the ratio of diffusion into zeolite and clay minerals. Experiments were also begun to study the transport of radionuclides through fractured Yucca Mountain tuff.

Progress was made in defining the limits of mineralogic control of Eh (oxidation-reduction potential) and fracture infilling mineralization at Yucca Mountain. These parameters affect the retardation of radionuclides by minerals within solid rock and by minerals on the surfaces of fractures in rock. Through work on the first parameter, it became apparent that the limited abundance of oxidizable iron provides no significant buffering capacity for Eh. A method was developed for studying the second parameter, fracture mineralogy. This method is based on X-ray diffraction analyses. Fracture aperture, inclination, paragenesis (mineral development in contact with other minerals), and a measure of mineral surface exposure within open fractures are aspects taken into account in the complete fracture analysis.

Data from both of these studies will be incorporated into fracture-flow and solid-rock-permeability radionuclide transport models.

Yucca Mountain mineralogic and petrologic studies provided quantitative data on the distribution of minerals in and below the potential repository host rock in both unsaturated and saturated rock units. Within the Topopah Spring Member of the Paintbrush Tuff and in the tuffaceous rock units beneath the potential repository host rock, there are significant variations in mineralization. Such changes in mineralization include the localized occurrence of such potentially reactive phases as cristobalite, tridymite, smectite, and volcanic glass. The important sorptive minerals, clinoptilolite and mordenite, also occur in discrete horizons and their distribution changes horizontally and vertically. However, within the thick, densely welded repository exploration horizon, which is located in the unsaturated zone, there is little variation in the mineralogic composition. At all points between the potential repository horizon and the static water level, the zeolitized tuff is a minimum of 25 yards thick. In addition, large amounts of sorptive zeolitized tuff lie deep below the repository horizon in the saturated zone beneath the static water table.

Geochemical and petrological data were entered into a data base management system. These data will be used to perform multivariate statistical analyses of radionuclide sorption and to identify mineralogic and water chemistry correlations affecting radioactive waste transport and retardation. These data were structured into five domains: X-ray diffraction, sorption-desorption, water chemistry, mineralogy/petrology, and cation exchange.

Studies of basaltic volcanism for hazard assessment were nearly completed. Field and laboratory petrologic studies were extended to include all basaltic volcanic rocks in the NTS region during the last 12 million years. Data show that there has been a uniformity in the nature and composition of basaltic volcanism during the last eight million years. This uniformity gives increased confidence in predictions of future patterns of volcanism. The potential for hydrovolcanic activity (vapor explosions due to magma/water contact) was identified as a subject requiring further investigation at the Yucca Mountain site and this topic will be a focus of studies in FY 1984.

The principal results from investigations of natural seismicity for FY 1983 indicated that Yucca Mountain lies within a broad "U" shaped zone of low-level seismicity extending on the west to the Funeral Mountains, on the south to the Black Mountains and Nopah Range, and on the southeast to the Spring Mountains. After two years of intensive highly sensitive monitoring, two earthquakes have been located there with magnitudes of 1.7 and 1.5, respectively. Faults at Yucca Mountain, however, do not exhibit evidence of significant movement in at least the last 500,000 years.

Seismometers were installed at and deep below land surface in major Yucca Mountain exploratory drill holes. The surface and downhole seismometers are being used to measure and compare ground motion caused by distant (greater than 20 miles away) underground nuclear tests. The data recorded include peak vector acceleration in the pressure wave and the Rayleigh wave (an elastic wave confined to the surface layer of a solid medium). The data gathered thus far indicate that there is substantially less ground motion arriving at depth than on the land surface and that ground motion is greatly diminished by distance from the test.

A network of ten tectonic activity measurement stations was established in the Yucca Mountain area to measure crustal deformation. Since crustal deformation can be directly observed, it is a useful indicator of the rate and nature of tectonic activity. Repeated distance measurements of refractivity using a laser instrument covering 25 lines between the network stations were begun to obtain precise data on crustal deformation to an accuracy of two parts in 10 million.

With various types of highly sophisticated photogrammetric equipment and a unique computer image processing facility, photogrammetric structural studies are providing high-resolution topographic information, including the compilation of highly detailed contour maps and the collection of digital terrain data. Utilizing digital image processing, a three-dimensional model of Yucca Mountain geology will be designed so the topographic features of Yucca Mountain and the adjoining region will be the base overlay of the geologic structures. These high-resolution topographic maps will support geologic as well as gravity studies and also will be useful for the construction of a repository. During FY 1983, two phases of site photography were completed. During FY 1983, three contour maps were compiled from 23 stereo models. Digital terrain data of the mapped area have also been collected and edited for use in three-dimensional (computer) modeling.

Preliminary conceptual designs of subsurface repository layout configurations were completed for Yucca Mountain. The layouts included comparisons of vertical and horizontal waste emplacement schemes. To make the comparisons more meaningful, supplemental information was produced on mine development, ventilation circuitry, and surface facility interfacing. In addition, preliminary conceptual designs for the underground waste transporter, waste emplacer, and waste retrieval equipment were completed. After inclined and vertical repository access arrangements were comprehensively evaluated, it was concluded that the inclined ramp entry concept was preferable for main access because it capitalizes on the adjacent topography and provides some unique features favorably affecting safety, flexibility, and operational functions not inherent with the vertical shaft concept.

Preliminary layouts of the repository surface facilities were also completed and architectural plans for the sections and elevations of the various administrative and service buildings were developed. Tentative waste handling procedures for receiving, packaging, transferring, and emplacing high-level waste packages were prepared. Preliminary guidelines, designs, and security system evaluations for the repository surface facilities were completed. Preliminary designs were also completed for the ramp and shaft underground accesses, waste handling facilities, and exterior utilities.

The small diameter heater experiment in unsaturated (about 90 percent saturated) nonwelded tuff was completed. This test took place about 1.3 miles back in G-Tunnel at the NTS at a depth of about 1,400 feet below Rainier Mesa. The heater was emplaced in a borehole array configured to yield data on thermally driven water migration phenomena. The tuff reached temperatures in excess of 160°C. The emplacement hole and heater temperature profiles indicated that convection was present because temperatures in the upper part of the hole were higher than predicted when considering conduction as the only heat transfer mechanism. Liquid water was not detected at any time in the bottom of the emplacement hole, but the relative humidity reached saturation within ten hours after turning on the heat. The results also showed the effects of dewatering on the thermal conductivity of the host rock.

Field preparations for the Heated Block Experiment were completed and testing began in September in the rock mechanics test area of G-Tunnel. The Heated Block Experiment is one of several experiments being conducted to measure and evaluate the response of welded tuff to thermally induced changes as would be expected in an actual underground nuclear waste repository in tuff. The experiment consists of four phases: slot cutting, flatjack initialization, ambient temperature testing, and thermal cycle testing; all but the last phase was completed in FY 1983. In preparing for the test, the floor of the drift was instrumented with a permeability measurement system and numerous displacement measurement devices. Data were collected which defined the pre-slot strain and stress state. Changes to the natural state were recorded during slot cutting. A diamond-studded chain saw was used to cut the slots into the floor surrounding the test block and this resulted in pressure being released. During slot excavation, the block was monitored with strain, deformation, and permeability measurement systems. All slot reloading phenomena were carefully monitored while normal stress conditions were reestablished in the slots prior to the Heated Block Experiment. The flatjacks installed in the slots were used to reestablish normal pressure and, during the experiment, to maintain a constant uniform stress across the load area for determining the effects of elevated temperatures and pressures on welded tuff and the accuracy of the values presently used in modeling those effects as they relate to repository design. Preparations were also completed for another major in situ rock mechanics experiment, the Rocha Slot Experiment, which is scheduled to begin in FY 1984. This test will allow an evaluation of the rock mass deformation modulus for welded tuff.

The DOE/NV reviewed and approved the Exploratory Shaft construction method (conventional mining of the shaft) recommended by the Ad Hoc Working Group in FY 1982. Conventional mining permits much more geologic and hydrologic data to be acquired as the shaft is being sunk compared to the alternative method, big hole drilling (a method that was developed at the NTS for the nuclear weapons testing program). Furthermore, with conventional mining, the resulting data would not be impaired by the introduction of drilling fluids into the surrounding rock. The DOE Title I design of the surface and subsurface facilities was completed early in FY 1983 and the Title II design was essentially completed at the end of FY 1983. In September 1983, the Exploratory Shaft Test Plan was also essentially completed. An Exploratory Shaft Construction/Test Plan Network was developed which provides a fully integrated PERT diagram for project construction, construction-phase data acquisition, and postconstruction-phase in situ testing and exploration.

The Exploratory Shaft will provide direct manned-access to the candidate repository horizon where horizontal drilling and at-depth testing will yield much more data on the selected horizon than is possible by remote exploration and testing from the surface. The underground work will reveal, for example, the extent and pattern of faults and fractures within, as well as above and below, the candidate horizon. Construction of the Exploratory Shaft is tentatively scheduled to begin in FY 1985, pending completion of the requirements imposed by implementation of the Nuclear Waste Policy Act of 1982, Public Law 97-425, which was signed into law on January 7, 1983. These requirements include the completion of an Environmental Assessment and formal nomination of the Yucca Mountain site for site characterization. During FY 1982 and FY 1983, evaluation of the data obtained from the Principal Borehole for the Exploratory Shaft, USW G-4, confirmed the suitability of the Coyote Wash location recommended by the Ad Hoc Working Working Group in FY 1982.

The waste package devolopment task focused on developing a suitable package for the candidate repository horizon in the unsaturated zone. Task activities included tuff-water interaction tests at elevated temperatures to define the geochemical conditions in the vicinity of waste packages and the formulation and initiation of tests to simulate the dehydration and rehydration of rock adjacent to the waste packages. Tests designed to determine the radionuclide release rates from various waste forms were also initiated. These tests are being conducted with both unreprocessed spent fuel and borosilicate glasses containing high-level reprocessed waste from civilian and defense activities. The development of waste-form tests specifically designed to simulate unsaturated zone conditions was begun.

The testing of candidate metallic barrier materials continued with principal emphasis on specific stainless steels and high-nickel stainless alloys under appropriate conditions to evaluate corrosion rates and mechanisms. Particular attention was directed toward local and stress-assisted corrosion modes. Corrosion testing of candidate emplacement hole liner materials continued with emphasis on carbon and alloy steels. In one test, several carbon, alloy, and stainless steels were placed in the same cell to simulate conditions where a carbon steel (or an alloy steel) emplacement hole liner is used in conjunction with a stainless steel canister. Another series of tests was begun to determine the general and localized corrosion susceptibilities of several stainless steels as a function of temperature in tuff-conditioned groundwater in the presence of crushed Topopah Spring Tuff. Tests were also conducted to determine the effects of tuff-conditioned water vapor on carbon, alloy, and stainless steels. These test data will be used to predict the effects of changes in the oxidation potential on the corrosion behavior of steels. Corrosion tests in ionizing radiation environments were also initiated to evaluate potential radiolysis effects.

Reference and alternative conceptual waste package designs were developed and preliminary thermal, structural, and criticality analyses were performed. The possible need for a tailored packing material as a waste package component was identified and initial fabrication tests for this material were conducted to determine variations in physical properties. Preliminary design studies were done to identify possible waste package performance differences between horizontal and vertical storage orientations and to estimate the impact of waste package diameter on repository system costs.

The requirements for the modification of waste package performance evaluation models and computer codes to reflect unsaturated zone conditions were identified. Preliminary code verification activities continued. Uncertainty analysis techniques were evaluated.

The three-year storage phase of the Spent Fuel Test--Climax was completed with retrieval of the spent fuel canisters during March-April 1983. The 6 electrical simulators and 20 auxiliary perimeter heaters involved in the test were also deenergized concurrently. The liners were removed from the 17 spent fuel and simulator emplacement holes to facilitate postretrieval geological sampling. The 11 spent nuclear fuel assemblies were returned to the NTS E-MAD spent nuclear fuel handling and packaging research and development facility, where they will remain pending further disposition. Radiation and decay-heat-level measurements of one spent fuel assembly were completed in FY 1983 and additional decay-heat calorimetry and dosimetry radiation measurements will be completed FY 1984.

Following retrieval of the canisters from the Spent Fuel Test--Climax test facility, rock temperatures, displacements, and stresses were monitored for about six months to study the response of the rock unit to cooling and to further evaluate the computer codes and models used to predict this response. Measurements of the in situ state-of-stress and the in situ deformation modulus of the rock unit were obtained for comparison with pretest values and for input to final calculations.

Analyses of the mineralogy and petrography of unheated, unirradiated core samples of the Climax granite (quartz monzonite) were completed. Geologic samples were obtained from near the spent-fuel, electrical-simulator, and auxiliary-heater holes. These samples will be compared with the pretest baseline results to determine the nature and extent of changes resulting from exposing the rock to heat and, to see if there is a significant difference, heat in combination with ionizing radiation. In addition, posttest instrumentation calibration activities were begun for the purpose of confirming the high quality of the data obtained during the nearly four-year monitoring period.

As part of the ongoing fuel integrity demonstration activities at the E-MAD Facility, hermetically weld-sealed steel storage canisters were cut open and spent, pressurized water reactor (PWR) nuclear fuel assemblies were removed under dry conditions in the E-MAD Hot Bay. Dry disassembly of portions of one PWR spent fuel assembly was also performed for the first time, in the E-MAD Hot Bay, when two fuel rods were removed, inspected, installed in a temporary storage container, and placed in the E-MAD Hot Bay lag storage pit. The first high-temperature (275°C) dry storage test was initiated, using the fuel assembly from which the two fuel rods were removed, with test conditions simulating the continually decreasing radioactive decay heat levels of the fuel. Gas samples of the test canister atmosphere are being taken each month to monitor the integrity of the fuel rods. This test will continue into FY 1984, after which additional fuel rods are scheduled to be removed from the fuel assembly and inspected for comparison with the pretest fuel-rod inspection result.

The NNWSI completed the public hearings required by the Nuclear Waste Policy Act of 1982. The Nevada hearings were held on March 30, 1983 in Las Vegas and on March 31, 1983 in Reno. The hearings were held to solicit comments from the State of Nevada and the general public regarding the nomination of Yucca Mountain, Nye County, Nevada, for site characterization as a potential high-level nuclear waste repository. The hearings were also held to solicit issues to be addressed in the Environmental Assessment (EA) supporting formal nomination of the site and issues to be addressed in the Site Characterization Plan (SCP) which would be issued prior to proceeding with site characterization. During FY 1983, the NNWSI focused extensive efforts on preparing an EA and SCP which would satisfactorily address the issues raised at the hearings and which would fulfill other statutory and regulatory requirements. To help fulfill the growing requirements imposed on the NNWSI by the Nuclear Waste Policy Act, the Nuclear Regulatory Commission, and the Environmental Protection Agency, a sixth major Project participant, Science Applications International Corp. (SAIC), was brought onboard to serve as the Technical and Management Support Services contractor for the NNWSI. By the end of FY 1983, SAI had assumed major roles in managing and participating in the preparation of the EA and SCP as well as in taking over responsibility for quality assurance and technical overview of the NNWSI Project.

Efforts to integrate and systemize data through the implementation and utilization of advanced computer technology and the in-house development of project-oriented software increased in intensity during FY 1983. These efforts were accentuated by the growing need to mutually share and organize the knowledge accumulated by the major NNWSI participants and their subcontractors, and the need to bring together and format data for model development and validation as well as to satisfy institutional requirements. Computer systems and codes were developed and/or modified to model, analyze, synthesize, and format data to fulfill informational needs. These efforts were largely focused on modeling and assessing the performance of a repository located at Yucca Mountain in the block of interest. A central example of the effort to integrate and systematically format, correlate, model, and evaluate the huge and diverse data base that now exists is the Total System Performance and Assessment Code (TOSPAC). This computer code consists of many subcodes which permit multivariate data correlation, system sensitivity studies, and repository disruption consequence analyses. TOSPAC and other data base management and modeling systems will provide Project participants with access to current multiparametric data on selected scientific and engineering subjects and the capability to readily utilize those data and the software available to assess the technical suitability of Yucca Mountain as a potential repository site and the efficacy of alternative repository and waste package designs.

FY 1984

The NNWSI drilling program focused on obtaining hydrologic data on the prospective Yucca Mountain repository site. Three unsaturated zone holes were drilled and instruments were installed to measure natural water movement at various depths in the unsaturated zone. Twenty-six neutron holes were also drilled for periodic logging of the unsaturated zone to monitor water movement and to locate perched water. Three hydrologic test holes were drilled and instrumented to measure hydrologic flow beneath the static water table downgradient from the candidate repository site. An additional three of a series of 18 water table holes were completed in an effort to determine the static water level around the entire block of interest at Yucca Mountain; eleven water table holes were completed in FY 1983.

Pumping and injection tests were performed in test wells UE-25c#1, 2, and 3. These three 3,000-foot-deep holes represent a triangular array constructed downgradient from Yucca Mountain for hydraulic and transport testing along directions parallel to and across regional fracture sets. Subregional flow modeling was completed to include Yucca Mountain to Alkali Flat and Death Valley. Parameter estimation modeling continued with respect to the groundwater flow system beneath Yucca Mountain and its environs.

Horizontal and vertical plugs from USW G-4 (the Principal Borehole for the Exploratory Shaft) and UE-25p#1 (the Paleozoic borehole located immediately downgradient from Yucca Mountain) were cored for use in determining hydraulic conductivity, grain density, and porosity. The hydraulic permeability of the plugs was also determined. In addition, magnetic susceptibility and remanent magnetization measurements were completed on Paleozoic carbonate samples from UE-25p#1 core.

Eleven precipitation stations were established to define the effects of storm tracks on the chemical and isotopic composition of precipitation. Two temperature recorders were installed near two precipitation stations located far from existing temperature recorders. Two precipitation samplers, capable of taking six sequential samples during a single storm event, were manufactured and installed on Yucca Mountain and at Kyle Canyon.

The one-dimensional model of air and gas flow in the unsaturated zone was completed. A two-dimensional flow model of the unsaturated zone was reviewed to determine what analytical solutions would be appropriate to test its validity. The finite difference model was executed to simulate the unsaturated zone. Realistic rain (flux and period) and evaporation data were developed for use in the model. The run was designed to obtain simulation data for two rain periods separated by a period of evapotranspiration.

Interpretive work continued on the cross sections along and perpendicular to the main ridges of Yucca Mountain. A relationship was developed between thermal conductivity and compressional wave velocity that will be used to predict thermal conductivity in boreholes for which core is not available. Downhole temperature measurements from Yucca Mountain cross sections were used to develop theoretical models. Temperature logs were reduced from drillholes in the vicinity of Yucca Mountain and entered into disk files. Additional analyses were completed on thermal conductivity data and heat flow distribution for the Yucca Mountain area. The distribution was tabulated and mapped.

Seismic network data made possible a detailed study of focal mechanisms in the entire southern Great Basin. Progress was made in the evaluation of ground motion attenuation and seismic hazard studies. Several seismic hazard maps were produced representing the results of differing sets of assumptions about the tectonic and seismic rates.

Aerial photo reconnaissance of faults was conducted over Yucca Mountain and a map was compiled. Various types of photo lineaments in the alluvium were classified and entered on the map. Faults were compiled on the 1:12,000-scale topographic base map of Yucca Mountain. A second map was assembled showing lineaments visible in air photographs of the repository site. In addition, a fault map was compiled of the Beatty 1:100,000-scale quadrangle from published data.

Detailed geologic mapping of Yucca Mountain was extended into the area south and west. A 1:12,000-scale geologic map of Yucca Mountain with cross sections was completed. The presence of a pre-Topopah Spring Member topographic high was identified. Detailed fracture mapping and characterization was started at exposed rock pavements near the Exploratory Shaft site. The mapping of fractures on two such pavements was completed.

A 2- to 3-meter section of sediments overlying a disconformity in the Amargosa Desert was sampled to establish the age of these sediments and the underlying disconformity based on magnetic polarities. Numerous widely disbursed outcrops of the Tiva Canyon and Topopah Spring Members were sampled to assess the extent of rotation about a vertical axis in response to movement on lateral shear zones and to different amounts of extension.

Work continued on a comparison of fracture orientations obtained by television camera observations of drillhole walls and those obtained by acoustic televiewer logging of the walls. Cuttings from boreholes were examined to refine detailed correlations of stratigraphic units in the vicinity of the repository site. The stratigraphic and lithologic description of the water table boreholes was completed.

Rock samples were collected for magnetic property analysis to aid in the interpretation of the Las Vegas 1:250,000-scale aeromagnetic sheet. This work included a preliminary evaluation of the aeromagnetic anomaly map of the Las Vegas-scale quadrangle and the evaluation of background material. Field susceptibility measurements made at the sites of major magnetic anomalies in the test site region were analyzed in an attempt to relate anomalies to regional structure and hence to the structure at Yucca Mountain. The crustal model of a broad area around Yucca Mountain was refined on the basis of teleseismic and deep refraction results.

Field work and data compilation for a geologic map of the northwest quarter of the Bullfrog quadrangle were conducted to reveal the tectonic framework of the Yucca Mountain region. Data compilation of the northwest and southwest quarters of the partially remapped Bullfrog 15-minute quadrangle was completed. Field work was performed to collect data for a 1:24,000 bedrock geologic map of the southwest quarter of the Bare Mountain 15-minute quadrangle.

A state-of-the-art autocorrelated photon spectroscopy system was developed and put in operation to study the geochemical aspects of potential radionuclide migration at Yucca Mountain. This system was used to measure the size and size distribution of colloids and plutonium polymers. Colloid transport was also considered theoretically and was incorporated into computer models. Laboratory experiments on radionuclide transport were conducted in both crushed rock and rock fracture systems. In addition, quantitative X-ray powder diffraction techniques were applied to the tuffs at Yucca Mountain to obtain a three-dimensional mineralogic model.

The mineralogy of fractures in USW G-4 drill core from a depth of nearly 800 feet above the static water level, which is located at 1,770 feet below land surface, was examined to determine the sequence of deposition and to identify any minerals that might serve as natural barriers to radionuclide migration from a nuclear waste repository. Mordenite was found to be present, although not abundant, at the top of the interval sampled; i.e., the top of the lower lithophysal zone of the Topopah Spring Member of the Paintbrush Tuff. Heulandite occurs from about 1,245 to 1,378 feet in depth; clinoptilolite rather than heulandite occurs alone or with mordenite below 1,378 feet in depth. Smectite in fractures is abundant only in the vitrophyre of the Topopah Spring Member of the Paintbrush Tuff and at the top of the Prow Pass Member of the Crater Flat Tuff.

The unsaturated zone below 800 feet in depth can be divided into three rock types: devitrified, glassy, and zeolitized host rock. The fracture-lining zeolites for each of these three rock types differ in mineralogy and morphology. Preservation of nonwelded glass shards in the host rock above the zeolite mineral transition in the fractures indicates that the water table was never higher than the lithic-rich base of the Topopah Spring Member in the vicinity of USW G-4. Fracture linings in the zeolitic Topopah Spring Member are clinoptilolite, but the crystal size is similar to that of the heulandite found in fractures of the vitric zone above it rather than to the size of the clinoptilolite in the Tuffaceous Beds of Calico Hills below.

Volcanic hazard investigations focused on five topics: (1) the mechanism of emplacement of shallow basalt intrusions; (2) the geochemical trends in the volcanic fields of the Death Valley-Pancake Range volcanic zone; (3) the possibility of bimodal basalt-rhyolite volcanism; (4) the age and process of enrichment of incompatible elements in young basalts of the NTS region; and (5) the possibility of hydrovolcanic activity. The investigations found that while the stress regime of Yucca Mountain may favor the formation of shallow basalt intrusions, the combined field and drillhole studies suggest that shallow basalt intrusions are rare in the geologic record of the southern Great Basin. Investigations of the geochemical trends of basaltic volcanism in the NTS region continued to provide no evidence of possible future increases in the rate of volcanism. The volcanic hazard investigations also continued to show that existing data are consistent with declining volcanic activity comparable to the late stages of the southern Death Valley volcanic field.

EQ3/6 is a set of related computer codes and data files for use in the geochemical modeling of aqueous systems. To satisfy NRC software requirements, work was begun on a series of EQ3/6 user's guides. These guides will not only describe how to use the codes, but will explain the underlying geochemical theory and the numerical and computational methods by which the theory is implemented in the codes.

The EQ3/6 codes were improved with the addition of fixed fugacity and precipitation models. The first allows modeling of the unsaturated (vadose) zone in Yucca Mountain where the void spaces in the tuff contain significant amounts of oxygen and carbon dioxide. The second allows modeling precipitation-growth kinetics according to simple rate laws. A graphics postprocessor was developed to allow the rapid graphic display of ion concentration versus reaction progress or of any of the other variables that can be related to each other. At the end of FY 1984, the EQ3/6 data base included many simple ions and most of the common rock-forming minerals.

The waste-package development task continued to center on the design of a canister for use in the candidate tuff repository horizon in the Yucca Mountain unsaturated zone. Task activities included characterizing the waste-package environment, testing various component materials, devising engineering designs, developing performance evaluation models/computer codes, and formulating waste-package-environment tests to be carried out in the NNWSI Exploratory Shaft.

Waste-package-environment characterization activities included: (1) tuff-water interaction tests at elevated temperatures to define the geochemical conditions to be expected in the vicinity of waste packages during and after repository operations; (2) tests to simulate the dehydration/rehydration of tuff subjected to a thermal field; and (3) the development of methods to analyze the stability of underground openings in jointed rock, such as those that would be created by drilling waste-package emplacement holes in a repository.

A test method was developed to allow investigation of waste-form performance to be expected for a repository located in the vadose zone at Yucca Mountain. A one-year test series was begun using this new test method. A series of parametric tests were carried out to study the influence of a number of parameters on the radionuclide release rate from three different borosilicate glass compositions. Also, a cooperative program was initiated with the Savannah River Laboratory to investigate radionuclide release rates from (U.S. Department of) Defense high-level waste (DHLW) under various conditions.

Testing of candidate metallic barrier materials to be used in waste-package fabrication was continued with principal emphasis on austenitic stainless steels and high-nickel stainless alloys under appropriate conditions to evaluate corrosion rates and corrosion attack morphology. Particular attention was directed toward localized and stress-assisted forms of corrosion. Electrochemical polarization determinations of the localized corrosion susceptibilities of the various stainless steels and alloys were carried out. Effects of radiolysis products on steel corrosion were studied using electrochemical potential measurements. Stress corrosion tests were initiated using the bent beam and slow strain rate apparatus. Evaluation of the corrosion performance of carbon steels for potential use in fabricating emplacement hole liners continued.

Revised conceptual designs were developed for spent fuel canisters using space frames to immobilize the spent fuel rods. Two-dimensional axisymmetric structural analyses of waste-package conceptual designs were undertaken to address the response of these package designs to stresses imposed during handling, emplacement, and possible retrieval operations. Two- and three-dimensional thermal analyses were completed for various configurations of spent-fuel canisters for both the vertical and horizontal emplacement options. The effects of varying such parameters as areal power loading and borehole spacing were studied in order to assure that the temperature limit for spent fuel would not be exceeded.

Some of the submodels of the waste-package system performance assessment code were modified for use in the Yucca Mountain vadose zone. Work was completed on the thermal and mechanical modules and work on the flow/transport module was begun. Work was also begun on the hydrothermal analysis of the waste-package subsystem and emplacement environment.

Acquisition of data from the Spent Fuel Test--Climax underground test facility was terminated at the start of this fiscal year following a three-year period of spent-fuel storage and a subsequent six-month period of cooling the rock mass. Approximately 8.7 million points of temperature, displacement, and change in stress data were acquired. Posttest calibrations were obtained for each of the nearly 1,000 geotechnical instruments deployed for the test. While many calibrations utilized established techniques, it was necessary to develop new techniques and apparatuses for others. A microprocessor-controlled calibration device was designed, fabricated, and used to calibrate borehole extensometers. A second device was developed and deployed to evaluate the integrity of the anchors and connecting rods of these extensometers. Laboratory calibrations were completed for those instruments which could not be calibrated in the field.

An intensive campaign of geologic characterization of the underground test facility of the Spent Fuel Test--Climax was undertaken to determine the nature and extent of changes in rock properties that occurred as a result of storing spent fuel in the granite formation. In situ stresses and deformation moduli were measured within the heated region as well as outward from the test facility. Core samples were obtained adjacent to each of the spent-fuel storage and electrical simulator boreholes and at selected auxiliary heater boreholes. The mineralogy and petrology of these samples will be compared with pretest samples to determine the effects on the rock of heat alone or heat in combination with ionizing radiation.

Analysis and documentation of the results of rock and personnel radiation dosimetry at the Spent Fuel Test--Climax test facility were completed. Personnel dose commitments were determined to be negligible. The test facility continued to be maintained and underground access was provided for public information purposes.

Two field tests were completed in the G-Tunnel underground rock machanics facility on the NTS--a small-diameter heater test and a heated-block test. Along with providing information about the large-scale thermomechanical response of fractured tuff, the results will be used to help evaluate thermomechanical and hydrologic models.

In the small-diameter heater test, the in situ degree of saturation and temperature of welded tuff were monitored with the heater in a horizontal orientation. In the heated-block test, a two-meter-square block of tuff was loaded biaxially with flatjacks and heated in three phases to 160°C. Load, displacement, temperature, compression-wave velocity, fluid flow, and percent saturation measurements were made.

Previously collected field and laboratory data were evaluated and condensed into a referenceable set of intact and rock mass thermal and mechanical properties for use in thermomechanical calculations. An experimental system designed to measure permeability of intact, fractured specimens of tuff was assembled and shakedown tests were run. Preliminary results have provided information about the variation of permeability and fracture aperture as a function of confining pressure and temperature. Advances in thermomechanical modeling using finite-element techniques have allowed for more accurate estimates to be made for the lower bounds of the expected in situ stresses at Yucca Mountain. Preliminary verification and validation of a compliant-joint-material model were accomplished. Routine use of the model in the future should improve calculation capabilities.

Exploratory boreholes were drilled on the east side of Yucca Mountain to obtain subsurface information about six sites that were being considered for the repository surface facilities. A reference site for conceptual design was chosen on the basis of its relative rank in regard to meeting various siting criteria. In addition, preliminary design concepts were developed for both the surface and underground facilities. This work will continue and a conceptual design report will be published.

Conceptual designs of equipment for underground operations were prepared. Specific designs completed were: (1) the drill and hole-liner installation equipment for long, horizontal emplacement holes; (2) the waste emplacement equipment for horizontal emplacement of spent-fuel and high-level waste canisters; (3) the emplacement equipment for the vertical emplacement of spent-fuel and high-level waste canisters; and (4) the waste handling equipment system for contact-handled waste.

The 24-month Dry Storage Fuel Integrity Demonstration Test being conducted at the E-MAD Facility continued. This test, which utilizes a spent nuclear fuel assembly in a metal cask, simulates storage at high temperatures (275°C) with decreasing radioactive decay-heat levels. To monitor any incremental release of fission product gases from suspected defective rods in the fuel assembly, the atmosphere of the test system was evacuated and replaced with fresh air during monthly canister gas sampling operations.

Four fuel assemblies were removed from their seal-welded canisters and characterized to verify their integrity following storage tests. The characterization included a visual inspection, photographic documentation, videotaping, and contamination swipe sampling. The condition inside the storage canisters was determined by evaluation of suspended particulates and internal surface contamination levels and by measurements of the activity of any residue remaining in the canister.

Material Interaction Test capsules containing a number of mineral and rock specimen experiments designed to reveal material compatibility, chemical transformation, and changes in structural properties as well as temperature profile instrumentation that measured actual maximum temperatures of the fuel assemblies in storage were retrieved from the four Turkey Point pressurized water reactor spent fuel assemblies in which they had been installed at Battelle-Columbus Laboratories prior to shipment of the fuel to the E-MAD Facility at the NTS. The Material Interaction Test capsules were disassembled and shipped, with the temperature-profile-capsule assemblies, to the Hanford Engineering and Development Laboratory for analysis.

The first draft of the NNWSI System Description document was completed. The document identifies the requirements that must be met by a radioactive-waste-disposal system at Yucca Mountain. The draft includes the functions that must be performed; identifies applicable requirements from legislation, regulations, policy, and other sources; and links the applicable requirements to the waste-disposal-system functions.

Work on the NNWSI Tuff Data Base continued with the addition of data from NNWSI field and laboratory experiments. The first phase of the user-friendly interface was completed; this allows NNWSI Project participants to gain access to the data base.

Work to evaluate the performance of the entire waste-disposal system conceptualized for Yucca Mountain contributed to the development of the necessary modeling tools. A relatively simple code, SPARTAN, was modified and used to perform preliminary performance assessments for the NNWSI Environmental Assessment document and to perform the study on the relative contributions of the engineered and natural systems at Yucca Mountain to long-term radionuclide isolation from the accessible environment. A larger, modular Total System Performance Assessment Code (TOSPAC) continued in development and was used in several code benchmarking exercises. The steady-state hydrology module and its dynamic counterpart were completed.

Development of a two-dimensional, multiple-phase, porous-medium, hydrologic-flow code, NORIA, was completed; NORIA was used in code benchmarking studies and as an aid for developing a hydrothermal laboratory experiment. A user's manual was completed for the code FEMTRAN, a saturated-unsaturated flow and radionuclide transport code.

Considerable effort was expended to produce and revise the NNWSI Environmental Assessment document and to produce supporting data and reference reports for the document. Much effort also went into providing information for DOE national program documents including the Siting Guidelines, Mission Plan, and Generic Requirements for a Mined Geologic Disposal System.

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