Simulated effects of climate change on the Death Valley regional ground-water flow system, Nevada and California

By Frank A. D'Agnese, Grady M. O'Brien, Claudia C. Faunt, and Carma A. San Juan

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CONVERSION FACTORS

Multiply	By	To obtain
meter (m)	3.281	feet
millimeter (mm)	0.03937	inch
kilometer (km)	0.6214	mile
square kilometer (km^2)	0.3861	square mile
meters squared per day (m^2/day)	10.76	feet squared per day
meters cubed per day (m^3/day)	35.32	feet cubed per day

Degree Celsius (°C) may be converted to degree Fahrenheit (°F) by using the following equation:

$$°F = (1.8 \times °C) + 32.$$

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929) - a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

SIMULATED EFFECTS OF CLIMATE CHANGE ON THE DEATH VALLEY REGIONAL GROUND-WATER FLOW SYSTEM, NEVADA AND CALIFORNIA

By Frank A. D'Agnese, Grady M. O'Brien, Claudia C. Faunt, and Carma A. San Juan

ABSTRACT

The U.S. Geological Survey, in cooperation with the U.S. Department of Energy, is evaluating the geologic and hydrologic characteristics of the Death Valley regional flow system as part of the Yucca Mountain Project. As part of the hydrologic investigation, regional, three-dimensional conceptual and numerical ground-water flow models have been developed to assess the potential effects of past (full-glacial) and future (global-warming) climates on the regional flow system. A simulation based on climatic conditions 21,000 years ago was evaluated by comparing the simulated results to observation of paleodischarge sites. Following acceptable simulation of a past climate, a possible future ground-water flow system, with climatic conditions representing a doubling of atmospheric carbon dioxide was simulated.

The steady-state simulations were based on the present-day, steady-state, regional ground-water flow model. The model covered approximately 80,000 square kilometers between lat. 35°N., long. 115°W. and lat. 38°N., long. 118°W. and encompassed the Death Valley regional ground-water flow system. The finite-difference model consisted of 163 rows, 153 columns, and 3 layers and was simulated using MODFLOWP. The grid was oriented north-south and cells were of uniform size, with side dimensions of 1,500 meters. Three layers of uniform thickness represented ranges of 0-500, 500-1,250, and 1,250-2,750 meters below a generalized representation of an estimated water table.

Climate changes were implemented in the regional ground-water flow model by changing the distribution of ground-water recharge. Global-scale, average-annual, simulated precipitation for both past- and future-climate scenarios developed elsewhere were resampled to the model-grid resolution. A

polynomial function representing the Maxey-Eakin method for estimating recharge from precipitation was used to develop recharge distributions for simulation.

Results of climate-change simulations were evaluated by observing simulated discharge areas, water level changes, potentiometric-surface configurations, and water budgets. During past-climate conditions, recharge increased in most areas to produce a significantly different regional ground-water flow system. Perhaps the most significant of these changes was the exclusion of underflow from Pahranagat Valley. Wetter conditions provided sufficient ground-water to maintain paleolake levels in the northern parts of the model domain and in Death Valley. Ground-water discharge occurred at most of the predicted paleodischarge sites, which indicated that the recharge distributions used in the simulations were reasonable. Large hydraulic gradients in the region were preserved and enhanced under past-climate conditions. The water budget for the past-climate model indicated that recharge over the region increased by a factor of about five, relative to simulated present day recharge. Under these extremely-wet conditions, simulated water levels beneath Yucca Mountain rose between 60 and 150 m.

Under future-climate conditions, simulated recharge both increased and decreased, relative to present day. The configuration of the potentiometric surface changed only slightly to indicate depressions at discharging playas. These playas, however, were not simulated to have discharged as much water as they did during full-glacial climate, and probably would not support perennial lakes. Several playa lakes in the north and northeast areas of the model domain were simulated as discharging ground-water. Under future-climate conditions, large hydraulic gradients were maintained and were enhanced in some areas. The water budget indicated that recharge throughout the model increase by a factor of about 1.5, relative to simulated present-day recharge. Under these climatic conditions, simulated water levels below Yucca Mountain rise less than 50 m.

Substantial limitations exist when evaluating the effects of climate change on the Death Valley regional ground-water flow system using numerical modeling. Therefore, the simulated effects of climate changes should be considered conceptual in nature and should be used only to describe potential relative impacts on the regional ground-water flow system.

INTRODUCTION

A mined, geologic, high-level nuclear-waste repository is being considered to isolate spent nuclear fuel from energy-producing nuclear reactors across the country. Yucca Mountain, which is on and adjacent to the Nevada Test Site in southwestern Nevada, is being studied as a potential site for such a repository (fig. 1). The U.S. Geological Survey, in cooperation with the U.S. Department of Energy, is evaluating the geologic and hydrologic characteristics of this site as part of the Yucca Mountain Project. Because of the potential for radionuclides from such a repository to be transported by ground water to the accessible environment, the ground-water flow system must be characterized. As a part of these investigations, regional three-dimensional conceptual and numerical ground-water flow models have been developed. Based on the numerical ground-water flow models, the potential effects of full-glacial and global-warming climates on the regional flow system are being assessed. Water-level changes associated with these climate scenarios are important due to their possible impact on the potential repository. Long-term climate changes are considered because the potential repository may have an operational life of thousands of years.

FIGURE 1.—NEAR HERE
Figure 1. The Death Valley regional ground-water flow system model domain.

Purpose and Scope

The purpose of this report is to document model simulations that investigate the effects of climate changes on the Death Valley regional ground-water flow system. Regional ground-water modeling studies conducted by the U.S. Geological Survey are part of the Yucca Mountain site-characterization project. Two climate scenarios are investigated: 1) past conditions representing a full-glacial climate; and 2) future conditions representing a global-warming climate. The climate changes are simulated by estimating the ground-water recharge associated with the increased precipitation. Methods used to estimate rates and distribution of recharge are described. Simulated water-level changes in the region and in the vicinity of Yucca Mountain are discussed. Simulated changes in discharge areas and flow in the Yucca Mountain are also discussed.

The scope of this study was dictated by Department of Energy Yucca Mountain Project guidelines, which are summarized as follows:

(1) The study is limited to the Death Valley region (fig. 1);

(2) The present-day, steady-state regional ground-water flow model described by D'Agnese and others (in press) was the basis for the simulations;

(3) Past-climate information is based on paleoclimatic data interpreted to describe conditions that likely existed approximately 21,000 years ago; and

(4) Future-climate information is based on predicted climatic effects due to doubling present-day atmospheric concentrations of carbon dioxide (Thompson and others, 1996a).

Several conditions mandated the simulation of the full glacial 21 ka and doubling of atmospheric CO_2 concentrations climate scenarios. The full glacial 21 ka scenario was chosen because of climate indicators available for this time period, which allowed the climate model to be validated. The cooler and wetter conditions present during the full glacial 21 ka were also considered to represent a reasonable potential wet climate that could occur in the future. The doubling of atmospheric CO_2 scenario was also considered to represent reasonable future climate conditions.

Several alternative climate scenarios could be considered to estimate the potential impact on the ground-water flow system in the Yucca Mountain area. The wettest conditions that have existed in the

Yucca Mountain area probably occurred during the Illinoian glacial stage about 140-170 ka (Richard Forester, U.S. Geological Survey, oral commun., 1997). These wet climate conditions would represent a pre-historic worse-case scenario for potential high water levels and thus highest recharge rates. Climate forcing conditions that were not simulated could occur in the future that would result in wetter conditions than estimated with a doubling of atmospheric CO_2. Additional precipitation distributions could be developed based on potential climate forcing. The simplest approach, however, to developing additional climate scenarios would be to multiply present-day recharge by constant factors and simulate the impact on the ground-water flow system. These alternative climate scenarios were beyond the scope of this study.

Quality-Assurance Considerations

Because interpretations of model results may be used to assess the expected performance of a high-level, nuclear-waste repository, confidence in the reliability of data used in model construction and model evaluation is necessary. A quality-assurance program has been implemented by the Yucca Mountain Project to support the reliability of the data and interpretations of data.

Data used by the Yucca Mountain Project are classified as either "qualified" or "unqualified". Qualified data are defined as "data acquired or developed for the Yucca Mountain Project under a Nuclear Regulatory Commission accepted quality assurance plan or qualified in accordance with appropriate Yucca Mountain Project procedures. Developed data cannot be classified as 'Qualified' if derived from unqualified data sources." (U.S. Department of Energy, written commun., 1993).

Because of the regional scope of this report, data used in the construction of the hydrogeologic framework and ground-water flow model were developed from published sources or obtained from publicly-available sources. Nearly all of these sources originated outside of the Yucca Mountain Project, or were obtained and published before the implementation of the project quality-assurance program. No qualified data, which are regional in scope, are available. Therefore, no data presented in this report can be classified as qualified, and the results of the modeling are based entirely on unqualified data. Model construction and review, however, were performed in accordance with accepted quality-assurance procedures and U.S. Geological Survey policy.

Acknowledgements

This study was conducted with the help of numerous individuals participating in the Yucca Mountain Project. Because of the interdisciplinary nature of this study, the information contained in this report could not have been possible without the contributions of many project participants. Starley Thompson of the National Center for Atmospheric Research in Boulder, Colorado provided the climate model results describing average annual precipitation distributions for past and future climate conditions. Alan Flint and Joseph Hevesi of the U.S. Geological Survey resampled the precipitation data and developed potential recharge distributions for both climate scenarios. Richard Forester, Platt Bradbury, and James Paces of the U.S. Geological Survey provided information on the potential paleohydrologic conditions of the Death Valley region approximately a period of 21,000 years ago.

Study Area

The study area is bounded by 35° and 38° N. latitude and 115° and 118° W. longitude and was chosen to include the limits of the Death Valley regional ground-water basin, first defined by Bedinger and others (1989). The Death Valley region is located along the border of southwestern Nevada and southeastern California. The boundary of the region was modified by D'Agnese and others (in press) for a regional ground-water flow model (fig. 1). The ground-water basin is immediately west of the city of Las Vegas, Nevada and includes parts of Esmeralda, Nye, Lincoln, and Clark Counties, Nevada, and Inyo and San Bernardino Counties, California. Yucca Mountain is located in approximately the geographic center of the region on the western border of the Nevada Test Site (fig. 1).

Past and Future Climate Scenarios

As part of evaluating the geologic and hydrologic characteristics of the Yucca Mountain site, the potential effects of climate change on the regional flow system are being assessed. Climate changes probably will affect the potential for radionuclides to be transported by ground water from the repository to the accessible environment. To simulate the affect of climate changes, the present-day, steady-state regional ground-water flow model developed by D'Agnese and others (in press) was modified.

To assess the potential hydrologic effects of climate change, two basic simulations were performed. First, as a reasonableness check on the future-climate scenario, a simulation based on past climatic conditions was evaluated by comparing simulated results to observed paleodischarge sites. The ground-water flow system based on climatic conditions approximately 21,000 years ago (21 ka) was simulated to represent ground-water flow under full-glacial conditions. Second, a possible future ground-water flow system was simulated with climatic conditions representing global warming.

Past Climate

The potential repository level is located approximately 200 to 400 m above the present-day potentiometric surface. Evidence for higher saturated-zone water levels at some time in the past has been suggested based on secondary mineral occurrences (Levy, 1991), Sr isotopic variations (Marshall and others, 1993) from borehole data, and from hydrologic models assuming increased recharge (Czarnecki, 1985). Past-climate records from throughout the southern Great Basin demonstrate that episodes of higher effective moisture relative to present-day conditions have occurred. Ground-water discharge deposits are commonly exposed in the region (R. M. Forester and others, U.S. Geological Survey, written commun., 1996). A map of possible paleodischarge sites (fig. 2), along with depositional history for 21 ka was developed by R. M. Forester and others (U.S. Geological Survey, written commun., 1997).

FIGURE 2.--NEAR HERE

Figure 2. The location of lakes and wetlands occurring approximately 21,000 years ago (R.M. Forester and others, U.S. Geological Survey, written commun., 1997).

Late Quaternary paleohydrology in the southern Great Basin has been summarized by R. M. Forester and Platt Bradbury (U.S. Geological Survey, written commun., 1997) as part of Yucca Mountain site characterization studies. Their synopsis of paleohydrologic conditions in the Death Valley region is paraphrased in the following three paragraphs.

During the late Pleistocene (40- 12 ka), effective moisture was higher throughout the Death Valley region. Higher effective moisture was a result of both a lower temperature, with a consequent reduction in evapotranspiration, and higher precipitation. During the late Pleistocene, the climate was generally cooler and wetter than present, but was nevertheless variable. Some time intervals were cold, but relatively dry, while other intervals, such as 23-21 ka, were perhaps less cold, but were much wetter than present.

In the Death Valley region, increased effective moisture was manifested by lakes, perennial drainage systems, some large-wetlands, and many small seeps and minor wetlands (fig. 2). Plant communities, such as juniper, existed at altitudes as much as 1000 m lower than they do at present. Within the region, shallow (less than 50 m deep) lakes existed in the Emigrant, Gold Flat, and Kawich basins. Fortymile Wash was a gaining stream and flowed through to the Amargosa River around 21 ka. This major tributary, and the Amargosa River itself, were probably perennial streams that helped supply the large Lake Manley in Death Valley. Wetlands, such as those represented by the deposits at Cactus, Corn Creek, and Tule Springs were supported by discharge from both the ground-water and surface-water systems. Increased recharge in both the Spring Mountains and Sheep Range resulted in spring discharge from the alluvial fans at the foot of the mountain ranges. Discharge from all sources greatly exceeded that which occurred during historical times.

The deposits in northern Amargosa Valley (fig. 2) represent an area of focused ground-water discharge during the last (40-12 ka) glacial period. Discharge also occurred in Crater Flat. The State Line deposits show an interplay of surface flow and spring discharge similar to the deposits at Lathrop Wells. Paleodischarge records, dated around 21 ka, do not exist for Ash Meadows or Pahranagat Valley. Quade and others (1995) have identified and studied wetland deposits in the Coyote Springs Valley and suspect that flow from the Pahranagat Valley reached the Coyote Springs Valley during the late Pleistocene. During that time, however, the White River was probably a continuous gaining stream. Extensive spring-discharge and wetland deposits are known from the Pahrump Valley, but according to Quade and others (1995), deposits from about 21 ka probably do exist there.

Future Climate

Descriptions of potential future hydrologic conditions are highly speculative. An anthropogenic worst-case future-climate scenario was simulated by the Yucca Mountain Project with a doubling of present-day carbon dioxide concentrations in the atmosphere that would result from burning all estimated reserves of petroleum and natural gas. Thompson and others (1996b) developed a distribution of the average annual precipitation that would occur with this type of climate change. This distribution results in a hydrologic system that contains significantly less moisture and ground-water than that which occurred at 21 ka.

Estimated Past and Future Recharge Conditions

Changes in ground-water recharge have a major impact on simulated changes in the regional ground-water flow system. Increased precipitation during wetter climatic conditions, will result in increased recharge to the ground-water flow system. Distributions of recharge developed for this study relied on the Maxey-Eakin method (Maxey and Eakin, 1949). The potential errors associated with using this method for estimating regional recharge rates is discussed in detail in D'Agnese and others (in press).

The recharge distributions used in the past and future climate simulations were based on climate models developed by the National Center for Atmospheric Research (NCAR). Details of the NCAR climate modeling are presented in Thompson and others (1996a) and Thompson and others (1996b) and the following discussion is a summary of these reports.

The NCAR modeling approach involved the use of nested global and regional climate models. A global circulation model (GCM) with 200 to 600 km grid spacing was used to capture the large scale climatic forcing due to the Earth's orbit and changes in greenhouse gas concentrations. A regional circulation model (RCM), centered over the Yucca Mountain area, with a 50 km grid spacing was used to capture local climatic changes influenced by complex topographic features and surface characteristics. The GCM and RCM are considered nested because the initial and time-dependent boundary conditions for the RCM were based on climate simulations produced by the GCM.

The climate models are complex representations of the physical processes that affect climate change. Conservation of momentum, mass, and energy for air parcels are incorporated in the models. The main physical atmospheric processes, such as radiative transfer, cloud and precipitation formation, boundary layer physics, and surface physics, are accounted for in these models. Accurate predictions of climate change also requires that the interaction between the atmosphere, oceans, and the cryosphere be represented, so the distributions of sea surface temperature, sea ice, and snow cover are included as model inputs.

The NCAR climate models were tested to determine if the simulation results were reasonable. Comparing present day and paleoclimate simulations with known climate conditions validated the circulation models. These simulation results indicated that the RCM was providing an adequate representation of the climate conditions. The RCM was not designed to provide Yucca Mountain site-specific simulations, rather the results are representative of an area several grid cells across (100 to 200 km).

Two climate scenarios were simulated by NCAR. A past, full-glacial climate occurred approximately 21 ka and a potential future climate represented by a doubling of atmospheric CO_2. The RCM full-glacial conditions were simulated using the GCM boundary conditions from 21 ka. NCAR concluded that these simulations were reasonable because, as expected, the simulated full-glacial climate was cooler and wetter than the present-day conditions. The recharge distribution used in the 21 ka ground-water model simulations was based on the mean precipitation distribution over a 2 year period determined from these climate simulations. Based on the success of the present day and 21 ka climate simulations it was determined that the nested modeling approach was adequate to provide future climate simulations.

A doubling of present-day atmospheric carbon dioxide (CO_2) concentration was the forcing used in the future climate simulations. With the current rate of fossil fuel consumption it is expected that atmospheric CO_2 concentrations will double within the next 100 years. In general, the future climate simulations resulted in a uniform temperature increase of 2-3 °C in the Yucca Mountain area. Compared to present-day conditions, precipitation dramatically increased during the winter season in California and this effect extended into southern Nevada. The simulated future precipitation during the summer, however, decreased in southern Nevada. A 4-year average of simulated precipitation was used to estimate recharge for the ground-water model simulations.

The average annual precipitation maps developed by Thompson and others (1996a) were calculated on a 50 km grid and required additional formatting prior to use in the ground-water flow model. The present-day precipitation distribution developed by Thompson and others (1996a) was similar to present-day climate conditions and was used as the baseline precipitation. Using this baseline distribution and the results of the full-glacial climate model, a ratio of the full glacial grid and the baseline grid was developed. The ratio grid was then multiplied by the map of average annual precipitation used in the present-day regional ground-water flow model. The resultant grid, therefore, was the predicted distribution of average annual precipitation under full-glacial climate conditions. For use in the ground-water flow simulations, these data were then resampled to a 1.5 km grid coincident with the regional ground-water flow model.

Next, a polynomial function representing the Maxey-Eakin area-altitude relationship for determining recharge from precipitation was applied (A.L. Flint and J.A. Hevesi, U.S. Geological Survey, written commun., 1996). The Maxey-Eakin polynomial function was used to produce a grid-format map of recharge for the 21 ka climate. The grid-format map was resampled to the grid resolution of the regional flow model (fig. 3) and was used to produce the recharge array for the past-climate simulations.

FIGURE 3.—NEAR HERE

Figure 3. Past-climate recharge distribution.

The simulated average annual precipitation map for future-climate conditions was based on doubling present-day atmospheric carbon dioxide concentration (Thompson and others, 1996b) and developed in the same manner as the past-climate precipitation distribution. The distribution of recharge used in the future-climate ground-water simulations was developed with a polynomial representing the Maxey-Eakin method (A.L. Flint and J.A. Hevesi, U.S. Geological Survey, written commun., 1996). The recharge map based on a doubling of present-day atmospheric carbon dioxide was resampled to the grid resolution of the regional flow model (fig. 4) and was used to produce the recharge array for the future-climate simulations.

FIGURE 4.--NEAR HERE

Figure 4. Future-climate recharge distribution.

The method used to determine recharge for the past-climate and future-climate simulations was different from the method used to determine recharge for the present-day simulation (D'Agnese and others, in press) (fig. 5). A detailed discussion of how recharge was determined in the steady-state model is provided in D'Agnese and others (in press). The difference in approaches results in recharge rates being somewhat different in some parts of the model domain. The high rates and distribution of recharge in the Spring Mountains, for example, are represented quite differently in the present-day and in the future-climate simulations. The climate simulations do not result in a simple linear increase in recharge across the model domain, and the ground-water simulations using the different recharge distributions do not result in simple linear increases in the potentiometric surface.

FIGURE 5.--NEAR HERE
Figure 5. Simulated present-day recharge distribution.

In addition to the changes caused by the differences in the methods for determining recharge, the climate scenarios result in different recharge distributions than those used in the present-day model because of different precipitation patterns (figs. 6 and 7). The total volume of recharge simulated in both the past-climate and future-climate simulations is greater than the simulated present-day recharge. The distribution of recharge, however, varies greatly between the different climate scenarios.

FIGURE 6.--NEAR HERE
Figure 6. Difference between past-climate and present-day recharge distributions.

FIGURE 7.--NEAR HERE
Figure 7. Difference between future-climate and present-day recharge distributions.

The recharge rates in the past-climate simulation were generally higher than rates used in the present-day simulation. The biggest difference between past-climate and present-day recharge rates were in the Spring Mountains, Kingston Range, and Sheep Range, where past-climate recharge was more than 100 mm/yr higher than present-day recharge (fig. 6). The Amargosa Range, Kingston Range, Spring Mountains, Sheep Range, Pahranagat Range, and the Timber Mountain-Rainier Mesa area had recharge rates that were at least 50 mm/yr higher in the past-climate simulations than in present day simulations (fig. 6). Most of the model domain in the past-climate simulations has recharge rates that are 0 to 50 mm/yr higher than in present-day simulations. The western part of the model domain, including Death Valley and the Sarcobatus Flat-Stonewall Mountain area, have recharge rates in the past-climate simulations that are less than in the present-day simulations (fig. 6).

Total recharge in the future-climate simulation was greater than in present-day simulations (figs. 7 and 8). Most of the north and northeast areas of the model domain had future-climate recharge rates that are greater than present-day recharge. Future-climate scenario recharge rates also were generally greater than present-day simulated recharge in higher altitude areas, including Pahranagat Range, Kingston Range, Spring Mountains, and Sheep Range (fig. 7). From the northeast part of the domain through the Amargosa River drainage and into Death Valley, the future-climate simulated recharge was less than or equal to present-day simulated recharge. The low-lying areas near the Spotted Range also had future-climate simulated recharge rates that are less than or equal to present-day simulated conditions.

FIGURE 8.--NEAR HERE

Figure 8. Difference between past-climate and future-climate recharge distributions.

The distribution of recharge was similar for the past-climate and future-climate simulations, but the rate was generally higher for the past-climate conditions (fig. 8). Because the same method was used to determine recharge for the past-climate and future-climate scenarios, areas of high and low recharge were generally similar. The variations were caused by differences between the simulated climate. A much larger portion of the model domain had zero recharge in the future-climate simulation (fig. 4). The simulated past recharge was 1 to 25 mm/yr greater than the simulated future recharge over most of the model domain (fig. 8). The Spring Mountains received the most recharge in both the past- and future-climate scenarios (figs 3 and 4), and this area received over 250 mm/yr more recharge in the past-climate simulations than in the future-climate simulations (fig. 8).

DESCRIPTION OF GROUND-WATER FLOW MODEL

The Death Valley regional ground-water flow model used for this study was developed as part of the U.S. Geological Survey Yucca Mountain Project site characterization program. The present-day model has been documented by D'Agnese and others (in press). The numerical code used in this study is MODFLOWP (Hill, 1992). MODFLOWP is an adaptation of the U.S. Geological Survey three-dimensional, finite-difference modular ground-water flow model, MODFLOW (McDonald and Harbaugh, 1988; Hill, 1992) in which nonlinear regression is used to estimate model parameters that result in the best fit to measured hydraulic heads and ground-water discharge rates. MODFLOWP is a block-centered finite-difference code that simulates a three-dimensional flow system as a sequence of porous-media layers.

Simplifying Assumptions

The ground-water flow model has three major simplifying assumptions:

(1) Ground water in the Death Valley region flows through fractured volcanic and carbonate rocks, as well in porous valley-fill alluvium. However, discrete-fracture flow simulation is impractical at a regional scale, and, therefore, all flow is assumed to occur through porous media. Zones of high or low hydraulic conductivity are used to account for highly faulted and fractured regions. This assumption probably produces reasonable approximations to regional-scale flow patterns.

(2) Hydraulic conductivity within each model cell is assumed to be homogeneous and horizontally isotropic. Thus, hydraulic conductivity variations smaller than the grid cells are not

represented. This assumption probably produces reasonable approximations to regional-scale flow patterns, but local-scale flow patterns probably are not adequately represented.

(3) The system can be assumed to be essentially at steady state. Four conditions may cause this assumption to be violated. First, the regional flow system still may be undergoing a drying-out sequence following a wetter climate cycle related to the late Pleistocene. Second, ground-water withdrawals by wells for domestic, municipal, mining, and irrigation uses have imposed recent stresses on the present-day system. This pumpage is derived initially from ground-water storage. The steady-state model, however, omits the possibility of deriving water from storage, so that water flowing to wells must be offset by capture of natural discharge. The future-climate simulation assumes that future pumpage remains at present-day rates; past-climate simulations assume no pumpage. Third, the flow system may experience seasonal or annual fluctuations that are not simulated. Longer-term average conditions are simulated. Fourth, water levels, spring flows, and other data used in model calibration were collected over an interval of many years, and these data may contain seasonal and annual variations to the ground-water flow system, and may not reflect steady-state, average-annual, ground-water conditions.

(4) In the Death Valley regional flow model, saturated thickness in model layers is constant. Although the top layer in the natural flow system is unconfined in most areas, defining its present-day thickness from a potentiometric-surface map and representing the layer as confined, produces a good approximation and is much more efficient numerically. During periods of increased recharge conditions, however, the uppermost layer will likely have a higher saturated thickness in many locations. This cannot occur in the model because of the current configuration.

This is an important limitation because a change in saturated thickness has a direct effect on transmissivity. If changes in water levels are small, then saturated thickness and transmissivity will likely not change dramatically. If changes in water levels are large, however, then water-level rises resulting from these climate-change simulations may be over-estimated.

Modification of the model to simulate these types of unconfined conditions is beyond the limited scope of this study. As a result, the simulations should be considered approximations of the effects of climate change on the flow system.

Model Grid

The model contains 163 rows, 153 columns and 3 layers for a total of 74,817-cells. The model grid is oriented north-south. Cell spacing along both rows and columns was 1,500 m. The three model layers represent aquifer properties at 0-500 m, 500-1,250 m, and 1,250-2,750 m below an interpolated and smoothed potentiometric surface; layers are 500, 750, and 1,500 m thick, respectively. The first and second model layers generally simulate local and subregional flow mostly within valley-fill alluvium, volcanic rocks and shallow carbonate rocks. The third layer generally simulates regional flow in the volcanic, carbonate and clastic rocks (D'Agnese and others, in press).

Present-day Model Parameters and Boundaries

The model used as the starting point in the current analysis is documented in detail by D'Agnese and others (in press). In general, the regional model boundaries extend to mountain ranges that generally consist of low-permeability consolidated rock. The external boundaries were assumed to be no-flow boundaries except in some areas in the north and northeast where constant-head boundaries were used to simulate potential ground-water underflow. A constant-head boundary was used at the Death Valley saltpan to simulate evaporation of water out of the system (D'Agnese and others, in press).

Hydraulic conductivities throughout the model domain was divided into nine different zones and values for hydraulic conductivity ranged from 1×10^{-6} m/day to about 20 m/day. Recharge was simulated as an areally-distributed input to cells in the upper layer that generally correspond to mountain ranges. Recharge rates were defined as a percent of present-day, average annual precipitation. Four recharge zones were used with values ranging from 0 percent of average annual precipitation in the valley bottoms to 23 percent of average annual precipitation on the tops of the highest mountains. Discharge occurred primarily as evapotranspiration, spring flow, and pumpage. Evapotranspiration was simulated as a head-dependent function with the rate dependent on depth to water below land-surface. Regional springs were simulated as head-dependent flux boundaries and were assigned to the lower layers of the model, which represented more regional flow. Pumpage was assigned to cells where estimated ground-water withdrawal occurred.

CLIMATE-CHANGE SIMULATIONS

The past- and future-climate simulations relied heavily on the present-day Death Valley flow-system model developed by D'Agnese and others (in press). The model domain and discretization was identical. Furthermore, model parameters and boundaries used in the present-day model, except recharge and pumpage, generally were not changed for the past- or future-climate simulations. Where model boundaries were changed, the changes are noted in subsequent sections. The hydrogeologic framework was assumed not to have changed or to change during these simulations.

Past-Climate (full-glacial) Simulations

Past climate simulations required the following changes to the present-day ground-water flow model: (1) modification of boundary conditions; (2) modification of recharge distribution; (3) conversion of evapotranspiration areas into wetlands; and (4) elimination of pumpage. Because few data were available to describe the hydrologic conditions under full glaciation, the simulation required numerous simplifying assumptions.

Boundary Conditions

The boundary conditions for past-climate simulations were modified from those used in the present-day flow model (D'Agnese and others, in press). Constant-head cells were used to simulate paleolakes (fig. 2) that were present 21 ka. The constant heads in the lake areas were assigned values equal to interpreted paleoshoreline altitudes. The four major paleolakes simulated were Kawich Valley, Cactus Flats, Emigrant Valley, and Death Valley. Lake Manley, in Death Valley, was the largest of these paleolakes (fig. 2).

The location of constant-head boundaries along the northern and northeastern edge of the model were the same as those used in the present-day model but constant heads were assigned to all three model layers (fig. 9) whereas only layer 3 was assigned a constant head in the present-day model. Assigning constant heads to all three layers allowed the potentially larger underflow of ground-water that may have occurred in the past into the model domain. Constant heads assigned to these model cells were designated to represent levels for paleolakes that existed just outside the model domain in Ralston, Stone Cabin, and Reveille Valleys (fig. 9). A constant-head boundary was also used in all layers on the northeastern edge of the model domain, near the Pahranagat Range, to represent ground-water flux to or from the Pahranagat Lakes area (fig. 9). In the present-day model, this area had constant-head cells only in layer 3.

FIGURE 9.--NEAR HERE
Figure 9. Distribution of paleodischarge areas represented as constant head cells and drains in the past-climate ground-water flow model simulation.

Recharge

Climatic conditions 21 ka were significantly wetter than present; average annual precipitation distributions for this period were developed by Thompson and others (1996). These simulated increases in average annual precipitation resulted in higher ground-water recharge rates than those that exist in the present-day region.

Regional ground-water recharge rates developed for the past-climate simulation (A.L. Flint and J.A. Hevesi, U.S. Geological Survey, written commun., 1996) were resampled to a 1,500 m model grid (fig. 3). The estimated recharge rates in several areas of the model domain exceeded the model hydraulic conductivity of layer 1, so water would be added to the system at a greater rate than the hydrogeologic units could transmit. This would have occurred in several mountain ranges with low hydraulic-conductivity units. Under natural conditions, surface runoff would occur when recharge exceeded hydraulic conductivity. The surface runoff may evaporate, may be consumed by vegetation, may infiltrate back into the ground-water system at some lower altitude, or may form ponds or wetlands.

To simulate rejected recharge, drains (McDonald and Harbaugh, 1988) were added to mountain-top areas of the model that were coincident with areas where recharge exceeded hydraulic conductivity. The drains were simulated as being at land-surface altitudes.

Conversion of Evapotranspiration Areas to Wetlands (Drains)

The present-day flow model included a head-dependent function to simulate evapotranspiration areas; however, in the past-climate simulations, potential wetland areas were simulated as head-dependent boundaries, or drains (McDonald and Harbaugh, 1988). The location and extent of potential wetlands under wetter climatic conditions was constrained to mapped paleodischarge deposits (fig. 9). Drains also were assigned to model cells where present-day wetlands. Ground water was discharged to these drains only where simulated past water levels rose above the land surface. Paleodischarge areas were simulated in Sarcobatus Flat. Oasis Valley, and several areas in the Amargosa Valley including Peter's Playa, Ash Meadows, and Alkali Flat. Additional ground-water discharge areas were located near Stonewall Mountain, Indian Springs Valley, Stewart Valley, and Pahrump Valley (fig. 9).

Drains also were simulated along major tributary surface-water drainages including the Amargosa River and Fortymile Wash (fig. 9). The drains along these surface-water features were used to simulate gaining-stream conditions.

The conductance (McDonald and Harbaugh, 1988) assigned to these drains was estimated to be similar to those used in the present-day ground-water flow model. Drains used to simulate Grapevine Springs and Oasis Valley were assigned a conductance of 10 m^2/day, which is approximately the conductance used for these features in the present-day model. The conductance of all other drains was set to 100 m^2/day, which was the value used in the present-day model for large volume springs at Ash Meadows and in Death Valley at Furnace Creek Ranch.

Future-Climate (global-warming) Simulations

Future-climate simulations required the following changes to the present-day ground-water flow model: (1) modification of boundary conditions; (2) modification of recharge distribution; and (3) conversion of evapotranspiration areas into wetlands. Because few data were available to describe the hydrology of the model area under future conditions, the simulation required numerous simplifying assumptions.

Boundary Conditions

The boundary conditions for future-climate simulations were modified from those used in the present-day model (D'Agnese and others, in press). The location of constant-head boundaries along the northern and northeastern edge of the model domain were the same as those used in the present-day model except that constant-head cells were assigned to all three layers. Assigning constant heads to all three layers allowed the potentially larger underflow of ground water that may occur in the future into the model domain. Constant heads assigned to these model cells were designated to represent future water table elevations in the northern and northeastern model boundaries in Ralston Valley, Stone Cabin Valley, Reveille Valley, and the Pahranagat Lakes area (fig. 10). For the future-climate simulation the constant-head cell elevations were set equal to land surface.

FIGURE 10.--NEAR HERE
Figure 10. Distribution of constant head cells and potential discharge areas represented as drains in the future-climate ground-water flow model simulation.

The location, extent, and elevation of lakes and wetlands under the simulated future climate conditions was unknown. Therefore, constant-head cells were not used to represent those surface-water features; instead, head-dependent nodes were used to simulate possible lakes and wetlands.

Recharge

The simulated future-climate conditions are wetter in most parts of the model domain than the present conditions (fig. 7). The increase in average annual precipitation rates results in higher than present-day infiltration rates and, likewise, is simulated as an increase in recharge to the ground-water flow system.

Regional ground-water recharge rates developed for the future-climate simulation (A.L. Flint and J.A. Hevesi, U.S. Geological Survey, written commun., 1996) were resampled to a 1,500 m model grid (fig. 4). As in the past-climate scenario, recharge rates in several areas of the model domain exceeded the model hydraulic conductivity of layer 1. As was done for past-climate simulations, drains

(McDonald and Harbaugh, 1988) were added to mountain-top areas of the model that were coincident with areas where recharge exceeded hydraulic conductivity.

Conversion of Evapotranspiration Areas to Wetlands (Drains)

Potential lakes and wetlands were simulated as head dependant boundaries, or drains, in the future-climate simulations. The extent of lakes and marshes under wetter climatic conditions was constrained by maps describing paleoshorelines and isolated paleodischarge deposits. Regional ground water will likely discharge in these areas as it had done in the past. Drains were assigned to model cells where present-day wetlands exist and where evidence for paleolakes and marshes exist (fig. 10). Ground water will discharge from these drains only where simulated future water levels rise above the land surface.

For past-climate simulations, the Death Valley saltpan was simulated as constant-heads cells set to a paleolake level for Lake Manley. In the future-climate simulation, however, these cells were assigned as drains. While ground-water is expected to discharge from the saltpan in the future its is unknown whether a lake would form. Therefore, drains were used to simulate the ground-surface elevation where discharge would occur.

As in past-climate simulations, drains were located along tributary surface-water drainages that are predicted to flow under wetter than present-day climate conditions. These surface-water tributaries include the Amargosa River and Fortymile Wash (fig. 10). Likewise, drains were added to mountain-top areas coincident with high recharge and low hydraulic conductivity units to account for rejected recharge (fig. 10).

Well discharge was simulated to remain at the present-day levels used in the regional ground-water steady-state model (D'Agnese and others, in press). Therefore, no changes were made to well parameters for future-climate simulations.

RESULTS OF SIMULATIONS

The past- and future-climate simulations produced results that generally were similar to those produced by the present-day Death Valley flow-system model (D'Agnese and others, in press). The following sections emphasize where the models differed.

Past-Climate (full-glacial) Simulations

The past-climate simulation contained much more recharge than the present-day simulation. In order to allow the past-climate simulation to produce reasonable results, the conductance of discharge-area drains was adjusted. The past-climate model simulated a potentiometric surface that was generally similar, but higher than that simulated with the present-day model. The past-climate model simulated numerous wetlands and lakes and had substantially more water flowing through it than the present-day model.

Evaluation of Drain Conductance

The model simulations indicated that water levels in the low-lying areas were highly sensitive to drain conductance. High-conductance drains allowed water that rose to the drain altitude to be discharged without restriction. As a result, water levels did not rise above land surface in the areas surrounding the drains. Low-conductance drains restricted the flow of water out of the discharge area. If the flow of water toward the drains was greater than the rate at which it can be discharged with the given conductance, water levels rose. Over-estimating the drain conductance resulted in artificially suppressed water levels in the low-lying areas of the Amargosa Valley and southern Amargosa River drainage.

Drain conductance for the Grapevine Springs and Oasis Valley areas was set to 10 m^2/day, which is the approximate value used in the present-day model (11 and 1.7 m^2/day respectively). Conductance of all other drains located in the model domain were set to 100 m^2/day for the past-climate simulation, which is the value used for the Ash Meadows springs in the present-day model.

During calibration, various conductance values were simulated. When the conductance of all drains was set to 10 m^2/day, higher water levels occurred throughout the model domain. Drain conductance equal to 10 m^2/day resulted in water levels rising up to 200 m more in the low-lying areas and 100 to 200 m in the higher areas when compared to simulations with drain conductance equal to 100 m^2/day. With drain conductance equal to 10 m^2/day, water levels at Yucca Mountain increased about 200 m relative to the present-day model. This water level rise also resulted in unacceptably large discharge rates at many of the specified paleodischarge sites. Therefore, conductance values of 10 m^2/day at Grapevine Springs and Oasis Valley and 100 m^2/day elsewhere resulted in the most reasonable potentiometric-surface configuration.

Higher water levels near the discharge areas resulted in a decreased hydraulic gradient away from the higher recharge areas, which caused water levels up gradient from the discharge areas to also rise. Water levels in the Timber Mountain area, for example, were 100 to 200 m higher in the 10 m^2/day conductance scenario than in the 100 m^2/day conductance scenario. Conversely, if drain conductance was set unreasonably high (10,000 m^2/day), water levels in the low-lying areas were below the water levels simulated under present-day conditions. The simulated conductance of 10 m^2/day for the Grapevine Spring and Oasis Valley drains and 100 m^2/day for the other drains is considered reasonable based on the alternative scenarios that were simulated. This combination of drain conductance values provided flux out of the model at expected paleodischarge sites and most nearly approximates the configurations used in the present-day flow model.

Discharge Areas

Discharge from the flow system under simulated past-climate conditions occurred as flow to constant-head cells or drains. Under past-climate conditions, ground water was simulated as flowing out of the model domain toward the Pahranagat Lakes area on the northeastern model boundary (fig. 11). Under present-day conditions, ground water was simulated as flowing into the model domain through these constant head cells. High rates of paleorecharge in the Pahranagat, Sheep, and Desert Ranges (fig. 3) formed a simulated ground-water divide along the southern Pahranagat Range. Therefore, recharge near the northeastern model boundary flowed toward the east and out of the model domain. Likewise, recharge on the west side of the ground-water divide was simulated as flowing toward the Frenchman Flat area.

FIGURE 11.--NEAR HERE

Figure 11. Distribution of drains and constant heads cells simulated as discharging during past-climate simulation.

The lakes in the north-central part of the model domain are predominately discharging water under the simulated past-climate conditions (fig. 11). As a result of the increased recharge, water levels rose in the northern part of the model resulting in discharge to the simulated lake areas. The lake in Emigrant Valley has cells with water entering the flow system as well as cells with water exiting the flow system. On the up-gradient side of the lake, ground water entered the lake and maintained this feature. A smaller volume of water moved out of the down-gradient side of the Emigrant Valley lake, indicating that a surface-water component may enter the ground-water system at this point.

The largest surface-water feature in the model domain is Lake Manley (fig. 2). All constant head cells representing Lake Manley were simulated as discharging water to the lake under the past-climate conditions (fig. 11). As in the present-day system, Death Valley (Lake Manley) is the major discharge point in the regional ground-water flow system with large volumes of water flowing toward this area.

Most of the drains in low-lying areas had water discharging from the model because simulated water levels rose above land surface (fig. 11). Discharging drains were simulated in the Sarcobatus Flat and Oasis Valley areas, and south through the Amargosa Valley. Peter's Playa, Ash Meadows, and Alkali Flat were simulated as major discharge areas under the past-climate conditions. The simulation indicated that surface-water drainages along the Amargosa River and southern part of Fortymile Wash were gaining streams. The simulated drains in Stewart Valley, Pahrump Valley, and Corn Creek Springs were discharging ground water that had entered the flow system in the Spring Mountains as recharge.

A few areas with simulated drains were predicted to not have discharge under the simulated past-climate conditions (fig. 11). Drains in the Indian Springs Valley discharged only in the area closest to the Spring Mountains near present-day Indian and Cactus Springs (fig. 11). Drains in the Three Lakes Valley also did not discharge water under the simulated past-climate conditions.

Potential discharge areas closest to Yucca Mountain are located in Fortymile Wash and the southern end of Crater Flat (fig. 11). The drains located in the northern portion of Fortymile Wash, to the east of Yucca Mountain, did not discharge water under the past-climate simulations. Although ground water was not simulated as discharging in the northern part of Fortymile Wash, the potentiometric-surface contours indicate that ground water is flowing toward the Fortymile Wash area. Water was discharging from drains in the southern portion of Fortymile Wash, in the Amargosa Valley area. Drains at the southern end of Crater Flat also were not simulated as discharging. The potentiometric surface, however, does appear to have been close to the land surface in this area. The proximity of the potentiometric surface to the land surface in southern Crater Flat could support a phreatophyte community.

In general, the past-climate simulation appears to replicate the predicted paleodischarge areas reasonable well. Based only on discharge areas, the simulation, therefore, is considered to be a valid representation of interpreted paleoclimatic and paleohydrologic conditions at approximately 21 ka.

Mountain-top Drains

Most mountain-top drains, used in areas of high simulated recharge and low hydraulic-conductivity hydrogeologic units, discharged water from the model under past-climate conditions (fig. 11). Water levels were generally simulated as being at land surface in the Amargosa Range, Stonewall

Mountain, and Gold Mountain. Rainier Mesa also had a majority of the drains simulated as discharging water. The high recharge rates that resulted in discharge through the drains could indicate locally perched water, rejected recharge becoming surface-water runoff, locally discharging springs, or increased evapotranspiration from upland wetlands.

Mountain-top drains in the Shoshone Mountain area, to the north and east of Yucca Mountain, were not simulated as discharging water under the past-climate scenario (fig. 11). Water levels in these areas did not rise substantially as a result of the increased recharge rates. In general, the Spring Mountains were simulated as having from 25 to over 250 mm/yr more recharge under past-climate conditions than under the present-climate conditions (fig. 6). These high recharge rates, however, only resulted in simulated water levels rising above land surface and discharging through drains only in a few locations in the Spring Mountains area (fig. 11). The scarcity of discharging mountain-top drains was most likely a result of the very high hydraulic conductivity units occurring in this area.

Potentiometric-surface Configuration

The potentiometric surface simulated using the wetter, past-climate conditions was compared to the potentiometric surface simulated using present-day climate conditions (fig. 12). The potentiometric-surface configuration simulated assuming the past-climate conditions was generally similar to the present-day simulated surface, but differences do exist (fig. 13).

FIGURE 12.--NEAR HERE

Figure 12. Simulated present-day climate potentiometric surface for model layer 1.

FIGURE 13.--NEAR HERE

Figure 13. Simulated past-climate potentiometric surface for model layer 1 and the difference between the past and present-day model layer 1 potentiometric surface.

Regional Potentiometric Surface

Water levels generally rose over the entire model domain as a result of the increased recharge rates. Higher altitude areas generally received the largest increase in recharge, and hence, water levels rose most dramatically in model layer 1 in these areas (fig. 13). Large-hydraulic gradients that exist in the present-day model became more pronounced, but remained in the same location under the past-climate conditions.

Water levels across the northern part of the model generally rose at least 100 m (fig. 13) as a result of up to 100 mm/yr more recharge in these areas (fig. 6). In the north central part of the model domain, increased recharge resulted in a more pronounced potentiometric-surface mound near Rainier Mesa (fig. 13). The large-hydraulic gradient between Rainier Mesa and Yucca Flat was even more pronounced than under present-day conditions because of the increase in water levels on Rainier Mesa.

The north-south trending Amargosa Range received up to 75 mm/yr more recharge in the simulated past-climate conditions than in the present-day model (fig. 6). The higher recharge rates coupled with generally low hydraulic-conductivity units resulted in water levels rising over 100 m (fig. 13) and reaching the land surface in some areas. Some of the infiltrating water was discharged through mountain-top drains in these areas (fig. 11). Most of the recharge appears to have flowed toward the Amargosa Valley and Lake Manley, where it was removed from the flow system.

The increase in recharge, and resulting rise in water levels, was most dramatic in the Spring Mountains where recharge rates in the past-climate simulations were over 250 mm/yr higher in some areas than in the present-day model (fig. 6). Water levels rose from 100 to over 1,000 m in the Spring Mountains, resulting in a much larger hydraulic gradient in this area (fig. 13). Some of the water from the Spring Mountains flowed toward Las Vegas Valley where it is discharged at wetlands near present-day Corn Creek Springs (fig. 11). The spring and marsh areas simulated as drains in the Pahrump Valley also were discharging water flowing from the Spring Mountains.

The simulated potentiometric surface indicates that ground-water flow is focused toward the simulated lowland discharge areas (fig. 13). From Oasis Valley to the southern part of the Amargosa River drainage, ground water is flowing toward drains creating a 'V-shaped' potentiometric surface along the Amargosa River.

In the Sarcobatus Flat area water levels rose up to 100 m, whereas water levels in the surrounding upland areas rose over 100 m (fig. 13). A pronounced ground-water basin formed in the Sarcobatus Flat area and a well-defined ground-water divide formed between Sarcobatus Flat and Oasis Valley to the southeast. Water that flowed into the Sarcobatus Flat area continued to flow toward the western model boundary where some water discharged at Grapevine Springs and some water continued south to discharge a Lake Manley (fig. 13).

Moderate water-level increases, up to 100 m, were simulated in the low-lying areas of the model under the past-climate conditions. The relatively small-gradient area in the central part of the model domain did not change substantially under the simulated wetter climate conditions (fig. 13). The water-level increases in this area were most likely limited because of the relatively high hydraulic conductivity of this region and the increased discharge to Ash Meadows. If the discharge areas had not been as efficient at removing water from the flow system, water levels in the low-lying areas would probably increase.

The potentiometric surface simulated for model layer 3 in the past-climate simulation is illustrated in figure 14. The simulated potentiometric surface in layer 3 was generally higher than simulated present-day levels (fig. 15) throughout the model domain. The generally higher recharge rates in the past-climate simulations affect the lower part of the regional flow system. The potentiometric surface increased up to 100 m in the low-lying areas and up to 250 m in most of the higher altitude areas. In the high-recharge areas, including the Spring Mountains, Timpahute Range, Sheep Range, and Timber Mountain area, simulated potentiometric-surface increases were over 500 m. The potentiometric-surface for model layer 3 is important because it describes deep regional ground-water flow.

FIGURE 14.--NEAR HERE

Figure 14. Simulated past-climate potentiometric surface for model layer 3 and the difference between the past and present-day model layer 3 potentiometric surface.

FIGURE 15.--NEAR HERE

Figure 15. Simulated present-day potentiometric surface for model layer 3.

Yucca Mountain Potentiometric Surface

Changes in the potentiometric surface in the vicinity of Yucca Mountain are of particular interest due to the potential impact water-level changes could have on the potential repository. Simulated water levels near Yucca Mountain were generally between 60 and 150 m higher than present-day levels (fig. 13). These simulated increases in water levels beneath Yucca Mountain are comparable with estimates developed by Czarnecki (1985, p.21) that indicated a maximum rise of about 130 m with an assumed 100 percent increase in precipitation. These water levels were still below the potential repository, which is situated between 200 and 400 m above the present-day water table.

The most dramatic water level increases in the Yucca Mountain area occurred to the north and northeast in the Timber and Shoshone Mountain areas. Water levels rose in the Timber Mountain area (fig. 13) because recharge was generally 25 to 50 mm/yr higher than under present-day conditions (fig. 6). Water level increases in these areas were 500 m or less.

The highest water levels in the present-day potentiometric surface occur in the Belted Range. Past-climate simulations indicate that this high water-level area would expand to the west, toward Timber Mountain. These higher water levels to the north of Yucca Mountain increase the areal extent of the present-day large hydraulic gradient. The increased water levels in the past-climate simulations caused the large-hydraulic gradient to the north of Yucca Mountain to become more pronounced. However, the large-hydraulic gradient at Yucca Mountain appears to be stationary and it does not migrate south toward the potential repository block.

Water-level rises to the east, west, and south of Yucca Mountain including Fortymile Wash, Frenchman Flat, Crater Flat, and Amargosa Valley, were generally less than 150 m. The shape of the potentiometric surface in these areas did not change substantially from the present-day conditions (figs. 12, 13).

Near Yucca Mountain, the potentiometric surface in layer 3 was approximately 100 m higher than in the present-day simulation. An increase in water levels in model layer 3 suggests that the dominantly upward gradient under the potential repository would be maintained under wetter climatic conditions. The past-climate potentiometric surface in layer 3 has the same general configuration throughout the model domain as the present-day surface (figs. 14, 15). Layer 3 water levels in areas with high recharge, such as Timber and Shoshone Mountains however, have the most dramatic increases (fig. 14).

The potentiometric surface down gradient from Yucca Mountain was basically the same in the past-climate and present-day simulations, so flow paths are expected to remain the same. Ground water will predominately flow south toward the discharge areas in the Amargosa Valley. Particle tracking simulations would be necessary to provide more detailed information and to further define the flow paths from Yucca Mountain, but this analysis was beyond the scope of this report.

Water Budget

The water budget provides information about water entering or exiting the model through specified cells (table 1). The past-climate simulation budget indicated that the model was very close to being in balance. The discrepancy between inflows and outflows was -0.08 percent, which indicates an apparent, slightly larger rate of water exiting the system than entering. Numerical errors associated with the convergence of the model solution probably were the source of the small budget discrepancy. Given the small discrepancy, the numerical solution obtained in the simulation was adequate.

TABLE 1. NEAR HERE.

Recharge accounted for nearly 97 percent of the water entering the model. The total recharge under the simulated past-climate conditions is 5.4 times higher than the recharge simulated in the present-day model (table 1). Underflow entered the model via constant-head cells on the northern boundary and as recharge. Most of the water that entered the model via constant-head cells entered through Ralston Valley and Kawich Valley (table 1).

Water exited the model via drains in recharge (mountain-top drains) and discharge (lowland drains) areas and via constant-head cells at simulated lakes. Most of the water, 72 percent of the total flux out, exited the flow system through discharge area drains most of which are located in the Amargosa Valley. The simulated lakes in Cactus Flat, Kawich Valley, and Emigrant Valley discharged 57 percent of the water leaving the model through constant-head cells. Lake Manley and the Pahranagat Lakes area account for 24 percent and 19 percent of water, respectively, that exited the model through constant head cells

Mountain-top drains discharged approximately 7 percent of the total flow that attempted to enter the system. Most of the simulated recharge was able to enter the flow system and was not converted directly to surface-water flow. The 7 percent recharge that was removed from the flow system via mountain-top drains should be considered rejected recharge because it did not have an opportunity to enter the flow system. Instead this water was probably discharge close to the recharge area as cold temperature springs, surface water runoff, or evapotranspiration. In table 1, rejected recharge was subtracted from total recharge to obtain net recharge; only net recharge actually entered the regional flow system.

Table 1. Net flux into and out of the model used to simulate past-climate conditions.

			PAST-CLIMATE SIMULATIONS Net flux, m³/day	PRESENT-CLIMATE SIMULATIONS Net flux, m³/day
FLUX IN:				
	CONSTANT HEADS:	Ralston Valley underflow	34,000	
		Stone Cabin Valley underflow	6,000	
		Kawich Valley underflow	26,000	
		NET CONSTANT HEADS	**66,000**	**69,000[1]**
	RECHARGE:	Total Recharge	1,951,000	
		Rejected Recharge	-136,000	
		NET RECHARGE	**1,815,000**	**338,000**
	TOTAL FLUX IN:		**1,881,000**	**407,000**
FLUX OUT:				
	CONSTANT HEADS:	Death Valley	103,000	98,000
		Pahranagat Lakes Underflow	79,000	0
		Other lakes	243,000	0
		NET CONSTANT HEADS	**425,000**	**98,000**
	WELLS		**0**	**88,000**
	DRAINS	Wetland discharge areas	**1,458,000**	**225,000[2]**
	TOTAL FLUX OUT:		**1,883,000**	**411,000**
FLUX IN - FLUX OUT:			**-2,000**	**-4,000**
	PERCENT DISCREPANCY[3]		**-0.11**	**-0.9**

[1]Constant-heads flux includes ground water entering through Pahranagat Lakes area.

[2]In present-day simulation discharge simulated using evapotranspiration and drain packages.

[3]Percent discrepancy reflects primarily numerical errors associated with convergence of the model solution.

Future-Climate (global-warming) Simulations

The future-climate simulation contained slightly more recharge overall than the present-day simulation. The simulated potentiometric surface under these conditions was generally similar, but higher than that simulated with the present-day model (fig. 12). Because the overall recharge was less than that simulated for the past-climate simulation, fewer drain cells were discharging water at both mountain-top areas and lowland areas.

Discharge Areas

Under simulated future-climate conditions ground-water flows into the model domain from the Pahranagat Lakes area located on the northeastern model boundary (fig. 16). Because of the decreased gradient in this part of the model domain resulting from increased recharge, the influx through these constant head cells is less than the influx simulated in the present-day steady-state model.

FIGURE 16.--NEAR HERE
Figure 16. Distribution of constant head cells and drains simulated as discharging during future-climate simulation.

Approximately half of the drains in the Cactus Flat, Kawich Valley, and Emigrant Valley areas discharged water under the future-climate conditions (fig. 16). The major lowland discharge areas in the future-climate simulations were Sarcobatus Flat, Oasis Valley, Peter's Playa, and Ash Meadows (fig. 16). The number of discharging drains in the Amargosa River drainage progressively increased to the south. Most of the drains in the Death Valley area discharged water.

The future-climate simulation did not increase water levels to land surface in several of the areas simulated as drains (fig. 16). For example, the majority of drains in Las Vegas Valley, Indian Springs Valley, Pahrump Valley, and Stewart Valley did not discharge water.

Mountain-top Drains

Mountain-top drains on Gold Mountain, the Amargosa Range, and Rainier Mesa discharged water under the simulated future-climate conditions (fig. 16). The Spring Mountains did not have any discharging drains, indicating that the recharge in this area was not high enough to cause water levels to rise above the land surface. Likewise, mountain-top drains in the Shoshone Mountains did not discharge water under the simulated future-climate conditions (fig. 16).

Potentiometric-Surface Configuration

Water-level increases greater than 100 m in layer 1 were common in the northern and northeastern areas of the model domain under the future-climate conditions (fig. 17). Recharge rates up to 75 mm/yr higher in the northeast portion of the model domain (fig. 7) resulted in water-level increases of up to 400 m. Areas of high recharge in the Spring Mountains and Amargosa Range had water-level increases greater than 100 m. The future-climate simulation resulted in a smaller area of the model domain with water-level increases greater than 100 m compared to the past-climate simulations.

FIGURE 17.--NEAR HERE
Figure 17. Simulated future-climate potentiometric surface for model layer 1 and the difference between the future and present-day model layer 1 potentiometric surface.

Regional Potentiometric Surface

The potentiometric surface rose less than 100 m in most areas of the model domain under the simulated future-climate conditions (fig. 17). Sarcobatus Flat had virtually no change in water levels compared to the present-day conditions. The potentiometric surface to the north and east of Sarcobatus Flat rose less than 100 m. Oasis Valley, PahrumpValley, and the low-lying areas near the Spotted Range had water-level increases that were generally less than 100 m.

Parts of the Amargosa Valley, Amargosa River drainage, and Death Valley had simulated water levels that were equal to or lower than present-day conditions (fig. 17). There are several possible reasons for the relatively minor increases and declines in the potentiometric surface throughout parts of the model domain under the simulated future-climate conditions. The source of water to these areas was less in the future-climate simulations than in the present-day model simulations. Simulated water-level declines in Death Valley and the southern portions of the Amargosa River were probably attributable to ground-water discharge through up-gradient drains and reduced recharge in these areas. The areas of only moderate water-level changes were generally coincident with areas of reduced recharge. While the simulated climatic conditions were generally wetter in the future, there were areas where recharge was less than simulated in the present-day model (fig. 7). Water levels did not rise significantly in the areas around drains unless the flux of water toward the drains exceeded the capacity of the drain. The combination of less recharge and adequate drain capacity resulted in moderate increases or decreases in the potentiometric surface. Under natural conditions it is unlikely that all of the lowland drain areas would discharge water.

There were no major differences between the shape of the simulated present-day and future-climate potentiometric surfaces, so flow directions were also similar. The potentiometric surface of model layer 1 simulated in the future-climate scenario is presented as figure 17. Minor differences in the potentiometric surfaces result from differences in the distribution of recharge.

The potentiometric surface in model layer 3 had generally moderate increases in the future-climate simulations relative to the present-day potentiometric surface (figs. 18, 15). The northern part of the model domain generally had water-level increases up to 150 m, except in the Timpahute Range area where increases were over 250 m. The largest water-level increases in layer 3 are generally coincident with areas of highest simulated recharge. Lower elevation areas within the model domain generally had water-level increases of 50 m or less.

FIGURE 18.--NEAR HERE

Figure 18. Simulated future-climate potentiometric surface for model layer 3 and the difference between the future and present-day model layer 3 potentiometric surface.

Yucca Mountain Potentiometric Surface

Water levels simulated at Yucca Mountain rose less than 50 m in the future-climate scenario (fig. 17). These water levels were still well below the potential repository which is situated between 200 and 400 m above the present-day water table. The Crater Flat and Fortymile Wash areas also had water-level increases of 50 m or less, which was common for the lower elevation portions of the model domain. The largest water-level increases in the Yucca Mountain area were to the north and northeast in the Timber and Shoshone Mountain areas. Water levels in these areas generally rose 100 m or less. Simulated water levels on Rainier Mesa were over 100 m higher than present-day conditions, which resulted in a more pronounced hydraulic gradient toward Yucca Flat.

The potentiometric surface configuration of layer 1 near Yucca Mountain in the future-climate scenario was very similar to the present-day simulations (fig. 12). The large-hydraulic gradient to the north of Yucca Mountain retained the shape and location simulated in the present-day and water levels rose less than 100 m. The large-hydraulic gradient does not migrate south toward the potential repository block in the future-climate simulation.

The potentiometric surface in layer 3 near Yucca Mountain had water-level increases of about 40 m relative to the present-day potentiometric surface (figs. 15, 18). Layer 3 water-level increases were less than 50 m in the Crater Flat, Fortymile Wash, and Amargosa Valley areas surrounding Yucca Mountain (fig. 18). The present-day upward gradient in layer 3 is maintained and enhanced in the future-climate simulation.

Flow paths from Yucca Mountain in the future-climate scenario are expected to remain the same as present-day conditions because the configuration of the potentiometric surface is largely unchanged (figs. 12, 17). Ground water will predominately flow south toward the discharge areas in the Amargosa

Valley. Particle tracking simulations would be necessary to provide more detailed information and to define flow paths further from Yucca Mountain, but this analysis was beyond the scope of this report.

Water Budget

The future-climate simulations budget indicated that the model was very close to being in balance (table 2). The discrepancy between inflows and outflows is -1.5 percent, which indicates an apparent, slightly larger rate of water exiting the system than entering. Given the small discrepancy, the numerical solution obtained in the simulation was adequate.

Most of the water, 74 percent of net inflow, entered the model as recharge. The total recharge under the simulated future-climate conditions was 1.5 times higher than the recharge simulated in the present-day model. Flow through constant-head cells in Ralston Valley, Stone Cabin Valley, Kawich Valley, and Pahranagat Lakes accounted for 26 percent of the inflow.

Water exited the model as drain and well discharge (table 2). The lowland discharge areas simulated as drains discharged 87 percent of the water leaving the model. Less than 1 percent of the flux that exited the model was through the mountain-top drains. Since 1.2 percent of the recharge was discharged through the mountain-top drains, the majority of the simulated total recharge entered the flow system as net recharge. Well discharge accounted for the remaining 12 percent of flux out of the model.

Table 2. Net flux into and out of the model used to simulate future-climate conditions.

			FUTURE-CLIMATE SIMULATIONS Net flux, m^3/day	PRESENT-CLIMATE SIMULATIONS Net flux, m^3/day
FLUX IN:				
	CONSTANT HEADS:	Ralston Valley underflow	23,000	
		Stone Cabin Valley underflow	38,000	
		Kawich Valley underflow	25,000	
		Pahranagat Lakes	98,000	0
		Underflow		
		NET CONSTANT HEADS	**184,000**	**69,000[1]**
	RECHARGE:	Total Recharge	524,00	
		Rejected Recharge	-6,000	
		NET RECHARGE	**518,000**	**338,000**
	TOTAL FLUX IN:		**702,000**	**407,000**
FLUX OUT:				
	WELLS		**88,000**	**88,000**
	DRAINS	lowland discharge areas	**625,000**	**225,000[2]**
	TOTAL FLUX OUT:		**713,000**	**411,000**
FLUX IN - FLUX OUT:				**-4,000**
	PERCENT DISCREPANCY[3]		**-1.5**	**-0.9**

[1]Constant-heads flux includes ground water entering through Pahranagat Lakes area.

[2]In present-day simulation discharge simulated using evapotranspiration and drain packages.

[3]Percent discrepancy reflects primarily numerical errors associated with convergence of the model solution.

LIMITATIONS OF CLIMATE-EFFECTS SIMULATIONS

Numerical modeling has substantial limitations when used to evaluate the effects of climate change on the regional ground-water flow system of the Death Valley region. To emphasize the conceptual nature of these climate change evaluations, the limitations of this study are enumerated below.

1) The predictive simulations can be no more accurate as the original present-day, steady state regional ground-water flow model. The limitations in the accuracy of that model were described in detail in D'Agnese and others (1997).

2). The past-climate simulation was evaluated for "reasonableness" by comparing it to the known distributions of paleodischarge areas. Paleohydrologic evidence is critical to the validity of the simulations and this evidence of past-discharge areas is incomplete. Many paleodischarge sites may not have been preserved and numerous locations of discharge may not have been included as potential areas of ground-water flux out of the model. Additionally, some of the paleodischarge areas described as potential regional ground-water discharge points may be points of local, rather than regional, ground-water discharge. Also, discharge rates from these paleodischarge sites was unknown and thus cannot be used as a reasonableness check.

3) The average annual precipitation distributions for past- and future-climate conditions are output from global-scale climate models used by Thompson and others (1996a, 1996b). These precipitation distributions were calculated from a 50 km grid model. Resampling this data to the 1.5 km grid required for the regional ground-water flow model reduces the accuracy of the data because the assumptions of climate-scale models are not valid at 1.5 km spacing.

4) The recharge estimates for past- and future-climate conditions were developed from the average annual precipitation maps that had been resampled to a 1.5 km grid. The recharge distributions, which were the input for climate-change simulations, were developed using a modification of the

Maxey-Eakin method (Maxey and Eakin, 1949). This method is based on using altitude ranges that approximate zones of recharge under present-day moisture conditions. Under different climate scenarios, the mechanisms controlling recharge likely would change because the moisture properties of the landscape would also likely change, and the Maxey-Eakin method may no longer be appropriate.

5) In these simulations, surface-water features, including lakes and rivers, were supported only by ground-water discharge and surface-water runoff was not simulated. Under natural conditions, these features would have at least some surface-water component. Because the rivers were simulated as drains, they could not lose water to the ground-water flow system. The Amargosa River and Fortymile Wash may have both gaining and losing reaches during different climate conditions.

6) Flux out of past or future discharge areas is unknown. Therefore, the validity of a simulation could only be qualitatively judged by evaluating if discharge was occurring in likely locations.

7) Flux out of specified discharge areas was very sensitive to simulated drain conductance. The conductance values for the drains specified in the past and future simulations were approximately similar to those used in the present-day model; however, the appropriate values for conductance in each of these drains was difficult to estimate. Because of model sensitivity to this parameter, the validity of model results was highly uncertain.

8) The boundary conditions for the present-day model were not completely known and boundary conditions are likely to change under different climatic conditions. Exactly how these boundaries will change in responses to climate change is unknown and a limitation to the regional climate-change simulations.

9) The past- and future-climate simulations did not utilize evapotranspiration as a means of removing ground-water from the model. Drains were used to achieve a similar effect. However, drains will remove ground water from the model only when simulated water levels rise above land surface. Evapotranspiration will remove ground water from the model even if simulated water levels do not rise

above land surface. Therefore, the model may be underestimating the amount of water that would be removed from the system in discharge areas.

10) For the future-climate simulation, ground-water pumping was assumed to remain constant from present conditions. Ground-water use likely would increase in the future. The amount of ground-water use expected in the future, however, is not known.

11) Both past- and future-climate simulations assume that the regional ground-water flow system would rapidly reach a steady-state condition following climate changes. Given the size of the ground-water flow system, this assumption may not be valid.

SUMMARY

In cooperation with the U.S. Department of Energy, the U.S. Geological Survey is evaluating the geologic and hydrologic characteristics of the Death Valley regional ground-water flow system as part of the Yucca Mountain Project. Because radionuclides could be transported by ground water from the repository to the accessible environment, ground-water flow system dynamics must be characterized. The evaluation of the Yucca Mountain site includes a detailed characterization of the ground-water flow system. As part of the detailed characterization, a regional three-dimensional numerical ground-water flow model was developed. Using this ground-water flow model, the potential effects of full-glacial and global-warming climates were evaluated.

The study area is located along the border of the southwestern Nevada and southeastern California. The area is immediately west of the city of Las Vegas, Nevada and includes parts of Esmeralda, Nye, Lincoln, and Clark Counties in Nevada, and Inyo and San Bernardino Counties in California.

To assess the effects of climate change, two simulations were made. First, as a reasonableness check on future-climate conditions, a simulation based on past climatic conditions was evaluated by comparing the results of the simulation to observations of paleodischarge sites. Using climatic conditions postulated to have existed 21,000 years ago under full glacial conditions, the ground-water flow system was simulated. Second, a possible future ground-water flow system representing global warming conditions was simulated. Climate changes were simulated with the regional ground-water flow model by changing the distribution of ground-water recharge.

Average annual precipitation maps for both past and future climate scenarios were developed by Thompson and others (National Center for Atmospheric Research, written commun., 1996a, 1996b) and were resampled to the model grid resolution. A polynomial function representing the Maxey-Eakin area-altitude relationship was then used to develop recharge distributions from precipitation that was suitable for simulation.

Results of climate-change simulations were evaluated by observing simulated discharge areas, water-level changes, potentiometric-surface configurations and water budgets. During past-climate conditions, recharge increased in most areas to produce a significantly different regional ground-water flow system. Perhaps the most significant of these changes was the exclusion of underflow into the area Pahranagat Valley. Under wetter conditions, a ground-water divide developed under the southern end of the Pahranagat Range isolating the Death Valley regional ground-water flow system from Pahranagat Valley. Wetter past-climate conditions provided enough ground water in the system to maintain paleolake levels in the northern parts of the model domain and at Lake Manley in Death Valley. Ground-water discharge occurred at most of the observed paleodischarge sites that indicated that the recharge distributions used in the simulation generally was valid. Large hydraulic gradients in the region were preserved and enhanced under simulated past-climate conditions. The water budget for the model indicates that recharge over the region increases by factor of about five, relative to present-day recharge

Under simulated future-climate conditions, both recharge increase and decrease occurred throughout the model domain. The configuration of the potentiometric surface changed only slightly relative to simulated present-day conditions to indicate depressions at discharging playas. These playas. however, were not simulated as discharging as much water as they were during the full-glacial climate, and probably would not support perennial lakes. Discharge under global-warming conditions was simulated as increasing at Ash Meadows, Oasis Valley, and Death Valley. Several playa lakes in the north and northeast part of the model domain were simulated as discharging ground water. Under future-climate conditions, large hydraulic gradients were maintained and enhanced in some areas. The water budget indicates that recharge throughout the model increase by a factor of about 1.5, relative to simulated present-day recharge.

The limitations to evaluating the effects of climate change on a regional ground-water flow system using numerical modeling are substantial. Therefore, the simulated effects of climate change should be considered conceptual in nature and should be used only to describe potential relative impacts to the regional ground-water flow system.

EXECUTIVE SUMMARY

The U.S. Geological Survey, in cooperation with the U.S. Department of Energy, is evaluating the geologic and hydrologic characteristics of the Death Valley regional ground-water flow system. As part of the hydrologic investigation, regional, three-dimensional numerical ground-water flow models have been developed to assess the potential effects of climate change on the regional ground-water flow system. Additional objectives of the study were to estimate changes in ground-water levels and flow paths in the vicinity of Yucca Mountain, and to provide boundary conditions to a site-scale saturated-zone flow model for two alternate climate scenarios. This report discusses the effects of climate change on ground water in the Death Valley region and at Yucca Mountain. Boundary conditions for the site-scale saturated-zone flow model were provided directly to other project participants (Attachment A), and are not included in the report.

To assess the effects of climate change, two simulations based on an existing regional flow model of present-day climate conditions (D'Agnese and others, in press) were made. First, a simulation based on climatic conditions postulated to have existed 21,000 years ago under full glacial conditions was evaluated by comparing simulated past discharge areas to the distribution of known or suspected of paleodischarge sites. This simulation was used as a reasonableness check on simulation results for future-climate conditions. Second, a future ground-water flow system representing potential global-warming conditions was simulated.

Average annual precipitation maps for both past- and future-climate scenarios were developed by Thompson and others (1996a, 1996b) using global and regional climate modeling. These maps were resampled from the 50 km climate-model grid to the 1,500 m ground-water flow model grid resolution. Precipitation maps for other, potentially wetter past climates, were not available to use for use in the regional flow model. Ground-water recharge rates and distributions were estimated, using the Maxey-Eakin area-altitude relationship, from the precipitation maps. For present-day conditions in the Death Valley region, the Maxey-Eakin method underestimates recharge at low elevations and overestimate recharge at high elevations. For climate conditions different from present day conditions in the region, however, the appropriateness of the method in estimating ground-water recharge is not known. Despite this uncertainty, the method was used in order to provide consistency in estimating recharge for the two alternate climate scenarios. Climate-change simulations were evaluated by observing the extent of predicted discharge areas, magnitude of water-level changes, potentiometric-surface configurations, and water budgets.

During past-climate conditions, total recharge increased by a factor of five over the present recharge, producing significant changes in the regional ground-water flow system.

Perhaps the most significant of these changes was the development of a ground-water divide under the southern end of the Pahranagat Range, which isolated Pahranagat Valley from the rest of the Death Valley ground-water flow system. Wetter past-climate conditions provided enough recharge to maintain paleolake levels in the northern parts of the model domain and at Lake Manley in Death Valley. Ground-water discharge occurred at most of the known or suspected paleodischarge sites, which indicates that the recharge distributions used in the simulation generally are valid. Water levels generally rose over the entire model domain as a result of the increased recharge rates. Simulated water levels at Yucca Mountain were 60 to 150 m higher than present-day levels. These simulated increases in water levels beneath Yucca Mountain are comparable to those of Czarnecki (1985, p.21), who estimated a maximum rise of about 130 m resulting from a simulated 100 percent increase in precipitation. The predicted water levels are below the potential repository level, which is 200-400 m above the present-day water table. Ground-water flow paths from Yucca Mountain under these past-climate conditions are generally similar to those of present-day conditions (Attachment A). Large hydraulic gradients in the region and near Yucca Mountain are preserved and enhanced under simulated past-climate conditions.

Under simulated future-climate (global-warming) conditions, recharge both increased and decreased throughout the model domain; however, total recharge increased by a factor of about 1.5, relative to present-day recharge. The configuration of the potentiometric surface changed only slightly relative to simulated present-day conditions, producing depressions at playas. Simulated discharge from these playas was less than simulated discharge for the full-glacial climate, and perennial lakes probably were not supported by ground-water flow. The future-climate simulation resulted in a smaller area of the model domain with water-level increases greater than 100 m compared to the past-climate simulations. The potentiometric surface and ground-water flow paths near Yucca Mountain were very similar to present-day conditions (Attachment A). Simulated water levels rose 15 to 40 m over present levels under future-climate conditions. These water levels are well below the potential repository level. Under simulated future-climate conditions, large hydraulic gradients in the region and near Yucca Mountain are also preserved and enhanced in some areas.

The limitations in evaluation of the effects of climate change on a regional ground-water flow system using numerical modeling are substantial. Therefore, the simulated effects of climate change should be considered conceptual in nature and should be used only to describe potential relative impacts to the regional and Yucca Mountain ground-water flow systems.

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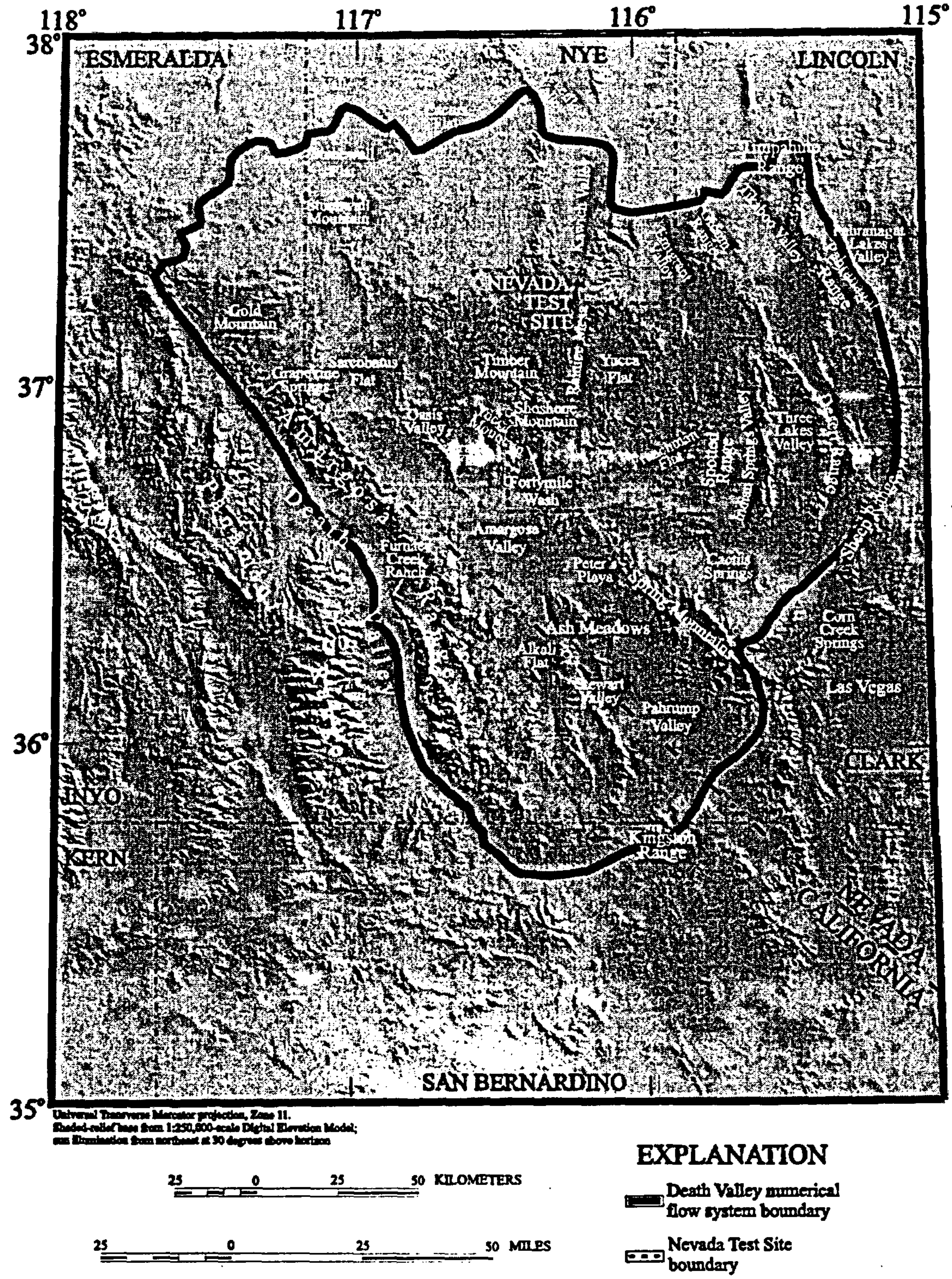

Figure 1. The Death Valley regional ground-water flow system model domain.

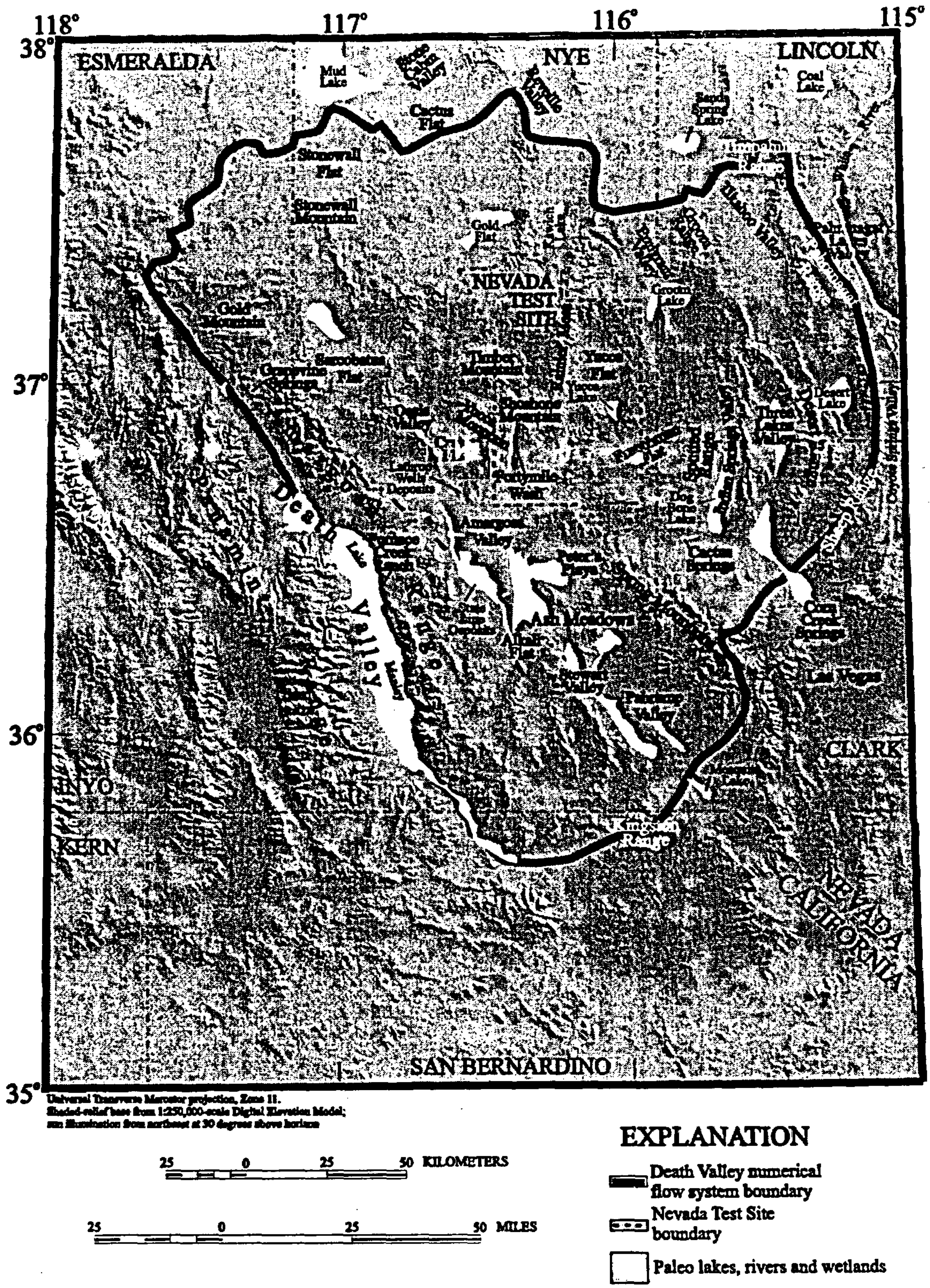

Figure 2. The location of lakes and wetlands occuring approximately 21,000 years ago (R.M. Forester and others, U.S. Geological Survey, written commun., 1997).

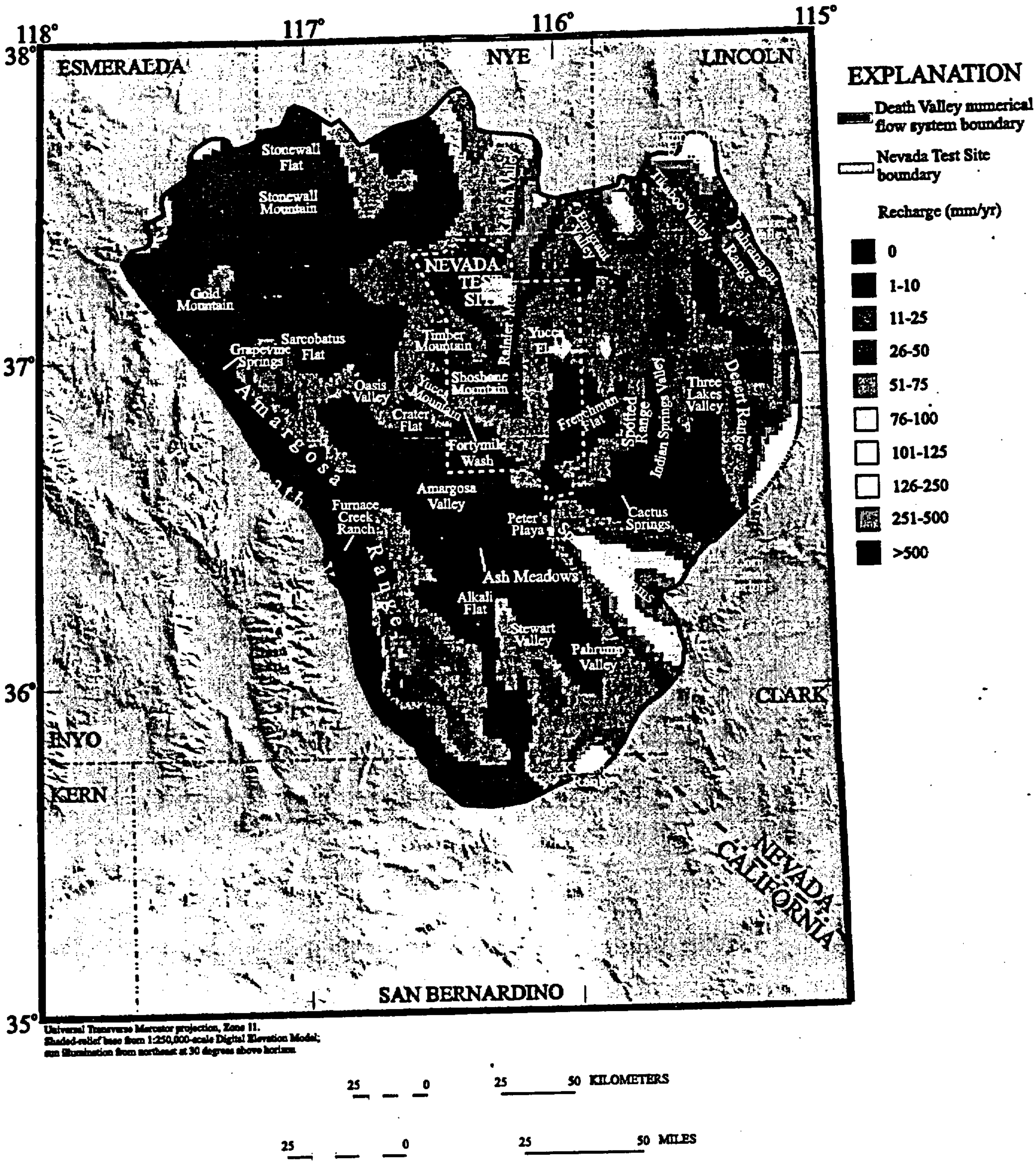

Figure 3. Past-climate recharge distribution.

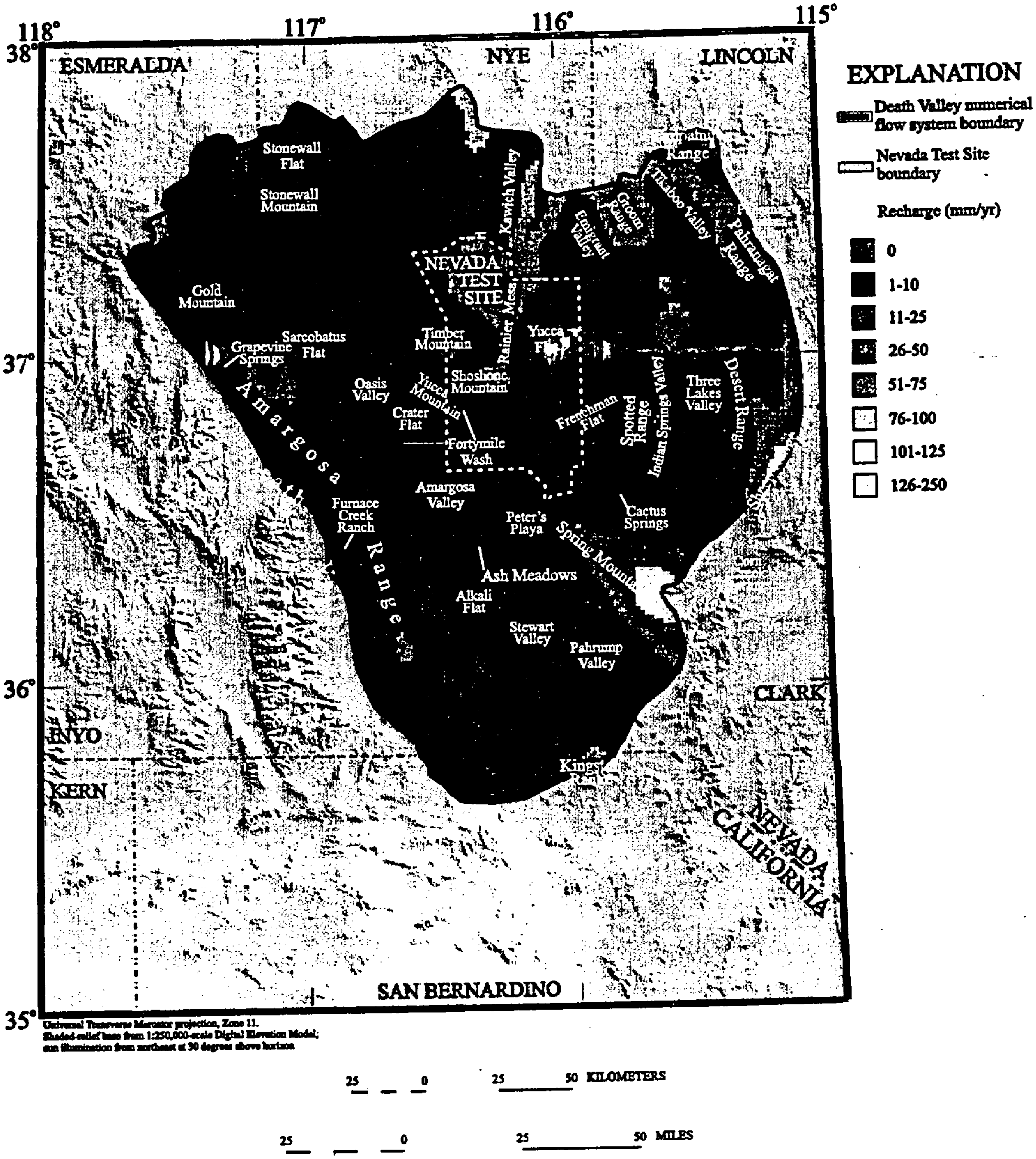

Figure 4. Future-climate recharge distribution.

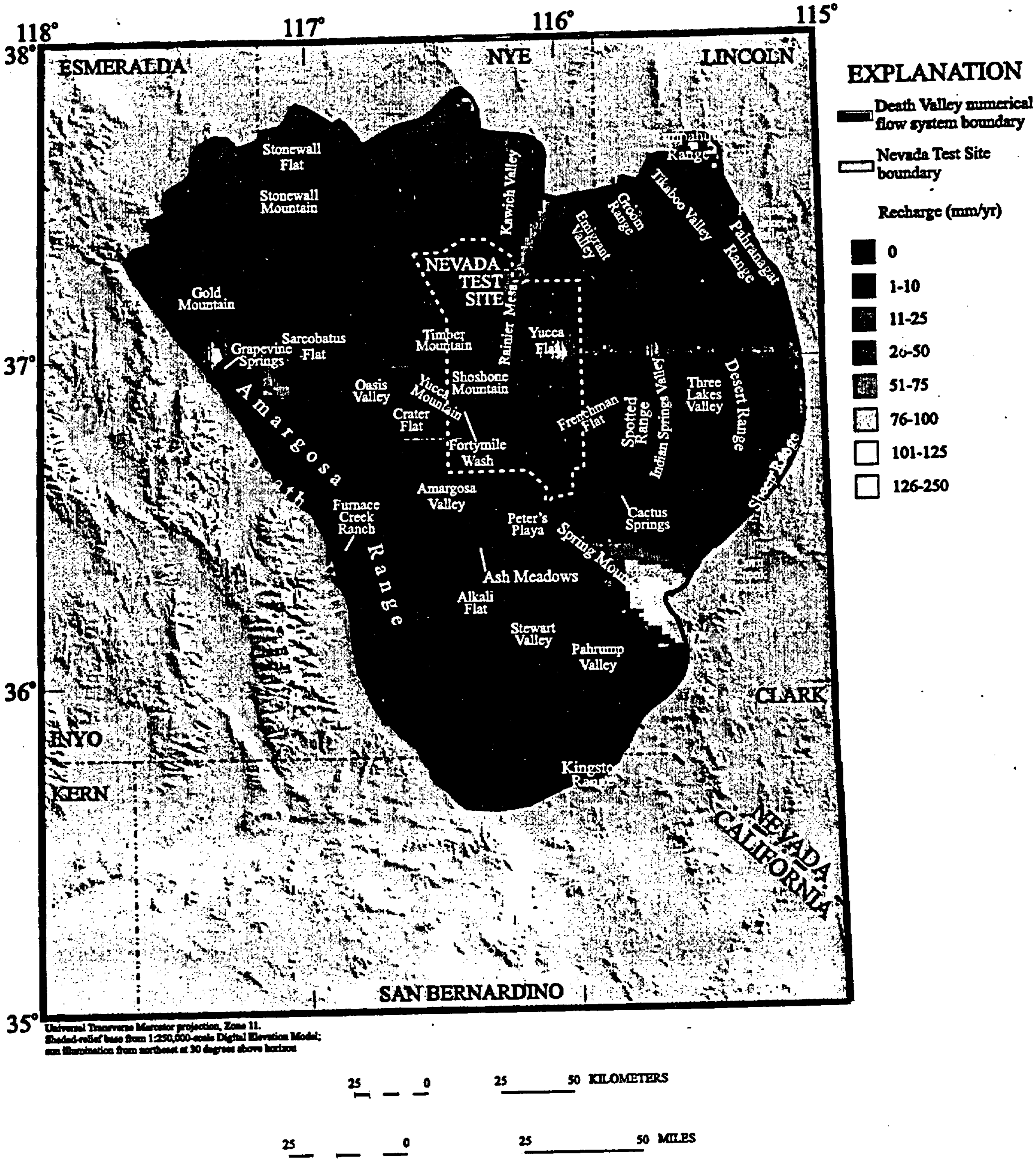

Figure 5. Simulated present-day recharge distribution (D'Agnese and others, in press).

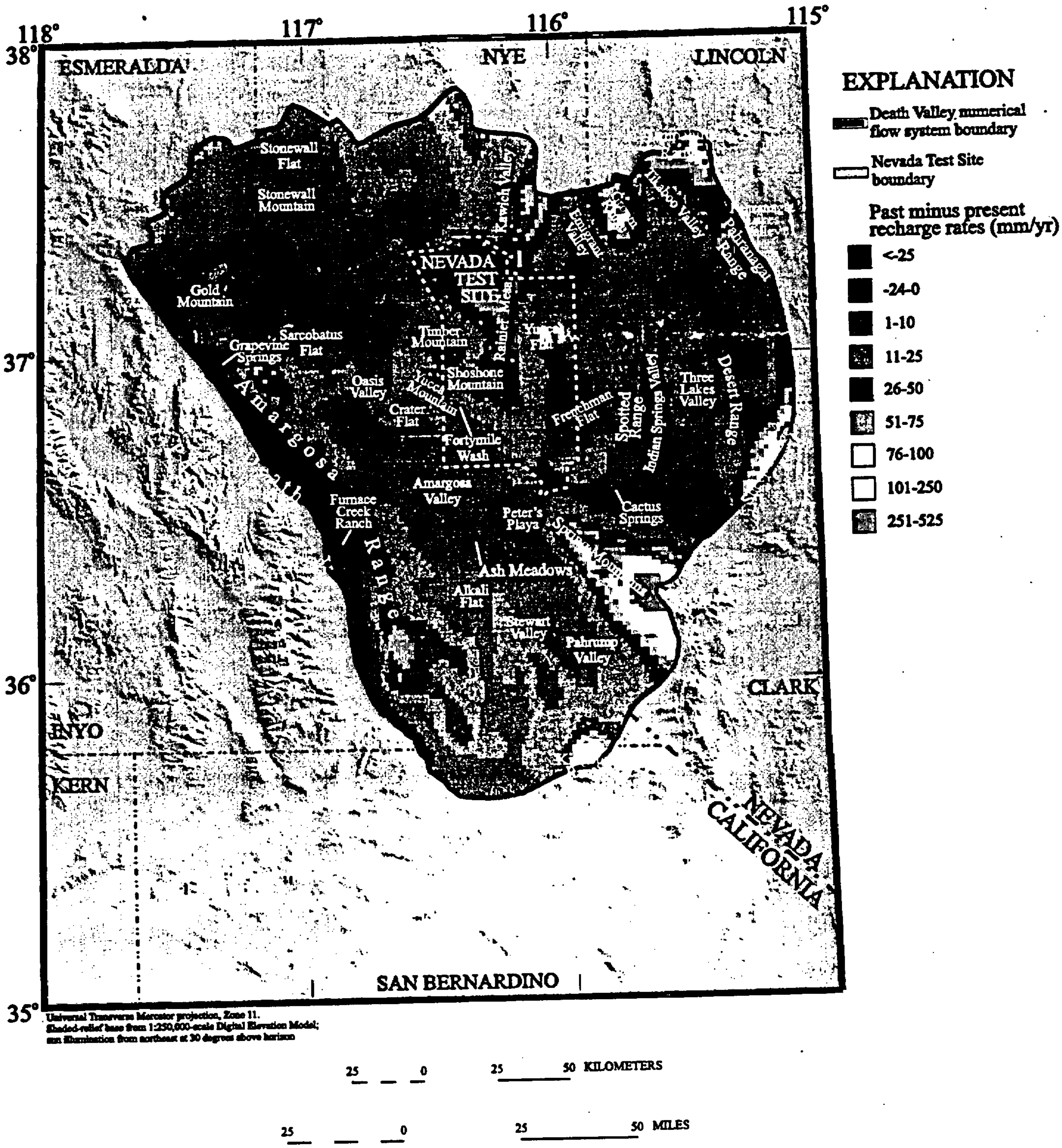

Figure 6. Difference between past-climate and present-day recharge distributions.

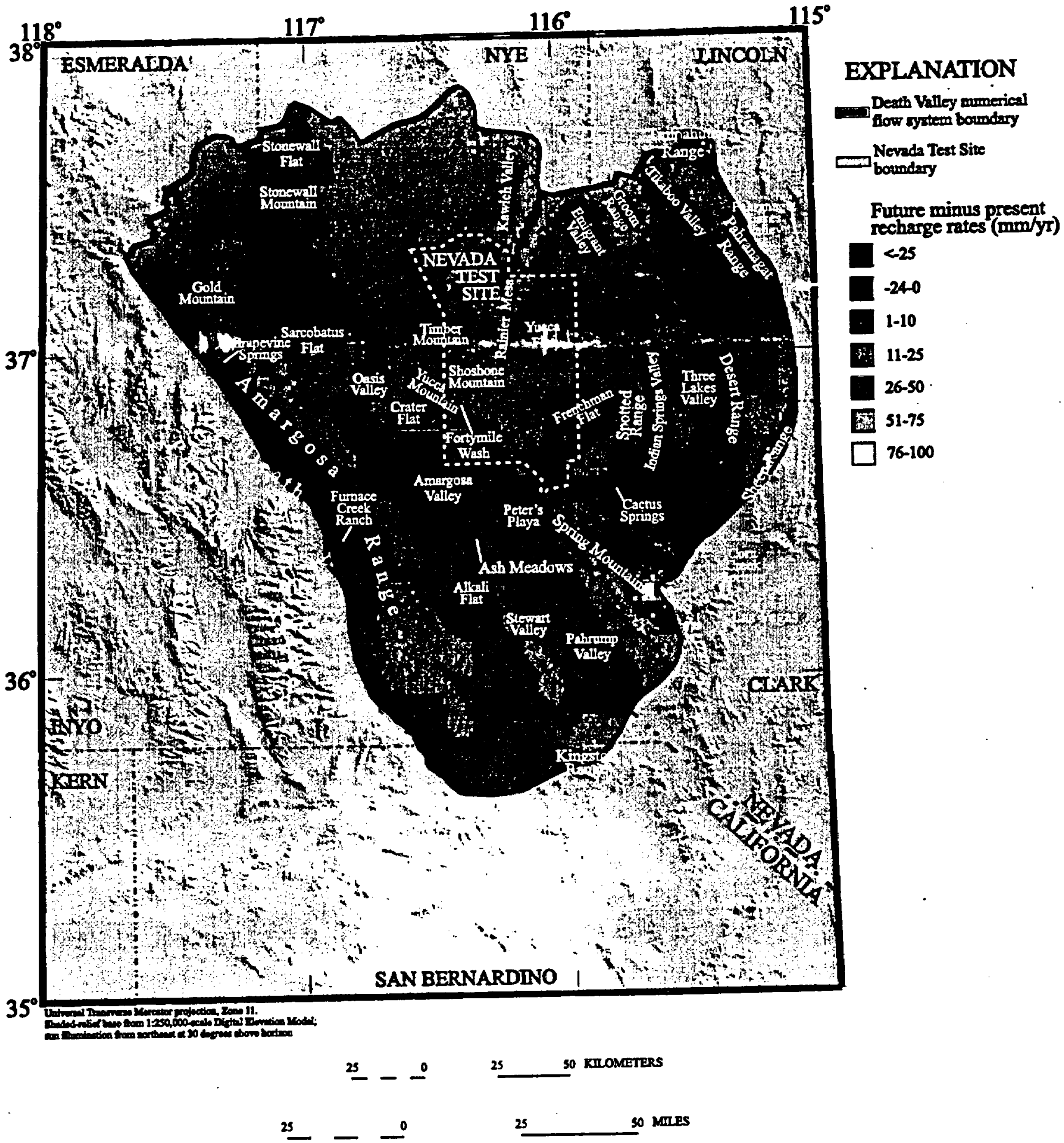

Figure 7. Difference between future-climate and present-day recharge distributions.

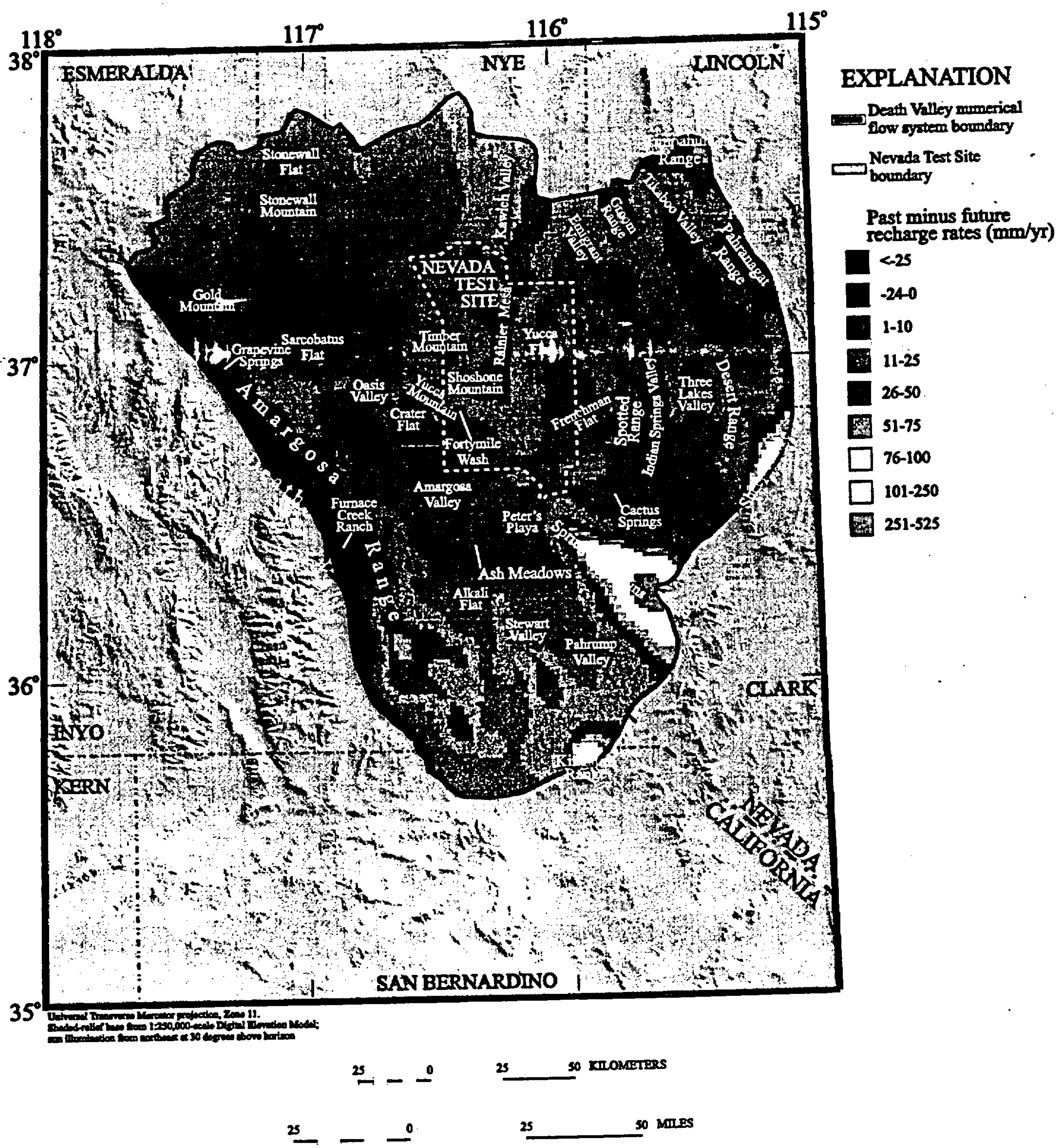

Figure 8. Difference between past-climate and future-climate recharge distributions.

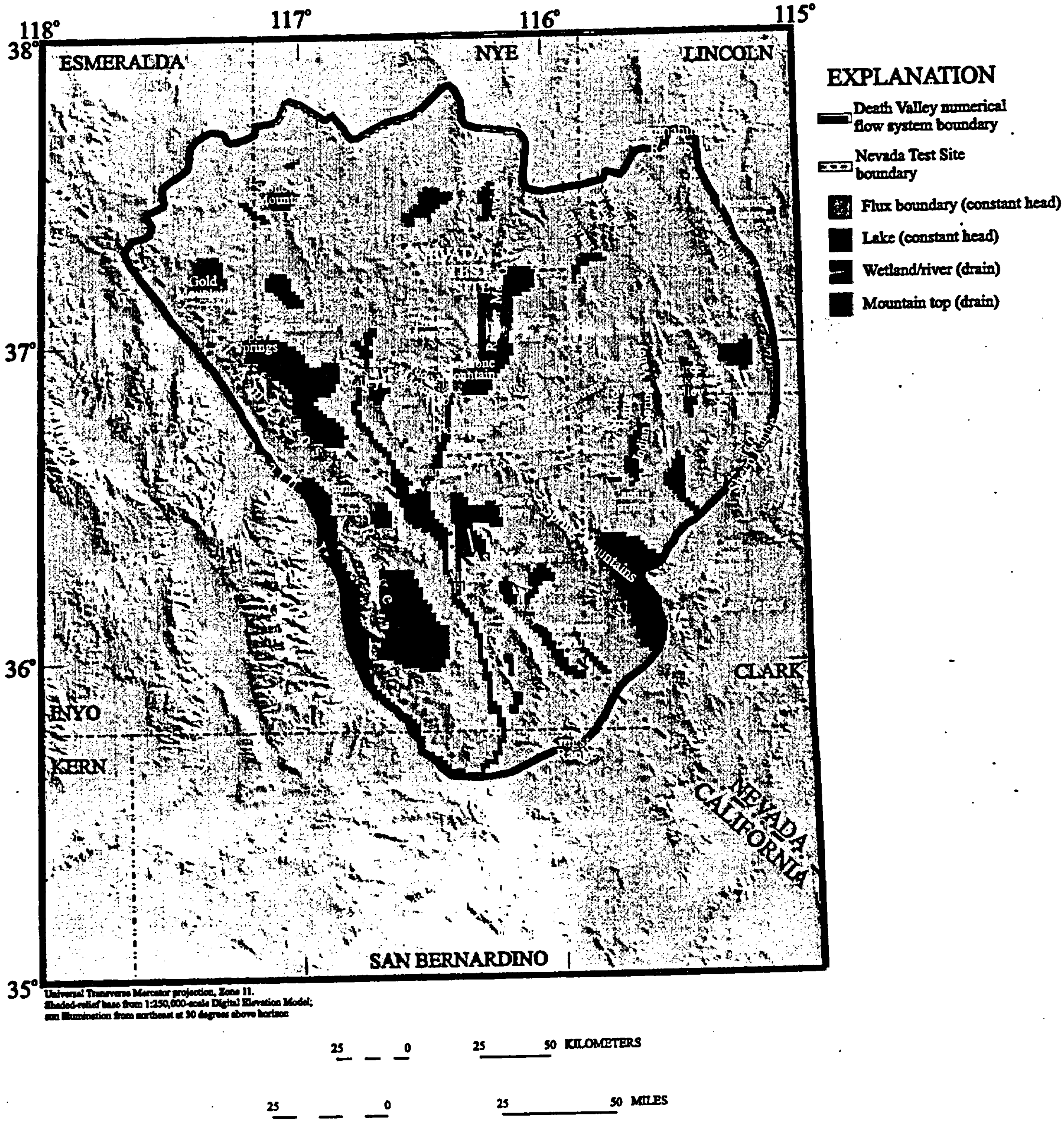

Figure 9. Distribution of paleodischarge areas represented as constant head cells and drains in the past-climate ground-water flow model simulation.

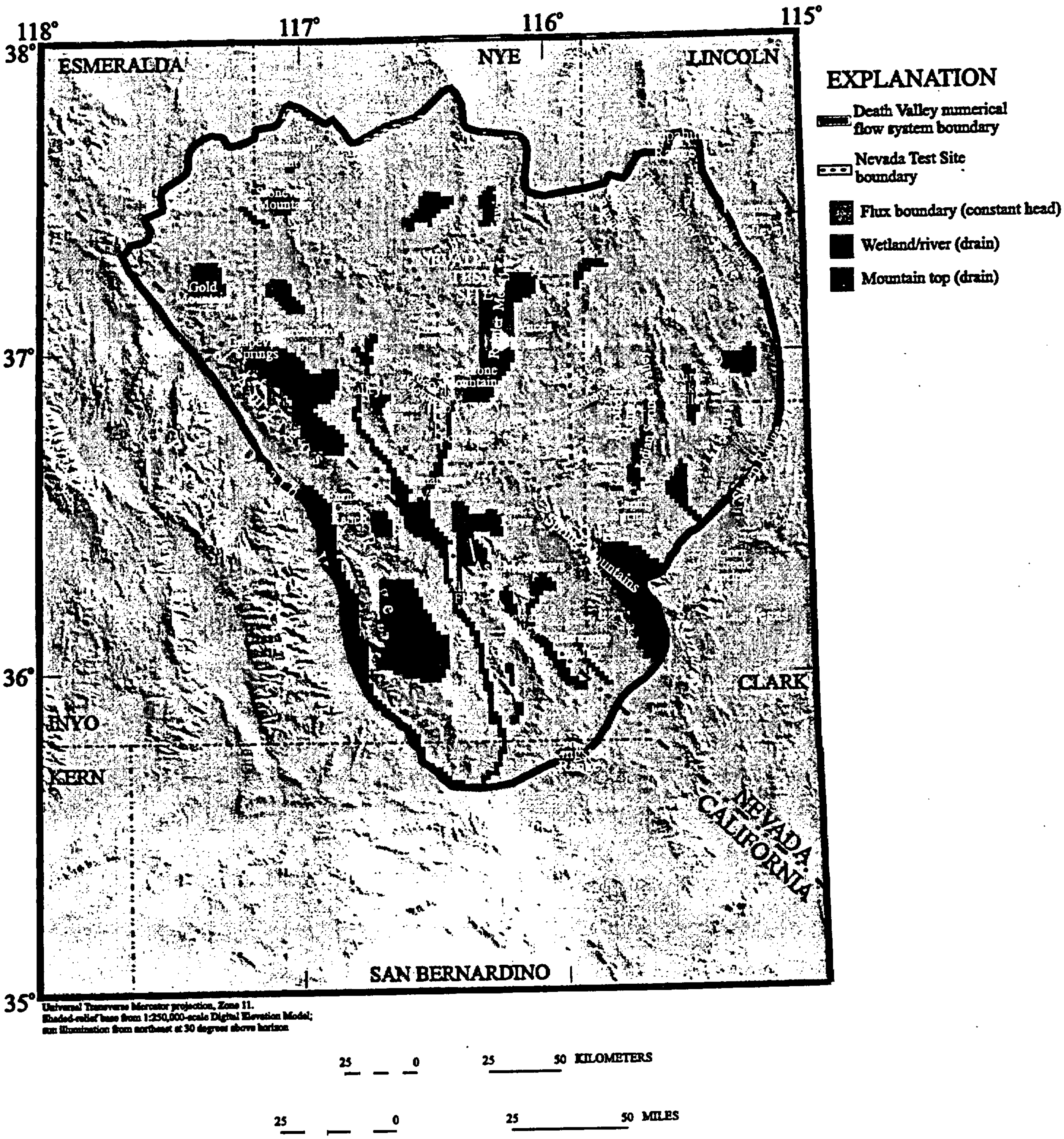

Figure 10. Distribution of constant head cells and potential discharge areas represented as drains in the future-climate ground-water flow model simulation.

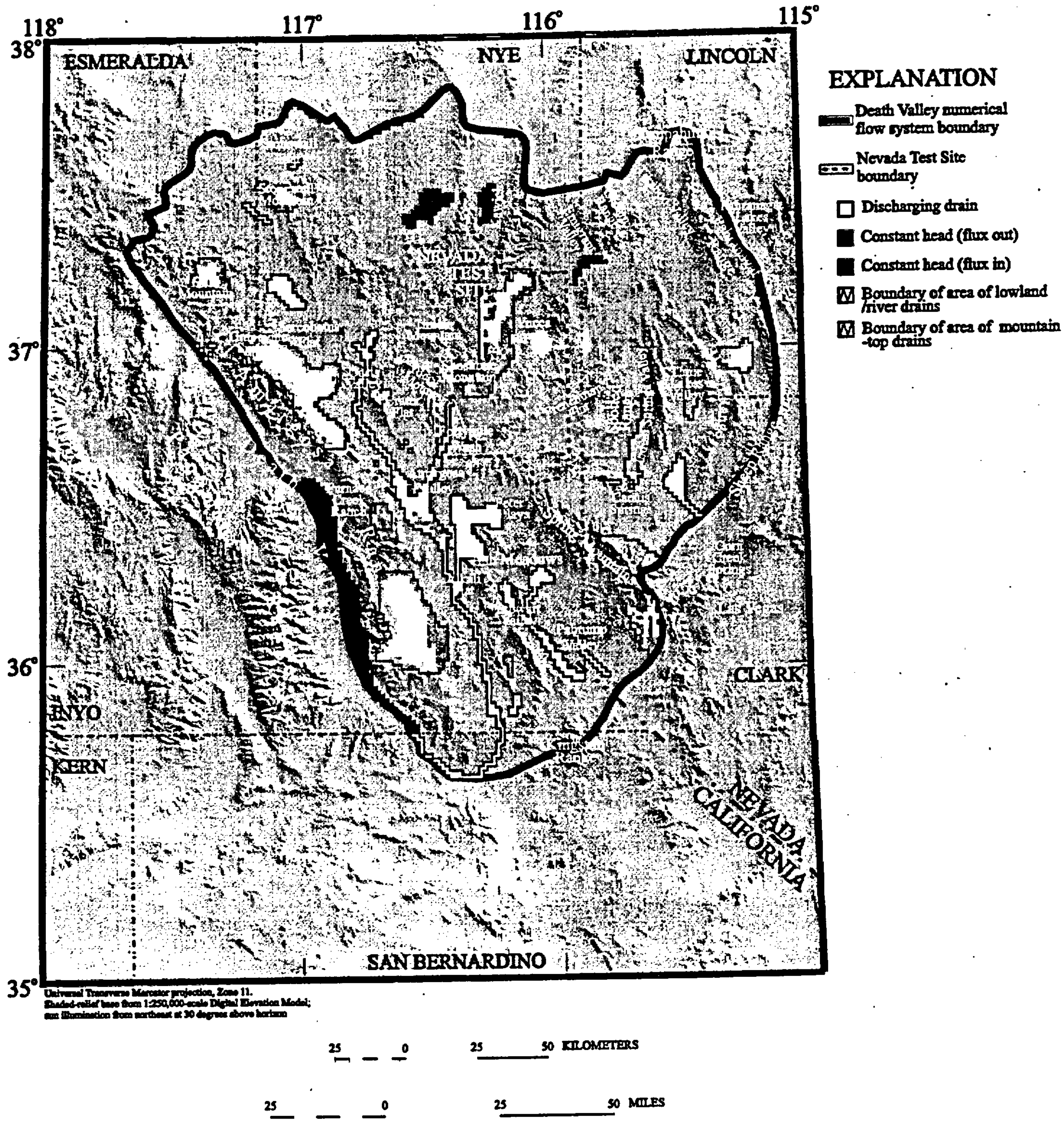

Figure 11. Distribution of drains and constant head cells simulated as discharging during past-climate simulation.

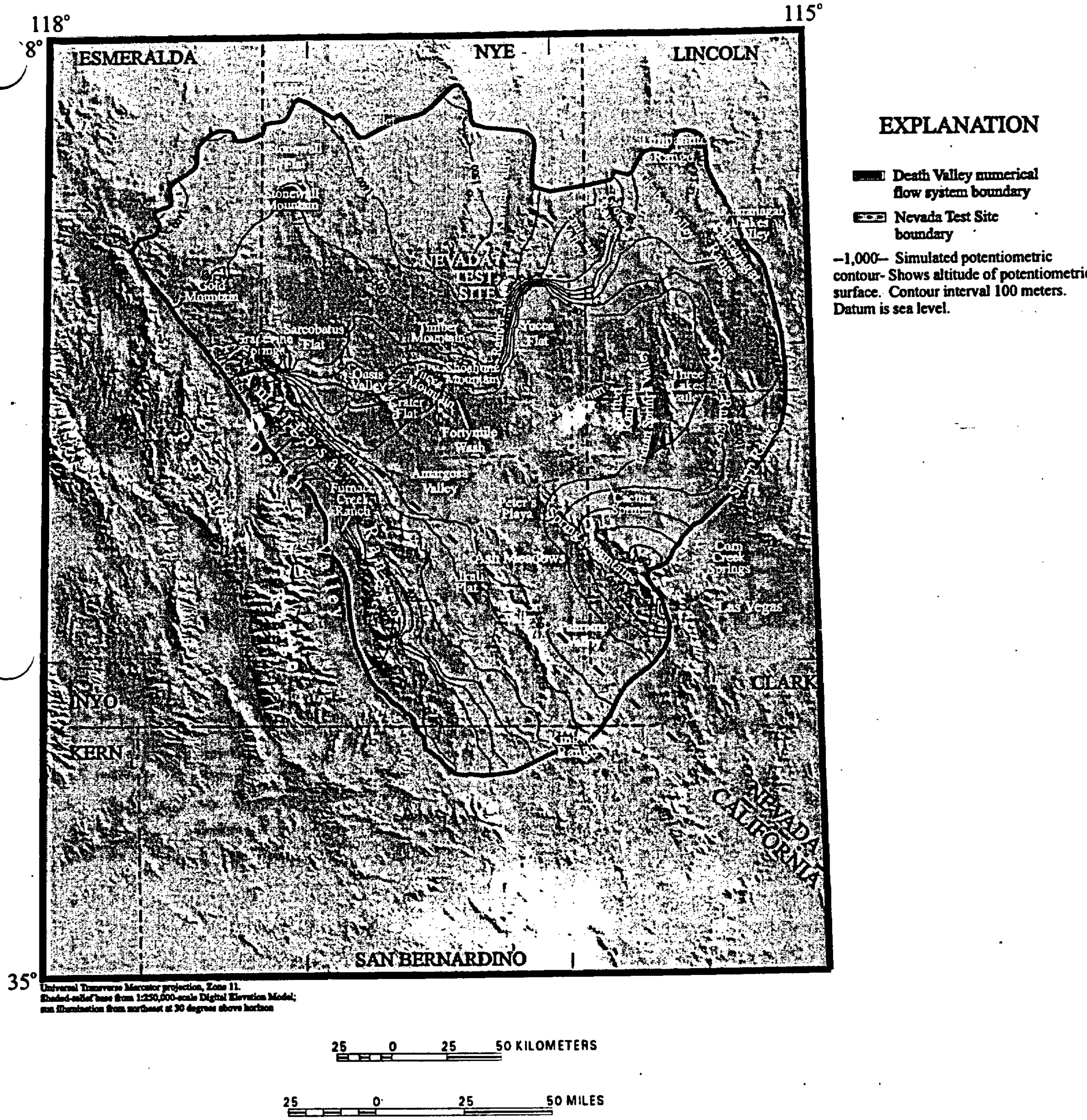

Figure 12. Simulated present-day potentiometric surface for model layer 1.

Figure 13. Simulated past-climate potentiometric-surface for model layer 1 and the difference between the past and present-day model layer 1 potentiometric surface.

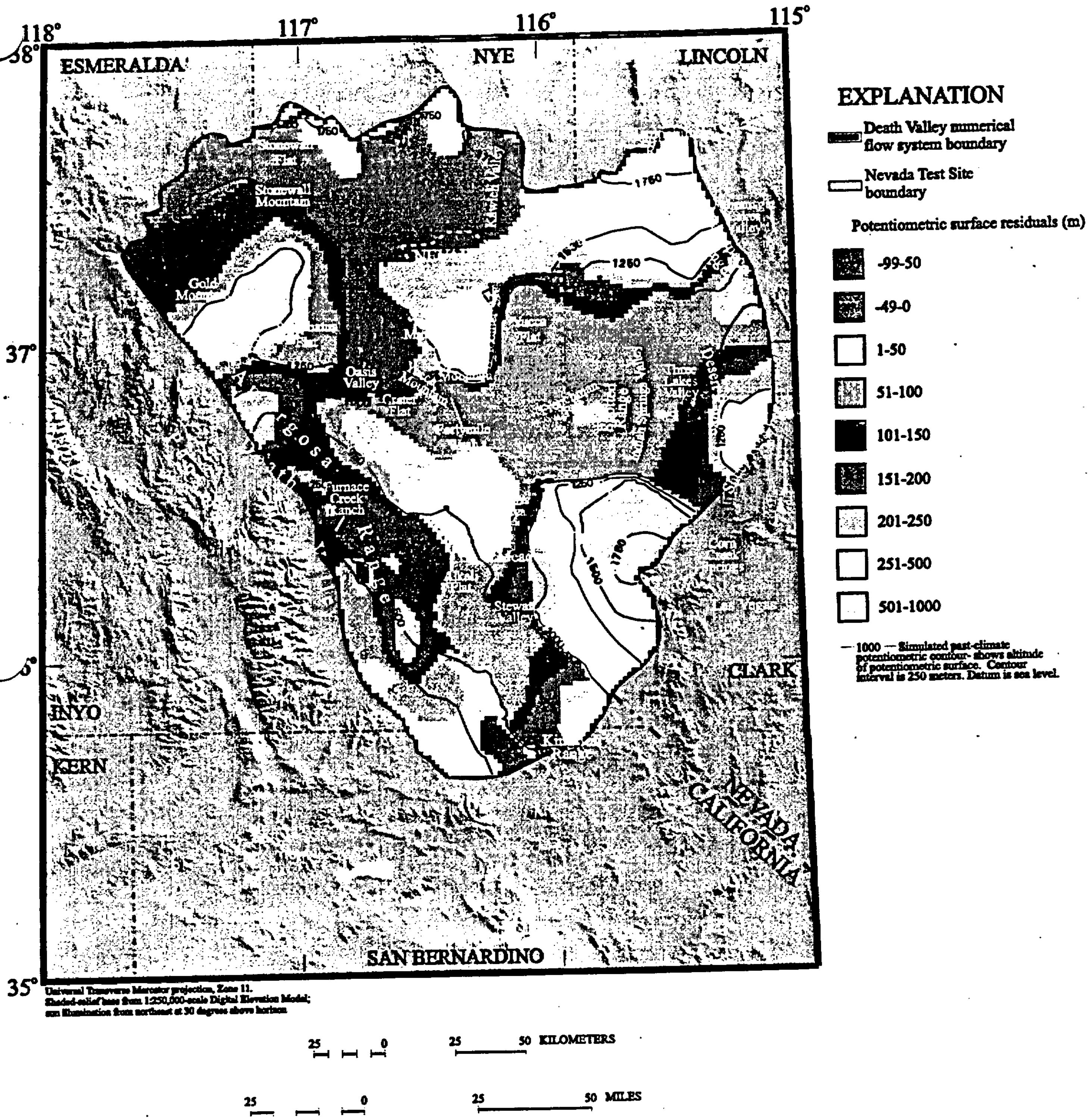

Figure 14. Simulated past-climate potentiometric surface for model layer 3 and the difference between the past and present-day model layer 3 potentiometric surface.

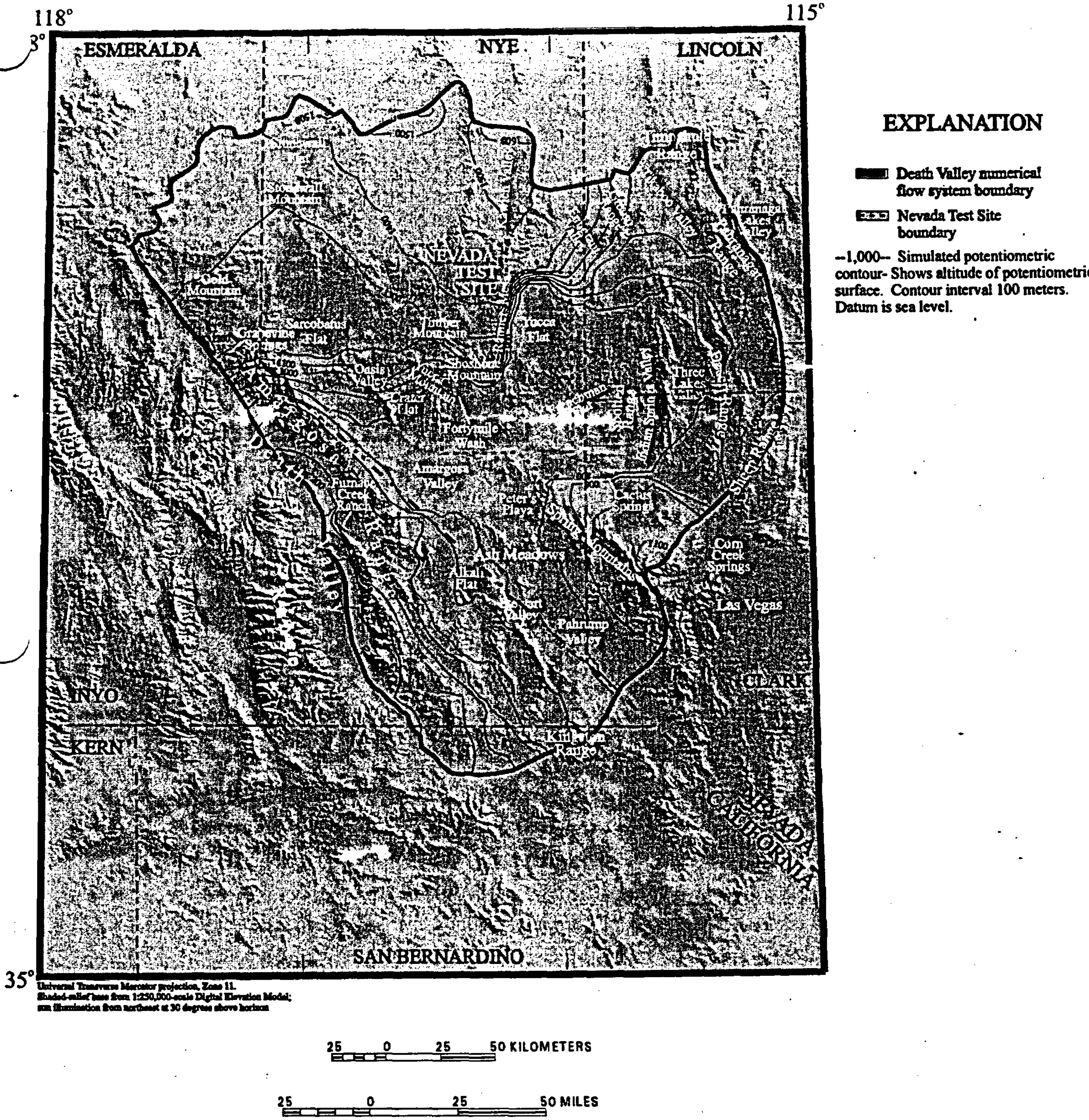

Figure 15. Simulated present-day potentiometric surface for model layer 3.

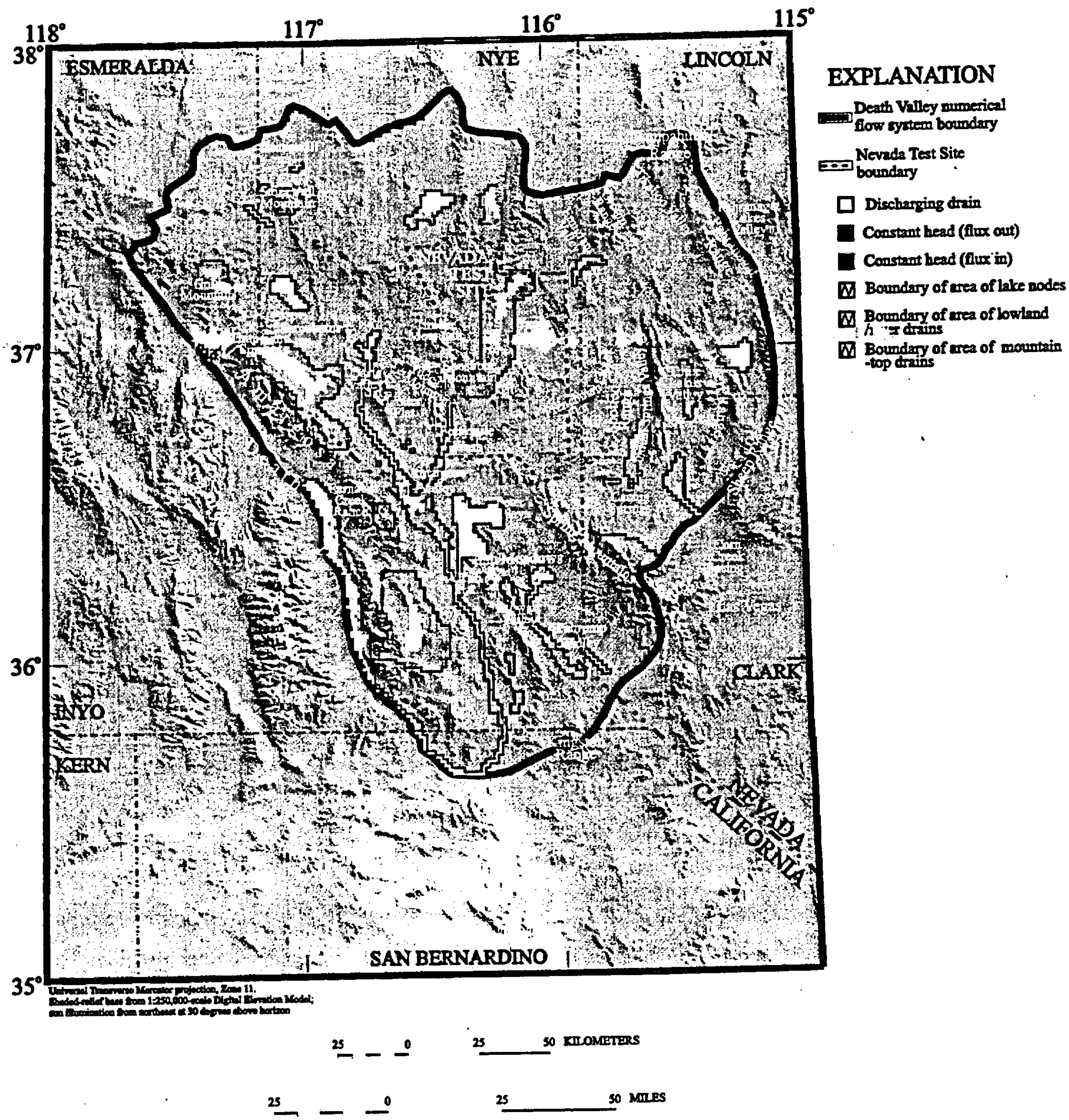

Figure 16. Distribution of constant head cells and drains simulated as discharging during future-climate simulation.

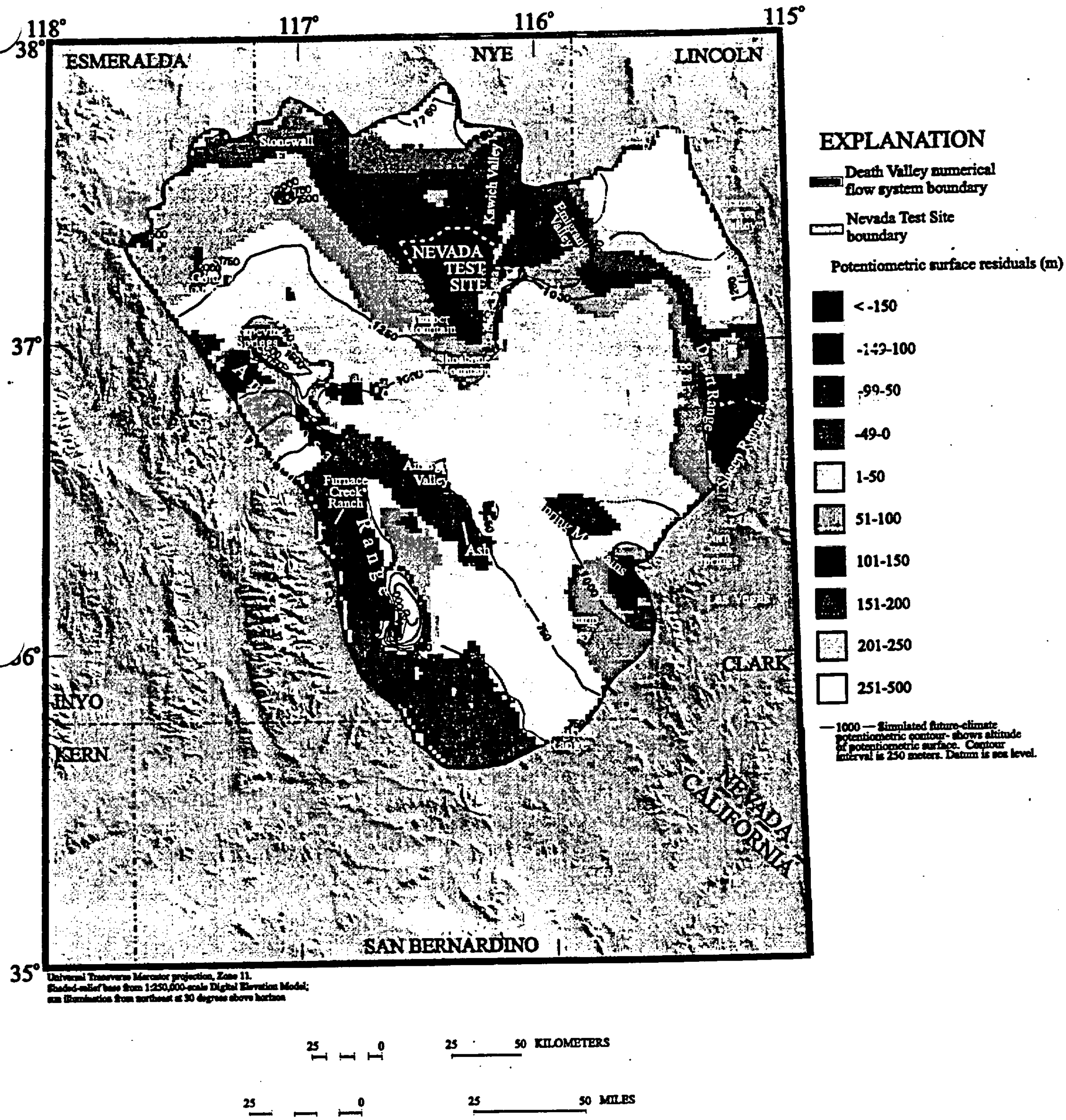

Figure 17. Simulated future-climate potentiometric surface for model layer 1 and the difference between the future and present-day model layer 1 potentiometric surface.

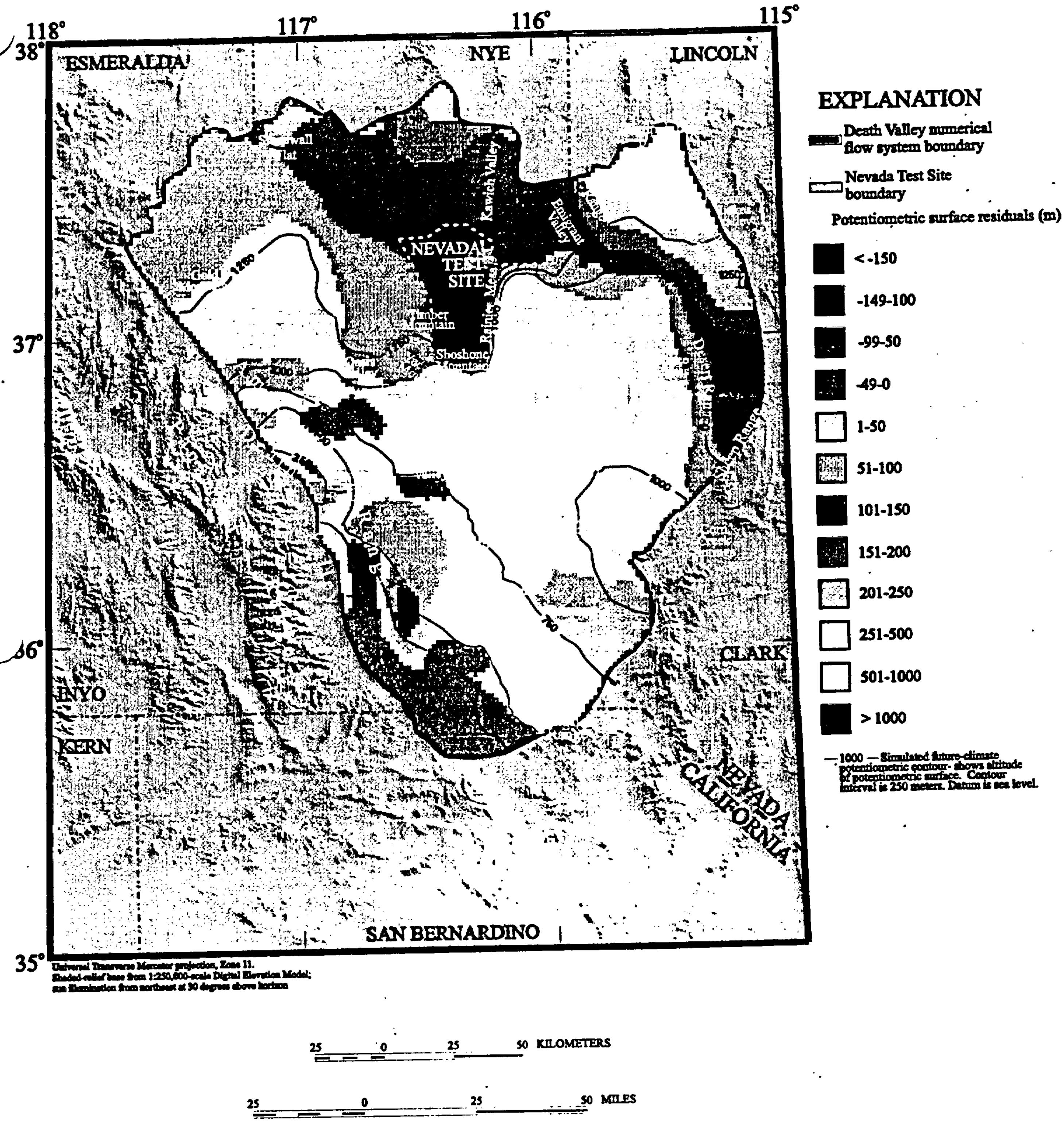

Figure 18. Simulated future-climate potentiometric surface for model layer 3 and the difference between the future and present-day model layer 3 potentiometric surface.

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September 3, 1997

Wesley E. Barnes
YMSCO Project Manager
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Las Vegas, Nevada 89134

Dear Mr. Barnes,

Enclosed is a final copy of the Yucca Mountain Project Repository Design Consulting Board Report No. 5. This report pertains to the briefings and consultations held in Las Vegas on April 24 - 25, 1997.

Very truly yours,

S. H. Bartholomew

S. H. Bartholomew
For the Board

cc: Stephen Brocoum (DOE) w/enclosure
L. Dale Foust (TRW) w/ enclosure
Richard Snell (TRW) w/ enclosure

YUCCA MOUNTAIN PROJECT

REPOSITORY DESIGN CONSULTING BOARD

REPORT NO. 5

August 27, 1997

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Appendix

EXECUTIVE SUMMARY

Following a brief review of the chronology and briefing information received by the Repository Design Consulting Board during meetings with the Design Team on 4/24/97 and 4/25/97, this report relates specific board response to the Design Team briefings presented on 4/24/97, and concludes with 23 specific comments/ recommendations relating to these briefings. A verbatim statement of the 18 previous board comments/recommendations contained in Board Report #4 and the Design Team's responses to each of them is also included in the Appendix.

Introductory matters discussed prior to the 4/24/97 briefing reported herein included a summary of recent changes to the NWTRB (relayed to the Board by Dennis Williams) and the need (noted by Richard Snell) to formalize the mass of presently available scientific data into a more narrow list for the Design Team's use for the design for the repository. Further, this report notes Mr. Snell's instructions that previous issues raised by the Board be formalized into two basic categories; (1) issues upon which substantial agreement has been reached with the Design Team and that could be considered closed, and (2), and issues upon which there is disagreement in which case the basis of the disagreement is to be formalized and made available for review by the eventual decision makers.

Specific commentary relating to the 4/24/97 briefings includes recognition by the Board that there are many interacting considerations involved in selecting additional site exploration activities to be conducted and that the Board concurs, based on Ron Smith's briefing, that one east-west drift, together with some combination of additional surface boreholes adequately responds to the Board's earlier expressed position that two east-west drifts were needed. Also noted is the Board preference for the northern location of the several east-west drift alternates presently under consideration. Commentary on Mr. Smith's briefing presentation concluded with the statement that the Board finds the general nature of current understanding of site fault and fracture systems to be consistent with our personal observations in the ESF tunnel and with our experience elsewhere in other underground construction projects.

Brief commentary on Rick Nolting's 4/24/97 briefing on concrete lining issues appears on page 5 of this report. Board comments are generally supportive of the presently planned series of laboratory and field tests to determine requisite concrete, physical, and chemical properties for the underground opening linings. One particular concern discussed is the problem of concrete set retardation due to the extremely long concrete transit time durations that will be involved in cast-in-place concrete operations for the Mains and Ramps. This report mentions the recently successful experience in retarding concrete sets at the Boston Harbor Inter-Island Tunnel project.

Commentary on the repository construction program commences at page 6 of the report, first focusing on recommendations for the termination points for the early construction of selected Emplacement Drifts so as not to disturb the ground in the area of the West Main alignment. Concern is also expressed regarding potential interference due to certain key operations unnecessarily made concurrent in present construction programming, the location of the northern-most muck transfer point to conveyor discharge in the East Main, and the number of required independent concrete placing operations. Commencing on page 7, the report also indicates the Board's view that, provided that other present board recommendations are adopted and put in place, the proposed production rates for several aspects of repository construction in present design team planning are too low and should be increased. Finally, the report expresses board concurrence with the presently contemplated method for sinking the Development and Exhaust Shafts, with the exception of the concreting phase which, in the Board's opinion, should be conducted from the bottom up rather than following the excavation down.

Comments on the repository ventilation issues covered by Dan McKenzie's 4/24/97 briefing commence on page 9. First, the Board indicates our current understanding of the Design Team's present intended development ventilation scheme and then raises four questions with regard to that scheme:

- What is the intended concept and what is are the essential configuration details of the two "Local Bypass For Dust Control" installations?

- What and where depicted are the TBM and Roadheader ventilation details indicated on the "layout to be separately shown"?

- How does the development side scheme relate to the Option A/Option B sketches presented in the briefing by way of response to an earlier board question regarding the study of alternate fresh air intake systems?

- Is it intended that the TBM and Roadheader exhaust air discharge be ducted to the surface, or alternately, scrubbed in some manner underground and then released in the East Main for return to the surface?

At page 10, this report relates the Board's current understanding of the intended Emplacement Drift Ventilation Control System presented in Dan McKenzie's 4/24/97 briefing. The Board indicates our concurrence that the design concept is sound and that it provides flexibility in operation and insures that any contamination from off-normal situations will be contained in the individual Emplacement Drift, ducts, and filters where the contamination occurred without interfering with other ongoing repository activities. However, the report does note that the presently recognized problem of development of detection equipment sensitive and reliable enough to detect nuclear contamination in exhaust air in the event of a WP breach. Also stated is the Board's present conclusion that air volumes contemplated for the alternate air supply study are reasonable, contrary to the board concerns expressed at the 4/25/97 debriefing.

This report states on page 13 the Board's present belief that results from presently conducted computer modeling studies indicating that, during the first 20 to 50 years after the placement of the waste there will be minimal influence of cooled PC Drifts upon the temperature contours around Emplacement Drifts, are encouraging. The Board further concludes that these studies seem to furnish a satisfactory basis for locating the presently contemplated 5 PC Drifts in their presently planned position above the Emplacement Drifts. The Board also stated that we do not believe that the 200 m requirement of 10 CFR 960 should apply to the PC Drifts, which will never contain Waste Packages.

Starting at page 14, the board position on respirable dust issues is stated. First, the Board indicates our current understanding that:

- Cristobalite and quartz constituents would not be expected to be higher or greater in the respirable dust portion of total airborne dust in the repository than for the balance of the total airborne dust.

- Cristobalite and quartz contents of the host repository rock can not be more accurately or more quickly determined by analysis of samples of the host rock itself rather than by X-Ray Diffraction Analysis of respirable dust samples. Further, current OSHA and NIOSH technical guidance requires that the silica content be determined through analysis of air samples.

- A level of accuracy that can be expected in determination of cristobalite and quartz constituents of respirable dust by X-Ray Diffraction methods is $\pm$ 20%.

- From an OSHA compliance standpoint, all 64 air samples taken ahead of TBM Deck 12 in the ESF after 10/7/96 reported in Exhibit 8, Board Report #4, are considered valid. Further, the detection limit for both cristobalite and quartz by X-Ray Diffraction method is approximately 30 micrograms per sample (0.03 milligrams).

The report commends the DOE, M&O and the constructor staffs for their efforts in collecting and analyzing the hundreds of respirable dust samples collected throughout 1996 and 1997 during the ESF tunnel drive. We further note that it is unlikely that this quantity and quality of air sample data for underground construction work has heretofore been collected anywhere.

Regarding the application of ESF experience to repository construction, the Board notes on page 15 our current understanding that for repository construction:

- Maximum quartz contents and dust samples measured in one location in time will not be combined with maximum cristobalite content measured in another location and time, creating a fictitious combination of quartz and cristobalite which does not actually exist. Instead, data will be accumulated underground to determine what combinations of quartz and cristobalite actually exist together. This will then form the basis for determining allowable dust levels.

- A PEL of 0.10 mg/m^3 will not arbitrarily be imposed.

- "Confidence limits" taken at the 95 percentile will not be used in analysis of data for determination of allowable dust levels. Rather, the controlling analysis will be made on the mean of the mineral constituent contents for air samples taken at and within discrete work areas, not the repository at large.

The report notes the Board's opinion that it will not be economically feasible to clean up the air by means of engineering controls simultaneously throughout all areas of future repository construction, and that some operations will no doubt require respirator use. The report reviews on page 16 and 17 examples of the differential impact of respirator use on underground construction operations. Also noted is the Board's expectation that once concrete linings are in place in the Mains and Ramps, the respirable dust problem will be considerably diminished. The overriding conclusion expressed is that the practical need to clean up the air to avoid respirator use during future repository construction will clearly be a variable and should be treated as such accordingly.

Finally, starting on page 18, the report addresses miscellaneous design team responses to other Board Report #4 comments. The Board indicates agreement with the currently planned approach to be taken with the NRC regarding NQA-1 standards but points out on page 18 we believe a fundamental difference exists between (a) Emplacement Drifts where waste will reside for the life of the repository, and (b), the Perimeter and Ventilation Mains, which are nothing more than transportation tunnels, totally accessible for inspection and whatever repair and maintenance may be needed, for as long as the repository is open, and which are planned to be backfilled when the repository is sealed for final closure.

Also on page 18, the Board indicated our agreement with the approach taken by the Design Team with regard to holding up the design pending receipt of necessary decisions on certain key issues. We agree the present approach of moving forward with the design on the basis of a reasonable assumption and then, if the eventual decision varies from that assumption, modifying the design accordingly. Finally, the Board repeats the previously expressed concern that the design may get too far ahead of a broad-based risk analysis (which presently will not be conducted until mid 1998) resulting in the possibility of future costly design changes.

BRIEFING CHRONOLOGY AND INFORMATION RECEIVED

4/24/97 Introductory Remarks

Richard Snell introduced the briefing session with a graphic indicating the formal organization of the full MGDS Consulting Board and stated that Salomon Levy would be present later in the morning to attend the day's briefings. All board members were invited to attend the planned Elicitation Committee meetings in May. Mr. Snell confirmed the appointment of Dr. Peter L. Andresen and Dr. David W. Shoesmith to the Waste Package sub-board of the MGDS Board and confirmed that the first full board meetings would occur in late July, including both sub-boards.

Dennis Williams then spoke briefly representing Dr. Stephen Broucom. He stated that Dr. Broucom was satisfied that the MGDS Board, the Design Team, and the NWTRB all understand the general nature and parameters of the Viability Assessment Document and it appears that all three groups are now on the same track. Mr. Williams distributed copies of the NWTRB report for the period January to December, 1996, and noted changes in personnel comprising that Board. He confirmed that board members Arendt, Cohon, and Wong were the only members continuing. All other previously sitting board members have been succeeded by new members. Thus, the composition of the NWTRB has changed considerably. The subject report reflects the conclusions of the previous Board prior to the recent personnel changes.

Richard Snell then continued the introductory remarks. He stated that the Viability Assessment remains the major Design Team objective and that the present Congressional/Administration debate concerning the interim storage issue adds further significance to the Viability Assessment.

Mr. Snell further noted his desire that specific scientific data (out of the present mass of data that has been assembled) be formalized into a more narrow list for the Design Team's use for the design of the repository. He noted his concern over the compression of available time for completing the necessary Phase 1 design work for Viability Assessment purposes.

Mr. Snell further stated that he considered it important that the various issues raised by the MGDS Board be classified into two basic categories:

- Issues upon which substantial agreement has been reached with the Design Team and that can be considered closed.

- Issues upon which there is disagreement. In this case, the basis of disagreement should be formalized in writing with respect to each issue so that it will be available for review by the final decision makers.

4/24/97 Detailed Briefings

Ron Smith presented a briefing on Anticipated Site Exploration in the Immediate Future. This briefing was in response to Board Comment #9 from Report #4 to the general effect that the Board believed that two additional cross-block drifts were necessary.

The briefing was accompanied by a 44-page hand-out and was supported by video projections from a 3-dimensional model study illustrating how the volumetric prism occupied by the repository Emplacement Drifts fits within the geologic restraints known (and inferred) from presently available information.

The briefing also covered potential future exploratory programs under consideration at the present time and delineated those most likely to be carried forward.

Rick Nolting then presented a briefing on Concrete Testing for Repository Ground Support. The briefing was accompanied by a 10-page hand-out covering the subjects Why Concrete Testing?, What Is the Appropriate Concrete?, Candidate Concrete Mix Designs, Concrete Chemical Testing, Concrete Physical Properties Testing, and Drift Scale Testing in the ESF.

Robert Saunders then presented a briefing on General Construction Issues in response to Board Comments #1, #4, #5, #11, & #15 of Board Report #4. The briefing was accompanied by a 28-page hand-out including 23 numbered pages and 5 unnumbered reduced size repository layouts illustrating different phases of construction.

Dan McKenzie then presented a briefing on Repository Ventilation Issues in response to Board Comments #2, #3, #10, & #12 from Board Report #4. The briefing was accompanied by a 34-page hand-out including numerous explanatory sketches and layouts.

Dan McKenzie then presented a briefing on Performance Confirmation Issues in response to Board Comments #6, #7, & #8 from Board Report #4. The briefing was accompanied by an 8-page hand-out including computer generated plots of thermal studies of the effect of PC Drift cooling on rock mass temperatures around the Emplacement Drifts.

Charles Parker and Thomas McManus made a brief presentation in response to Board commentary on Respirable Dust Issues in Board Report #4 including Summary Comments #17 and #18. The presentation included a 2-page written hand-out answering four specific questions raised in comment #18 in Board Report #4. In addition, the Board received three additional hand-outs from Russell Baumeister consisting of a one page abstract from a 17-page paper entitled "Review of Quartz Analytical Methodologies", a 6-page NIOSH June 1996 update on Silicosis Risks in Construction, and a 9-page hand-out of pages taken from the NIOSH 8/15/94 Manual of Analytical Methods containing details of testing for Crystalline Silica by the X-Ray Diffraction Method. (Since the 4/24/97 briefing, the Board has received considerable additional material of this nature from Mr. Baumeister.)

Alden Segrest completed the formal briefing session with a presentation in response to Board Comment #16 in Board Report #4 (concerning NQA-1 Standards), Board Comment #13 from Board Report #4 (concerning importance to repository design of early key decisions), Board Comment #12, Board Report #3 (concerning the decision for the degree of mapping required for the Emplacement Drifts), and finally, Board Comment #14, Board Report #4 and Board Comment #11, Board Report #3 (concerning the need for an early broad-based risk analysis).

4/25/97 Activity

The Board conferred privately throughout the morning and then met with representatives of the Design Team and other M&O and DOE personnel for an oral debriefing where the Board presented our initial impressions from the 4/24/97 briefings. More complete responses are contained in this following Board Report #5.

List of 4/27/97 Briefing Attendees and Design Team Responses to Board Comments Contained in Board Report #4

The sign-up sheet for the briefing sessions held on 4/24/97 and the verbatim Design Team responses to the board comments from Board Report #4 are contained in the Appendix to this Board Report #5.

Board Internal Meeting on 6/30/97

The Board met for one day on 6/30/97 for the purpose of further internal discussion preparatory to drafting this Board Report #5.

ANTICIPATED SITE EXPLORATION PROGRAM

Summary Comment #9 of Board Report #4 recommended a minimum of 2 east-west Cross Block Drifts, one extending from the ESF North Ramp and one extending from the South Ramp. These were intended to explore the nature of the repository block across its width, to define the location of the westerly bounding Solitario Canyon Fault, and to later function as Performance Confirmation Drifts.

Ron Smith, with assistance from Warren Day, presented a briefing on 4/24/97 summarizing the current status of knowledge of various features of the site geology, and describing additional site exploration which is being considered. The anticipated additional exploration includes one east-west drift, and various boreholes. Alternative locations being considered for the east-west drift include a northerly location similar to the Board suggestion, and a central location. Proposed boring WT-24 located north of the repository site, and boring SD-6 located toward the west side of the site are the most probable to be carried forward. Other borings are being considered at various locations, particularly around the Solitario Canyon Fault, and in a saturated zone testing complex south of the repository.

The Board recognizes that there are many interacting considerations in selecting the additional site exploration to be conducted. We concur that one east-west drift, together with some combination of additional surface boreholes, would respond to our principle concerns. For practical construction considerations, we prefer the northern location for an east-west drift extending westerly from the ESF North Ramp. The Board is not in a position to offer recommendations for specific locations of surface boreholes.

We found the general nature of current understanding of site fault and fracture systems, as described by Ron Smith and Warren Day in the briefing, to be consistent with our personal observations in the ESF Tunnel, and with our experience elsewhere at other underground construction projects.

CONCRETE LINING ISSUES

Rick Nolting's 4/24/97 briefing described the nature of various programs being planned and implemented for testing of concrete materials, including the concrete lining heater tests in the ESF heater test alcove. The planned program includes tests for concrete physical and chemical properties at temperatures to 200°C for time periods ranging from 6 months to several years. Various concrete mixes are being considered. Chemistry of the concrete is important because of concerns about possible effects on radionuclide transport on the long term function of the repository. Data in the technical literature, from previous similar testing at Hanford and for commercial nuclear plants, is encouraging.

An example of one current issue is the desire to minimize the organic content of the concrete, since organics may enhance microbially induced corrosion. This issue can have a practical construction aspect also, in that it can impact selection of various organic admixtures commonly used in concrete to control workability and set time. Because of the size of the repository, the use of cast-in-place concrete involves long transit time durations from surface mixing to underground placement, for which retardation of set time will be necessary. As an example of current tunnel technology, the 25,000 ft. long Boston Inter-Island Tunnel, presently nearing completion, successfully placed concrete which had been retarded for travel time periods exceeding 3 hours. An alternative which may be practical for repository construction would be to establish an underground mixing plant (or plants) in order to reduce travel times and limit the need for retardation additives. We note that problems of this type are eliminated by use of precast concrete tunnel lining systems.

Selection among various alternative solutions to such questions will depend in part upon the results of the testing programs described by Rick Nolting. In previous board recommendations, we agreed that such testing is necessary. We do not offer specific suggestions on concrete mixes and laboratory testing programs, leaving that to experts in concrete chemistry and technology.

We believe that initial testing of concrete mixes containing steel fibers is appropriate, but suggest that similar tests should also be run on conventional concrete with rebar or mesh reinforcement. If steel fiber particles from deteriorated drift linings could come in contact with waste packages and be a point source of long term corrosion, conventionally reinforced concrete may be desirable in the Emplacement Drifts.

REPOSITORY CONSTRUCTION PROGRAM

The Board is pleased to note that previous general recommendations concerning Tunnel Boring Machine operational characteristics have been accepted by the Design Team. One very important operational characteristic is the ability of the TBM to back up through completed works. This will require special procurement attention during the TBM acquisition, but will prove to be an invaluable feature for both the 7.62 m and 5.5 m machines that will allow a more orderly development of not only the Emplacement Drifts but of the overall repository as well.

We are also pleased to learn that there was not an intention to store construction materials in completed underground drifts as a normal routine. It was clarified at the 4/24/97 briefing that the storage of material in these drifts would be limited to special situations only and that normal planning would contemplate delivering materials underground directly to the point of use as needed. This will eliminate substantial costs in rehandling material and certainly will create a tighter and more efficient operating environment for the construction contractor and others who will perform work in the completed areas of the repository.

We note that early construction of selected Emplacement Drifts continues to be contemplated for ventilation purposes and to define the western limits of the repository block. The Board agrees with this concept but we again state that the drifts should be terminated prior to crossing the West Main alignment. Should more investigation be required, the utilization of exploratory core drill holes through the TBM cutterhead would be more in order. That would minimize the amount of drift excavation required and would leave initial ground conditions in their natural state prior to driving the West Main. The distance we visualize these early Emplacement Drift drives should be left short is slightly less than the length of the turnout connection with the West Main.

The Board notes that there is currently an expectation that production Emplacement Drift excavation at the north end of the repository would start early in the construction program prior to completing the concreting operation in the main perimeter tunnels. While the Board feels this can be done, we believe that serious efforts should be made to program the various operations in the construction phase in a manner that will cause as little interference, one operation to the other, as possible. There is much more opportunity for cost efficient operations without interference from other concurrent operations. The Board believes that certain of the progress estimate rates discussed at the 4/24/97 briefing can be enhanced over those now considered, but only if critical operations are separated and unencumbered. From our initial understanding, there seems to be a good opportunity in the contemplated time schedule to program these various critical operations in a manner that will assure a minor amount of interference. That programming effort should be refined to the point that all interference is eliminated from the program to the extent possible. It may be possible, for instance to drive the most northerly Emplacement Drifts from the East Main while portions of the West Main remain unconcreted provided the concreting operation does not interfere with Roadheader Excavation in the West Main, ventilation for the West Main work, the ventilation air supply for the Emplacement Drift operations in the East Main, material movements for the Emplacement Drift operations, etc. However, there is a better chance of sustaining an efficient Emplacement Drift Excavation operation, and follow up Emplacement Drift finish operations, if all of the Mains and Ramps have first been concreted and muck discharge conveyors and ventilation systems (with air locks) installed prior to starting the major Emplacement Drift operation.

We also note the present position of the muck transfer point in the East Main north of the junction between the East Main and the North Ramp in Bob Saunder's presentation. This creates the potential for interference with material movements at the junction of the North Ramp and the East Main. If the muck transport conveyor can be located so that it does not cross this junction, there will be less confusion in the traffic that must serve the tunneling and overall repository operation during the early phase of the Emplacement Drift construction. We suggest that this transfer point location be re-examined and moved just south of the junction of the North Ramp and the East Main.

With regard to the cast-in-place concrete operations proposed for lining the various drifts and main transportation tunnels, it appears to the Board that the Design Team contemplates several concreting spreads operating on a concurrent basis. We believe the need for this should be re-examined and an effort made to minimize the number of spreads. If the cast-in-place concreting operation in the Mains and Ramps is programmed at the right time in the schedule and set up properly, the number of spreads could be cut down to one or two. Also, by utilizing highly mechanized state-of-the-art equipment, significant improvement in the progress rates planned in the schedule can be realized. Much of the work could be done on a continuous concrete placing basis. This was a common practice years ago in long tunnels and may have an application here. The Board feels that, at a minimum, this possibility should be investigated.

Production rates that were presented at the 4/24/97 briefing in most instances are lower than those the Board believes possible provided that present Board recommendations on TBM selection, construction programming, NQA-1 standards, and commercial terms for the construction contractors are carried out. We suggest that these production rates be re-examined and recommend the following for planning purposes:

- The 7.62 m TBM advance in the mains should be increased from 24 meters per day to nearer 35 meters per day.

- The 2 shift per day TBM operation for the 5.5 m Emplacement Drifts should be reconsidered and the 20 meter per day advance rate increased to 30 meters per day. The Board reiterates its opinion expressed at the 4/25/97 debriefing that all TBM excavation operations should be run on a 3 shift per day basis.

- We expressed concern at the debriefing about Roadheader machine availability operating in the type of ground expected in the repository. The Board had also previously expressed this concern. We have since been furnished recent Roadheader job data by the Design Team staff indicating that machine availability in similar ground conditions has improved significantly compared to prior experience. We are relieved to receive this information and appreciate the efforts that have been made to investigate the issue.

- With regard to concrete placing rates, we stated at the debriefing that a properly organized single concrete spread should be able to achieve 50 meters per day in the 7.62 m diameter main tunnels. There is good precedence for this level of production and with a properly organized and supplied program, we believe that even higher production rates could be achieved. The Board also confirms our opinion expressed at the debriefing that the arch should be poured first with the final repository configuration invert following. However, careful review of all of the job considerations should be made before dictating that level of detail at this point.

In our debriefing the Board stated that we felt it might be more efficient to perform the shaft sinking operation for the exhaust and development shafts using a 2 stage approach. We have since investigated the feasibility of this suggestion with several shaft sinking experts and have studied additional material furnished to us by the Design Team staff since the debriefing. The Board now feels that the excavation method proposed by the Design Team in Bob Saunder's briefing is the most efficient. However, we do suggest that the concrete lining in the Development and Exhaust Shafts be placed from the bottom to the top rather than following the excavation down from the top. Slip form techniques should be considered in reviewing the plans for this phase of the work.

REPOSITORY VENTILATION

Revised Development/Emplacement Ventilation Concept

Dan McKenzie's 4/24/97 briefing was in response to Board Comments #2, and #3 from Board Report #4 where the Board stated that we did not understand a previous depiction of the intended ventilation concept during the phase of continuing repository development when waste was also concurrently being emplaced. The 4/24/97 presentation centered around a layout entitled "TYPICAL VENTILATION BALANCE OF EMPLACEMENT/DEVELOPMENT ACTIVITIES". This layout showed the new location for the Development Shaft near the southwest corner of the repository perimeter that is consistent with the location shown and discussed in Robert Saunder's earlier presentation on repository configuration and construction issues. Total free air intake and exhaust quantities on both the emplacement and development sides were shown on this layout as 600,000 cfm.

At the 4/25/97 oral debriefing, the Board indicated that we now understand the intended ventilation concept and considered it promising. While our overall impression of the potential merit of the concept remains unchanged, further study has raised the following questions in our mind regarding the development side:

- What is the intended concept and what are the essential configuration details of the two "Local Bypass for Dust Control" installations?

- What and where depicted are the TBM and Roadheader ventilation details indicated on the layout "to be separately shown"?

- How does the development side scheme relate to either or both of the Option A and Option B sketches presented later in the briefing in response to the separate Board Comment #12 regarding the study of alternate fresh air intake systems?

Another aspect of the above questions is the following further question:

- Is it intended that the TBM and Roadheader exhaust air discharge be ducted to the surface, or alternately, scrubbed in some manner underground and then released in the East Main for return to the surface?

We realize that the design is still in an early stage, but even if these and other matters are at present undecided, we are very interested in more detail about what is being considered and request further briefing in this area.

Emplacement Drift Ventilation Control

In Dan McKenzie's 4/24/97 presentation of repository ventilation, we received numerous sketches and diagrams which illustrated the intended control of air through the following four different stages of Emplacement Drift ventilation:

- Empty drifts which are on the emplacement ventilation system, (no waste emplaced).
- Active Drifts which have waste emplacement activities in progress.
- Drifts in which emplacement is complete and are in a performance confirmation state.
- Drifts which are in an off-normal waste package breach condition.

The information received was in response to Board Comment #10 in Board Report #4.

As we understand the 4/24/97 presentation, air flow which exits the emplacement drifts via the ventilation raises passes through monitoring instrument packages which have the ability to sense a Waste Package breach, and to measure air temperature, humidity, and other factors. Once through the monitoring package, the air flow can be directed by the controlled use of regulator valves and a door into either of two 6 foot diameter insulated ducts running longitudinally in the Exhaust Main, or, alternately, through an insulated door into the Exhaust Main directly. Air flow from the 6 foot diameter ducts can be passed around HEPA filters near the bottom of the Exhaust Shaft to join the emplacement side exhaust flow out the Exhaust Shaft in the normal mode, or alternately, be directed through the HEPA filters and then into the Exhaust Shaft in the off-normal situations.

Air is planned to flow through each empty drift at a minimum of about $5m^3/s$ (10,000 cfm). This air will pass through the open, insulated, access door then directly into the Exhaust Main. This air volume may be increased, if necessary, to supply additional cooling air to the Exhaust Main.

The volume of air flow through each of the active Emplacement Drifts will be controlled to maintain the air temperature for the gantry operations at or below 50°C. This air volume may be $5m^3/s$ (10,000 cfm) or more per active drift and will be directed by regulators into one of the 6 foot diameter insulated ducts running in the Exhaust Main. As explained above, this air flow will bypass the HEPA filters to join the Exhaust Shaft flow in the normal mode, or be directed through the HEPA filters in off-normal situations.

The volume of air flow through each of the Emplacement Drifts which are in the performance confirmation mode will be controlled to a very low air flow of about 0.1 m^3/s (200 cfm). This flow will be directed by regulators into the other 6 foot diameter insulated duct running in the Exhaust Main. Again, this air flow will bypass the HEPA filters and joint the Exhaust Shaft air flow in the normal mode, or be directed through the HEPA filters and then to the shaft in the off-normal situation.

In all off-normal situations involving a Waste Package breach, the monitoring package in the Emplacement Drift Raise would start the off-normal sequence of events. The flow in the contaminated exhaust duct would be switched by dampers to flow through the HEPA filters. The air flow from the contaminated drift could be increased or reduced, but would not be shut off. The direction of air flow would be maintained to prevent contamination spread. Monitoring data would be assessed to locate the source of the contamination. The air flow rate could be increased to about 50 - 60 m^3/s (120,000) cfm) if it is decided to cool the drift down to 50°C in order to deal with the breached WP. It is our understanding that a time period of 2 to 3 weeks would be required to accomplish this cooling.

Although not presented in the briefing, we suspect that when the repository is in the caretaker mode, the air flow from all the Emplacement Drifts could be directed into only one of the 6 foot ducts, thereby allowing maintenance to be performed on the other duct including its separate HEPA filter system. Similarly, in an off-normal situation in the caretaker mode, the air flows from the non-contaminated drifts could be directed into the unused or standby 6 foot duct as an additional protection against cross contamination.

We concur that the location of the HEPA filtration system should be subsurface near the base of the Exhaust Shaft to eliminate the need for installing and maintaining the two 6 foot diameter ducts in the Exhaust Shaft throughout the repository operation period.

All in all, we believe the above design concept to be sound in that it provides flexibility in operation and insures that the contamination from off-normal situations is contained in the individual Emplacement Drift, ducts, and filters, without interfering with other ongoing repository activities. We understand, however, that a potential problem lies in the development of detection equipment sensitive and reliable enough to detect nuclear contamination in exhaust air in the event of a WP breach.

When the PC drift designs are further along, the Board would appreciate a briefing explaining how they will be ventilated during the construction, emplacement, and caretaker phases.

Air Volumes Required For Ventilation

During Dan McKenzie's 4/24/97 presentation on alternate repository ventilation systems evaluation, he included a sketch entitled "OPTION A" which illustrates an intended air flow of 55,000 cfm being ducted into the 5.5 m Emplacement Drifts, 25,000 cfm being exhausted in duct work, and 30,000 cfm being exhausted as air flow in the open tunnel. We noted in our oral presentation that this air flow seemed excessively high. This is not the case. Upon further calculation and study, we conclude that the air flows presented, although perhaps a little high, are reasonable. Minimum air flows of 60 ft/min. for an idle tunnel and 100 ft/min. for an active tunnel, common in the tunnel industry, were presented by Dan McKenzie in an earlier presentation (see Airflow Velocity Criteria subvent7.ppt.124/8/26/96). That calculates to a minimum volume of 25,000 cfm for an unlined 5.5m emplacement tunnel during excavation. The effect of the precast lining would increase air flow velocity in the open tunnel somewhat. For reference, minimum velocities of 60 to 100 ft/min. in the 7.62 m Mains calculate to be 29,500 to 49,000 cfm which comports well with actual operational experience during ESF tunnel construction.

PERFORMANCE CONFIRMATION DRIFTS

Dan McKenzie presented a briefing on Performance Confirmation (PC) Drifts on 4/24/97 in response to Comments #6, #7, and #8 of Board Report #4.

While details of the PC requirements are still being developed, an assumption that 5 PC Drifts will be constructed has been adopted for present planning purposes. The Board judges this to be a reasonable number compared to the size of the repository. The Board is pleased to learn that the Design Team agrees that use of roadheader excavation should be minimized, and TBM excavation maximized, in construction of the PC Drifts.

A question has been raised about the possibility that PC Drifts located above the Emplacement Drifts might infringe upon the 10 CFR 960 requirement for 200 m cover over the repository. The Board hopes this will not be a controlling factor. Because we understand the intent of the 200 m requirement is to provide adequate cover over emplaced Waste Packages, it seems unreasonable to us to apply this criteria to the PC Drifts, which will not contain Waste Packages.

Comment #7 of Board Report #4 concerned the perception that cooling of the PC Drifts could have a large disturbing influence on temperature distribution around the Emplacement Drifts, so that PC measurements would not be a valid indication of repository behavior. Dan McKenzie explained that analyses by computer modeling of temperature contours over time following waste emplacement have indicated that disturbing thermal effects due to the presence of the cooled PC drifts will be minimal during the first 20 to 50 years after waste emplacement, which will be the most important time period for initial monitoring purposes. Only after longer time periods do disturbing thermal effects become significant. This influence can be monitored by use of instrumentation in long boreholes extending well away from the PC drift itself. The proposed use of a modest number of PC drifts (5), with instrumentation in long boreholes extending well away from the drifts, is in agreement with the board interpretation and prior suggestions. These factors, plus the apparent minimal influence of cooled PC drifts upon temperature contours during the first 20 to 50 years after the placement of waste, have provided a satisfactory response to the Board's earlier concern.

RESPIRABLE DUST ISSUES

4/24/97 Briefing Response to Previous Board Comments

The discussion and analysis of respirable dust issues in Board Report #4 was based on the Board's understanding of events and data from the ESF tunnel drive. We were concerned that several fundamental aspects of the ESF experience should not be applied to construction of the repository itself. The Board appreciates the collective efforts of Charles Parker, Thomas McManus and Russell Baumeister to brief us on respirable dust matters generally and, in particular, for providing answers to the four specific questions raised by us in Board Comment #18 of Board Report #4. From Mr. McManus' written response, we understand the following:

- Cristobalite and quartz constituents would not be expected to be higher or greater in the respirable dust portion of total airborne dust in the repository than for the balance of the total airborne dust.

- Cristobalite and quartz contents of the host repository rock can not be more accurately or more quickly determined by analysis of samples of the host rock itself rather than by X-Ray Diffraction Analysis of respirable dust samples. Further, current OSHA and NIOSH technical guidance requires that the silica content be determined through analysis of air samples.

- The level of accuracy that can be expected in determination of cristobalite and quartz constituents of respirable dust by X-Ray Diffraction methods is ± 20%.

- From an OSHA compliance standpoint, all 64 air samples taken ahead of TBM Deck 12 in the ESF after 10/7/96 reported in Exhibit 8, Board Report # 4 are considered valid. Further, the detection limit for both cristobalite and quartz by X-Ray Diffraction methods is approximately 30 micrograms per sample (0.03 milligrams).

Value of ESF Experience

The ESF experience has resulted in a tremendous quantity of data derived from X-Ray Diffraction Analysis of hundreds of respirable dust samples collected mostly in 1996 from a point when the TBM was approximately at ESF Station 44+00 to hole-thru in 1997. To our knowledge, the Board has been furnished all of this data through 2/26/97. We think it unlikely that this quantity and quality of air sample data on airborne silica has heretofore been available anywhere for underground construction. The DOE, M&O, and Constructor staffs are to be commended for their obvious concern when dangerous levels of cristobalite and quartz in airborne dust were detected and for their efforts in collecting and analyzing this mass of data.

The unprecedented magnitude of the underground excavation task for the construction of the repository that lies ahead, requiring adequate and safe ventilation, escalates justifiable concern with respirable dust issues. The importance of sensible application of what has been learned through the ESF experience is obvious. Therein lies the Board's concern expressed in Board Report #4.

<u>Application of ESF Experience to Repository Construction</u>

During ESF excavation, underground personnel were required to wear several different types of face respirators when, based on analysis of air quality samples, readings indicated by the "DataRam" air quality monitoring device indicated total respirable dust levels that were considered excessive. It is the Board's understanding that the level considered excessive was initially set at 0.350 mg/m^3, then reduced to 0.192 mg/m^3, and finally to 0.10 mg/m^3. Eventually, after consultation with various consultants and experts, operational procedures requiring respirator use until expiry of a set time period after any temporary cessation of TBM operation was instituted that, with some modification, was employed until hole-thru. This policy resulted from a statistical analysis of dust samples collected throughout all reaches of the ESF over a considerable period of time from which it was concluded that, for regulatory purposes, the percent of cristobalite and the percent of quartz that would be considered present in <u>all</u> of the dust in <u>all</u> areas of the ESF was 31.5% and 10.8%, respectively.

These percentages were determined at the 95 percentile level of all the air samples taken which was tantamount to considering only the most extreme 5% of the individual mineral constituency percentage determinations made from tests of the air samples. The Board viewed this procedure as inappropriate for repository construction and stated in Board Report #4 that the controlling analysis should be made for (1) individual discrete work areas of the larger project, and, (2) based on the mean of the air samples taken, not the 95 percentile.

The Board's present understanding is that at the procedures established during ESF construction were an initial response to the cristobalite problem, based upon the initial limited data obtained of uncertain reliability. We further understand that criteria for the construction of the repository will be based on a broader data base of actual dust composition, as discussed below and on an appropriate method of PEL calculation using average values implicit in the concept of time weighted averages. Specifically, we understand that for repository construction:

- Maximum quartz contents in dust samples measured at one location and time would not be combined with maximum cristobalite content measured at another location and time, to create a fictitious combination of quartz and cristobalite which does not actually exist. Instead, more data will be accumulated underground to determine what combinations of quartz and cristobalite actually exist together. These will form the basis of determining allowable dust levels.

- A PEL of 0.10 mg/m^3 will not arbitrarily be imposed

- "Confidence limits" taken at the 95 percentile will not be used in analysis of data for determination of allowable dust levels. Rather, the controlling analysis will be made on the mean of the mineral constituent contents for air samples taken at and within discrete work areas, not the repository at large.

The Board concurs that certain operations during repository construction at times will no doubt require respirator use and, in these situations, respirator use should be strictly enforced. The alternative would be to clean up all the air in the entire repository development by means of engineering controls to reduce the total respirable dust content to such low levels that unacceptable levels of cristobalite and quartz will not be present in the dust. As more fully explained below, we do not think it economically feasible to clean up the air by means of engineering controls simultaneously throughout <u>all</u> areas of future repository construction - which construction will constitute an enormous, unprecedented, underground complex.

<u>Engineering Controls vs Respirator Use</u>

The ESF experience after 10/7/96 (when a dust curtain/HEPA scrubber installation successfully reduced respirable dust levels forward of TBM Deck 12 to levels so low that the presence of cristobalite and quartz could not be detected) clearly demonstrated that exposure to harmful levels of cristobalite and quartz in the tunnel heading area can be eliminated efficiently.

In responding to question #4 in Board Comment #18 of Board Report #4 (see previous discussion), Mr. McManus stated, "It is our overall desire to lower silica concentrations in air samples to as low as feasible through effective engineering controls." We agree, provided that "as low as feasible" does not mean reduction of respirable dust levels to such low levels throughout the entire repository development simultaneously that respirator use would not be required <u>anywhere</u>.

Respirator use can be more easily tolerated in some areas (without unacceptable safety risk and adverse impact on job performance) than in others.

For instance, the adverse effect is far less where only a few workers are employed performing routine, repetitive, tasks such as track and utility maintenance, mapping, etc., behind the advancing heading (as opposed to TBM operation and erection of ground support, track, etc., at the heading). Similarly, the adverse effect on safety and operational efficiency of locomotive operators and others routinely transiting between the heading and the portal is minimal. Even if heading crews were required to wear respirators while in transit to and from the heading when changing shifts, operational efficiency would not be seriously affected (this should never be necessary because the period of possible exposure would be so short).

Once the concrete linings are in place in the Mains and Ramps, we expect that the respirable dust problem will be greatly diminished. The exposure to the mechanical and electrical trades installing piping, mechanical equipment, and controls in the completed Emplacement Drifts should therefore be minimal. However, the highly labor-intensive work of placing the concrete linings in the Mains, Ramps, and Turnouts conceivably might expose workers to the cristobalite risk and would be severely impacted if respirator use was required for those work crews.

Undoubtedly, cleaning up the air in the work areas immediately surrounding Roadheader operations will provide the greatest challenge. In the event a way can not be found to economically clean the air, respirator use may not be avoided in these limited work areas, in spite of the adverse consequences to job safety and efficiency of performance.

The practical need to clean up the air to avoid respirator use is clearly a variable and should be treated as such accordingly.

4/24/97 BRIEFING RESPONSE TO OTHER BOARD REPORT #4 COMMENTS

Approach to NRC Regarding NQA-1 Standards

Alden Segrest responded on 4/24/97 to Comment #16 of Board Report #4 concerning the need for application of NQA-1 standards to construction of repository underground openings.

He stated that the Design Team fully recognizes the adverse cost and schedule impacts of NQA-1 standards on underground construction. The Design Team's initial approach to the NRC will be to determine and demonstrate that NQA-1 standards are not necessary, possibly, for example, by demonstrating that rock falls will not seriously damage waste packages, or by showing that adequate redundancy will be provided in critical systems (electrical, control, communications, etc.) In instances where this approach is not successful, the Design Team will request use of a "graded" approach, which identifies the key features of the work for which some parts of the NQA-1 standards will be necessary, in contrast with other features for which NQA-1 standards are not necessary.

The Board agrees with this 2-step approach. However, we wish to call attention again to what we believe to be a fundamental difference between a) the Emplacement Drifts in which waste packages will reside for the life of the repository, and b) the Perimeter and Ventilation Mains, which are nothing more than transportation tunnels, totally accessible for inspection and whatever maintenance and repair may be needed, for as long as the repository is open, and which are planned to be backfilled when the repository is sealed for final closure.

Need for Key Decisions Effecting Repository Design

At the 4/24/97 briefing, Alden Segrest responded to Board Comment #13 from Board Report #4 (concerning the necessity for making key design decisions). He explained that the approach being taken by the Design Team was to press for the necessary decision as strongly as possible, but if it proves not to be possible to obtain the decision in time for VA design, to move forward with the VA design on the basis of a reasonable assumption. Then, it would be made clear in the supporting VA documentation that the design is based on that assumption and, if the assumption is changed, the design necessarily would have to be modified.

We agree that in the absence of the decisions themselves, the suggested procedure is about the only way the Design Team can sensibly proceed. The number of design changes required later will obviously depend on the extent to which the eventual decisions correspond to the assumptions made earlier.

Broad-Based Risk Analysis

Alden Segrest confirmed at the 4/27/97 briefing that it was still intended that the broad-based risk analysis suggested by the Board be deferred until mid 1998. Our concern remains that without at least parts of this risk analysis being made now, design could get so far ahead that later expensive and time consuming changes might become necessary after the 1998 risk analysis is carried out Obviously, the more consideration that can be given to risk analysis now, the less the likelihood for design changes later.

SUMMARY OF BOARD COMMENTS AND RECOMMENDATIONS

1. The Board concurs that a future site exploration program consisting of one east-west drift, together with some combination of additional surface boreholes, responds to our principle earlier concerns. We find the general nature of current understanding of site fault and fracture systems, as described in the 4/24/97 briefing, to be consistent with our personal observations in the ESF tunnel, and with our experience elsewhere at other underground construction projects. We await further details on the planned east-west drift.

2. Cast-in-place concrete operations for lining the Mains and Ramps will involve long transit time durations from surface mixing to underground placement for which retardation of set time will be necessary. Alternately, it may be found practical to consider in-tunnel mixing plants to reduce travel time and eliminate the need for concrete set retardation. To the extent the use of precast concrete can be considered, the set retardation problem is eliminated.

3. Although we believe initial testing of concrete mixes containing steel fibers is appropriate, we suggest that similar tests also be run for conventional concrete with normal ferrous reinforcing bars or mesh. The use of steel fibers may be found to be unnecessary and eliminating this use, reduces a potential source of long term corrosion of waste packages following eventual deterioration of the Emplacement Drift linings.

4. We request a future briefing to explain the intended concept and the essential configuration details of the "Local Bypass for Dust Control" installations presently contemplated for the repository development side ventilation plan.

5. We also request a briefing to more fully explain the intended details of the OPTION A and OPTION B sketches presented at the 4/24/97 briefing in connection with the study of alternate fresh air intake systems and a briefing resolving how the TBM and Roadheader exhaust air discharge is to be treated; i.e., is it to be ducted to the surface, or alternately, scrubbed in some manner underground and then released in the mains for return to the surface?

6. The Board concurs that the HEPA exhaust air filtration system should be located subsurface near the base of the exhaust shaft.

7. We concur that the present design concept for the Emplacement Drift Ventilation Control System will provide flexibility in operation and should

ensure that contamination from off-normal situations will be contained in the Emplacement Drifts, ducts, and filters, without interfering with other ongoing repository activities. However, the Board understands that there is a concern with the development of detection equipment sensitive and reliable enough to detect nuclear contamination in exhaust air in the event of a WP breach. Resolution of this concern is key to the success of the Emplacement Drift Ventilation Control System and we would appreciate an update on progress in its resolution.

8. The Board would also appreciate a future briefing when the PC Drift designs are further along, explaining how the PC Drifts will be ventilated during the construction, emplacement, and caretaker phases.

9. The Board concurs that the present Design Team assumption that 5 PC Drifts will be constructed is reasonable for planning purposes and that 5 such drifts seems a reasonable number compared to the size of the repository.

10. The Board does not believe that the 200 m requirement in 10 CFR 960 should apply to the PC Drifts since they will not contain waste packages and urges the Design Team to emphasis this position in their discussions with the NRC.

11. The results of present thermal model studies indicating the apparent minimal influence of cooled PC Drifts upon temperature contours around Emplacement Drifts during the first 20 to 50 years after the placement of waste resolves our earlier concern with possible thermal contamination resulting from the forced cooling of PC Drifts. We regard this issue as closed.

12. Early Emplacement Drift drives, made for ventilation purposes and to define the western boundary of the repository block, should be terminated prior to crossing the West Main alignment. If more investigation is required, it can be provided by means of exploratory core drill holes through the TBM cutterhead. The distance we visualize these early Emplacement Drift drives should be left short is slightly less than the length of the turnout connection with the West Main.

13. We recommend that the repository construction program be structured in a manner that eliminates unnecessary interference between concurrent construction operations to the maximum extent possible. In particular, the most efficient Emplacement Drift excavation operation and follow up Emplacement Drift finish operations can be achieved if the Mains and Ramps have first been concreted and muck discharge conveyors and

ventilation systems (with appropriate air locks) are installed prior to starting the major Emplacement Drift excavation operation.

14. We suggest that the location of the northern most muck transfer point in the East Main be moved to a point just south of the junction of the North Ramp and the East Main to eliminate confusion in traffic serving the tunneling and overall repository operation during the early phase of the Emplacement Drift excavation operation.

15. There should be no need for more than one or two major concreting spreads operating concurrently during repository development. The length of the Ramps and Mains lends itself to consideration of a continuous concrete placing operation as commonly utilized in the past for long tunnels. This possibility should be seriously considered.

16. The Board believes the repository development production rates presented at the 4/24/97 briefing are too low. We suggest the following for planning purposes:

    - The 7.62 m TBM advance in the mains be increased from 24 m/day to 35 m/day.

    - The 2 shift per day TBM operation for the 5.5 m Emplacement Drifts be changed to a 3 shift per day operation and the production rate increased from 20 m/day to 30 m/day.

    - The average concrete placing rate in the mains be increased to 50 m/day.

17. The Board is satisfied that recently obtained large Roadheader experience indicates relatively high machine availability percentages that should insure continual roadheader availability during repository development. We regard this issue as closed.

18. Based on our independent study and materials furnished by the Design Team staff, the Board concurs that the excavation method for the Development and Exhaust Shafts proposed in the 4/24/97 briefing appears to be the most efficient method. We suggest however that the concrete lining for these shafts be placed from the bottom up rather than following the excavation down from the top and that slip form techniques be considered for this phase of the work.

19. Regarding respirable dust issues, the Board currently understands that PEL limits for repository construction are presently intended to be determined on the following basis:

- Maximum quartz contents in dust samples measured at one location and time will not be combined with maximum cristobalite contents measured at another location and time, to create a fictitious combination of quartz and cristobalite which does not actually exist. Instead, data will be accumulated underground on a work area by work area basis to determine what combinations of quartz and cristobalite actually exist together in that work area. This will form then the basis of determining allowable dust levels.

- A PEL of 0.10 mg/m^3 will not arbitrarily be imposed for repository construction.

- "Confidence limits" taken at the 95 percentile will not be used in the analysis of data for determination of allowable dust levels. Rather, the controlling analysis will be made on the mean of the mineral constituent contents for air samples taken at and within discrete work areas, not the repository at large.

20. The Board does not believe it economically feasible to clean up the air by means of engineering controls throughout all areas of future repository construction simultaneously. Some operations during construction will, at times, require respirator use. Further, respirator use can be more easily tolerated in some areas than in others. The practical need to clean up the air to avoid respirator use in future repository construction is therefore a variable and should be treated as such accordingly.

21. The Board concurs with the Design Team's intended approach to the NRC regarding NQA-1 standards. We regard this issue as closed.

22. The Board also concurs with the present Design Team approach of moving forward with the VA design in areas that are dependent on key decisions that have not been finalized on the basis of reasonable assumptions regarding the nature of the future decision and then modifying the design, if necessary, if the eventual decision does not correspond with the assumption made. We regard this issue as closed.

23. The Board continues to urge that as many elements as possible of the previously suggested broad-based risk analysis (now scheduled to be performed in mid 1998) be performed now to avoid potential later expensive and time consuming changes in repository design.

SIGNATURE PAGE

The foregoing Report No. 5 of the Yucca Mountain Project Repository Design Consulting Board is submitted this 27 day of August 1997.

S. H. Bartholomew
s/ S. H. Bartholomew

Ronald E. Heuer
s/ Ronald E. Heuer

Jack K. Lemley
s/ Jack K. Lemley

Larry Snyder
s/ Larry Snyder

APPENDIX

Repository Consulting Board Meeting
Attendance list for April 22 and 23, 1997

Name	Affiliation	Telephone #
Ralph Dresel	M&O / ICMO / MK	295-4250
David Stahl	M&O / MGDS-WP Matl's	(702) 295-4383
Mark Tynan	DOE/AML LV	702 794 5457
Warren Day	USGS-Denver	303-236-5050 x269
Ralph Rogers	M&O/WCFS/SPO	702-295-5785
Ron Smith	M&O/WCFS/SPO	702-295-3453
Kal Bhattacharyya	M&O/Repository	702-295-4414
Dan McKenzie	M&O/Repository	702-295-4393
Mitch Brodsky	DOE	45437
Russ McFarland	NWTRB	702 225-4473
Keith J. Lobo	MTS	(702) 794-5424
Bill Seddon	AECL / DOE	702 794-5422
Robert Saunders	M&O Repository	702 295-4380
Rick Nolting	M&O/Repository	702/295-4450
Jaime Gonzalez	DOE/AML	702 794 5454
Dennis R. Williams	DOE/AML	(702) 794-1417
Ron Heuer	Repository Board	815-675-2003
Vic Dulock	M&O/TRW	702 295-4370
Alden Segrest	M&O DE&S	7022954416
Raymond J. Durante	Board member	703-276-8444
Jack Lemley	" "	208-345-5226
J.H. Bartholomew	" "	916-894-7411
Larry Snyder	" "	303 420 1544
Salomon Levy	SQF	408-369-6500
Russell Baumeister	YMP	702-794-5442
Mark VanderPuy	YMP	702-794-5563
Charles Parker	YMP	702-295-4807
Thomas McManus	M&O	~~702~~ 702-295-5420

SUMMARY OF DESIGN TEAM RESPONSE TO RECOMMENDATIONS CONTAINED IN BOARD REPORT #4

As presented in the April 24, 1997 briefing, the Design Team's response to earlier board comments contained in Board Report #4 is summarizes as follows:

Board Comment #1 - The Board sees no need for the 5.5 m TBM disassembly chambers shown on the Phase I and Phase II sketches accompanying the briefing presentation "Subsurface Construction and Development Sequence". The Board's concept is that the 5.5 m TBMs be designed for easy partial disassembly so that they can be quickly backed up through the installed support to the East Main.

Design Team Response:

- Agree with Board's concept
- Board's concept substantiated by information from TBM manufacturer
- Layout design based on TBM back-out concept - i.e., Emplacement Drift Turnout configuration and early excavated Emplacement Drifts accommodate back-out concept
- The 5.5 m TBM will be specified for backing out from the completed heading without need of disassembly chamber.

Board Comment #2 - The Board does not understand the intended ventilation concept for the "Subsurface Construction and Development Sequence" presented to us. We request that the intended concept be explained in greater detail at future briefings.

Design Team Response:

Consisted of an oral explanation by Dan McKenzie of a layout drawing entitled "TYPICAL VENTILATION BALANCE OF EMPLACEMENT/ DEVELOPMENT ACTIVITIES" which served to resolve Board uncertainties as to the intended system.

Board Comment #3 - The Board does not understand the intended function of the scrubber units shown at the end of a fully excavated Emplacement Drift near the East and West Mains on the Emplacement Drift construction sequence sketch accompanying the "Subsurface Construction and Development

Sequence" presentation. We need additional explanation for what is intended and/or how the operation is expected to work.

Design Team Response:

Same as for #2.

Board Comment #4 - The Board does not favor the planned utilization of excavated Emplacement Drifts for storage of construction material. Careful logistic planning should minimize the need for underground storage and rehandling.

Design Team Response:

- Agree with Board's position that careful logistics planning will minimize need for underground storage and rehandling
- As shown in the sketch, the intent was not to use emplacement drifts for wholesale storage of construction materials, but only as a routing for materials when material handling might otherwise interfere with construction activities in the main

Board Comment #5 - Although the development sketches provided to the Board are a broad-based first step in developing a construction plan for costing and scheduling purposes, the Board encourages the development of a more comprehensive and detailed construction plan in the near future.

Design Team Response:

- We are currently developing a more comprehensive schedule for construction, development and emplacement
- The schedule for repository development follows the methods and sequence discussed and agreed to with the Board
- A Primavera "Bar Chart" schedule will be presented to the Board when completed - Deliverable due to DOE July 31, 1997
- The following viewgraphs explain repository construction sequence

Phase 1

- Excavate launch chamber by roadheader for 7.62 m TBM at bottom of S. Ramp
- Excavate by roadheader the three early emplacement drift turnouts along East Main

- Complete installation of cast-in-place concrete lining in East Main and commence lining in West Main
- Remove muck from Emplacement Drift TBM by railcar and dump onto East Main conveyor
- Load muck from Turnouts and Ventilation Raises into railcars for transfer to East Main conveyor or surface

Phase 4

- Complete construction of Emplacement Shaft and installation of surface fans and associated structures
- Continue excavating and lining Emplacement Drifts
- Excavate chambers for HEPA filters and adsorption units
- Raisebore and concrete line ventilation shafts between Emplacement Drifts and Exhaust Main
- Complete installation of Cast-in-Place concrete lining in perimeter mains, and Exhaust Main
- Construct Isolation Airlocks between Emplacement and Development sides
- Finish first block of 4 to 8 (TDB) Emplacement Drifts with gantry track, electric power, doors and actuators, monitoring and control systems, etc.
- Finish E. and W. Mains with emplacement track, utilities, electric power, and monitoring and control systems, etc.
- In Exhaust Main install duct work, gates, and monitoring and control systems for emplacement exhaust air system
- Commission completed Emplacement Drifts. Constructor will check dimensions, clearances, etc. on development side. After handover Waste Emplacement Operations will perform systems operation tests on Emplacement side.

Phase 5 (Note: corresponds to Board's Phase 5 & 6)

- Continue excavating, lining, and equipping Emplacement Drifts
- Move muck dump to next location as development advances southwards
- Continue raise boring and concrete lining ventilation raises
- In Exhaust Main continue installing duct work, gates, and control and monitoring systems for emplacement exhaust air system
- Continue installing emplacement track, utilities, electric power supply, and monitoring and control systems in E. and W. Mains
- Install Isolation Airlocks every 20 drifts (TBD)
- Continue handover and commissioning completed Emplacement Drifts

Board Comment #6 - The limiting cases illustrated in the briefing material for Performance Drift construction involved driving a large number of drifts above and across the repository block, representing construction activity into the range of 10% - 20% of the balance of repository construction. The Board discourages such a concept for providing access for performance confirmation purposes and hopes a way can be found to provide the necessary access without embarking on such a huge construction undertaking.

Design Team Response:

The Performance Confirmation Program is still in a very early stage of development.

The design team has prepared, and presented to the DOE, several options for gaining access to acquire the needed data.

The Board's comment has been noted, and will be considered in the decision process.

The VA design must include a specific option due to the fact that a cost estimate is required. The option incorporating 5 cross drifts (~ 5% of the total repository drifting) will likely be assumed for VA costing.

Board Comment #7 - The thermal studies presented to the Board of Performance Drift Confirmation cooling to achieve a tolerable working environment for instrumentation suggests such a major disturbing influence on temperature distribution above the repository that PC measurements would not be a valid indication of repository behavior. This indicates to the Board the desirability of using a smaller number of PC Drifts in order to minimize disturbance effects with most instrumentation located in long boreholes extending beyond the disturbed cooled zone around the PC Drifts.

Design Team Response:

Preliminary input from Performance Assessment indicates that the cooling effect noted in the thermal modeling is not a significant problem.

There may actually be a positive aspect, as it will allow examination/evaluation of the "boiling/sub-boiling" interface.

May allow validation of computer models to predict post-closure behavior of the "thermal front".

In addition, the passage of air will remove significant moisture, which is likely to be considered quite favorable to performance.

Much work remains before final PC plans are made.

Board Comment #8 - The Board recommends against any further consideration of excavating Performance Confirmation Drifts by roadheader methods. We favor layouts that permit TBM excavation.

Design Team Response:

The design team agrees that roadheader excavation is much less cost effective than TBM excavation.

Appl.cation of the 200 meter cover criterion can make it difficult to locate potential PC drift alignments.

Clarification of the application of this criterion is needed to guide future design of PC drifting.

Board Comment #9 - The Board recommends that a minimum of 2 east-west cross block drifts be driven by TBM methods as soon as possible. These cross block drifts would meet the same objectives to be obtained by the previously recommended early excavation of selected Emplacement Drifts. We suggest the first drift extend from the North Ramp westerly above and across the repository to the area where the west boundary of the repository is now expected to be located. We recommend the second drift extend similarly from the existing South Ramp. These cross block drifts can later be used for performance confirmation purposes. If it is eventually concluded that additional PC Drifts are needed, they can best be excavated during repository operation by TBM methods from a north-south tunnel extension off of the same breakout from the South Ramp as that utilized for the second of the recommended two early drifts.

Design Team Response:

Overview

- Recently completed or soon to be completed studies have added to the knowledge of the repository area.
- Two major change requests are in progress to expand Site Exploration to serve a variety of scientific, design and construction interests.
- This presentation provides an overview of anticipated Site Exploration programs focused on how they impact the repository design.

- The site Exploration programs are anticipated to include:
  - One East-West Drift
  - Four to Seven Boreholes
  - A Saturated Zone Testing Complex

<u>Repository Host Horizon (RHH)</u>

- Consist of lower TSw1 and TSw2
- A zone of relatively low lithophysae
- Geophysical density log average > 2g/cc
- Upper boundary generally recognizable by borehole video
- Overlies the basal vitrophyre, TSw3

<u>Repository Design Objectives for Site Exploration</u>

- Define the Western Perimeter
- Provide Input to Emplacement Drift Orientation
- Assess Key Constructability Issues

<u>Defining the Western Repository Boundary</u>

<u>Objective of Repository Design:</u>

Get all the useable real estate possible without encroaching on a ground condition that would necessitate design changes.

<u>Key Issues:</u>

- Location and condition of the Solitario Canyon Fault and its splays
- Depth to the vitrophyre

<u>Recent Reports</u>

1.	ISM2.0: A 3D Geologic Framework and Integrated Site Model of Yucca Mountain	M&O	Feb. 1997
2.	Determination of available Volume for Repository Siting	M&O	Apr. 1997
3.	Integrated Fracture Data in Support of Process Models, Yucca Mountain, Nevada	USGS	Apr. 1997
4.	Geology, of the Main Drift-Station 28+00 to 55+00, ESF, YMP, Yucca Mountain, Nevada	USBR, USGS	1997

<u>Solitaro Canyon Fault Geometry</u>

- Extensive surface mapping by USGS

- Surface outcrops
- Fault dips
- Surface geophysics
- 3-D modeling constraints to fit geometry and kinematics

Site Exploration Change Requests

- Boreholes WT-24 & SD-6
- Enhanced Characterization of the Repository Block

Boreholes WT-24 and SD-6

Borehole WT-24

To investigate the steep hydraulic gradient north of the repository area and gain additional stratigraphic data.

- LM 300 Rig; 12 1/4" Borehole; HQ3 Core
- Depth = 2800 ft.; Water table @ 1600 ft
- Samples:
  - ♦ Cuttings
  - ♦ Core 300 ft at the water table
- Geophysical Logging

Borehole SD-6

To obtain stratigraphic, hydrologic, and geotechnical information in the west-central repository area

- LM 300 Rig: 12 1/4" Borehole; HQ3 core
- Depth = 2600 ft; Water table @ 2300 ft
- Samples:
  - ♦ Cuttings
  - ♦ Core - 4 intervals totaling 430 ft with 100 ft in TSw2
- Geophysical Logging

Enhanced Characterization of Repository Block Program

- Currently in the planning stage
- "Best Guess" of options being considered
- Key decision input groups
  - Performance Assessment
  - Design/Construction
  - License/Regulatory

- Site Evaluation
- Controls and Requirements

Enhanced Characterization Program Likely Elements

- East-West Drift
- Southern Crest Borehole
- Northern Borehole
- Solitario Canyon Fault Angle Borehole
- Twin Water Table (WT) Boreholes Across the Solitario Canyon Fault (SCF)
- Southern Testing Complex

East-West Drift

Status

- Several options are being considered by the five groups with direct interest in this exploration
- Highest probability; either a single north or central drift

Data Needs Addressed

- Cuts across the full depth of the RHH
- Provides direct measures of constructability
- Identifies possible, unexposed faults
- Provides extensive data on fractures
- Provides geotechnical properties of the rock in and near the faults
- Aids in establishing emplacement drift orientations
- Evaluates health & safety issues of dust and hazardous minerals
- Provides access for in-situ geotechnical testing
- Provides access for in-situ testing of the SCF
- Provides access for in-situ hydrologic testing
- Examines multiple units of the TSw2

Southern Crest Borehole

Status

- High probability

Data Needs Addressed

- Elevation of the basal vitrophyre

- Spatial distribution of the strata
- Distribution of hazardous minerals in the rock
- Distribution of zeolites
- Gas flow patterns and distribution of gaseous environmental isotopes
- Spatial distribution of moisture tension and saturation in the rock
- Elevation of the water table

<u>Northern Borehole</u>

<u>Status</u>

- High probability

<u>Data Needs Addressed</u>

- Elevation of the basal vitrophyre
- Spatial distribution of strata
- Distribution of hazardous minerals in the rock mass
- Distributions of zeolites
- Age and distribution of perched water
- Gas flow patterns and distribution of gaseous environmental isotopes
- spatial distribution of moisture tension and saturation in the rock
- Elevation of the water table

<u>SCF Angle Borehole</u>

<u>Status</u>

- Depends on location of the E-W drift

<u>Data Needs Addressed</u>

- Rock conditions on either side of the northern splay and the position of the splay at depth
- Spatial distribution of strata
- Moisture condition in the vicinity of the splay

<u>Twin WT Boreholes Across SCF</u>

<u>Status</u>

- Medium probability

<u>Data Needs Addressed</u>

- Hydraulic properties of the fault
- Saturated zone flow conditions

Southern Testing Complex

Status

- Medium probability

Data Needs Addressed

- Saturated zone flow
- Saturated zone transport of radionuclide
- Saturated zone dilution and mixing
- Western Repository Boundary needs can be addressed using:
  - Existing data, maps and reports
  - A single East-West Drift
  - SCF Angle Borehole
  - Northern & Southern Boreholes
- Emplacement Drift Orientation needs can be addressed using:
  - Fracture distribution in the Repository Host Horizon from the ESF and E-W Drift
  - Fracture information in proximity to the fault
  - Elevation of the top of the vitrophyre and top of RHH from the boreholes
- Constructability needs can be addressed using:
  - TBM performance related to geotechnical parameters in the ESF and E-W Drift
  - Dust and hazardous rock minerals based on tunneling and borehole data

Board Comment #10 - The Board requests that the issues of the intended degree of air flow through Emplacement Drifts in both normal and off-normal situations, air quality monitoring arrangements, and how contaminated air will be isolated be revisited in future briefings.

Design Team Response:

Stages of Emplacement Drift Ventilation:

- Drift on Emplacement Ventilation System, but no waste yet emplaced
- Active waste emplacement

- Emplacement complete, drift in Performance Confirmation Mode
- Off-normal

<u>**Ventilation of Empty Emplacement Drifts**</u>

- Empty emplacement drifts will be supplied a minimum airflow of approximately 5 m^3/s
- This volume may be increased if needed to supply cooling air in the Exhaust Main
- The air which passes through empty Emplacement drifts flows back to the Emplacement Exhaust shaft via the Exhaust Main

<u>**Ventilation of Emplacement Drifts During Active Emplacement Operations**</u>

- Once waste emplacement is started in a drift, its exhaust airflow is directed to a duct network in the Exhaust Main
- The volume of air supplied will be sufficient to maintain the temperature in the gantry operations area at or below 50°C
- Several emplacement drifts may be active at any one time
- This may be required in order to avoid placing very hot or very cool waste packages adjacent to each other
- Airflow will be managed using a control system to increase/decrease flow as needed among the active drifts

<u>**Emplacement Drift Fully Emplaced and on PC Mode**</u>

- After emplacement is completed in a drift, it is ventilated with a very low, continuous flow of ~ 0.1 m^3/s
- This flow will help remove water vapor, can be monitored for signs of waste package leakage [*This is currently being evaluated for feasibility of detection*], and helps ensure that flow remains in the proper direction
- This flow is directed into the ductwork in the Exhaust Main, and controlled by valves

<u>**Ventilation of Emplacement Drifts During Off-Normal Conditions**</u>

- The off-normal condition assumed for this discussion is a WP breach
- Radiation detected above the set-point of the monitoring system in the ductwork in the Exhaust Main would initiate the off-normal sequence
- The flow in the two exhaust ducts would be automatically switched, by dampers, to flow through HEPA filters

- The location of the filtration system is under consideration. Both surface and subsurface locations are being considered
- Airflow volume would be reduced, but not shut off. The direction of flow should be maintained to prevent contamination spread should the airflow direction reverse
- Monitoring data will be assessed to locate the source of the contamination
- If it is decided to cool the drift for equipment reentry, a flowrate of 50-60 m^3/s would be applied through the drift
- This may require an auxiliary fan/filtration unit in the Exhaust Main in order to handle the large flow rate

Board Comment #11 - The Board looks forward to reviewing after July 1997 the preliminary list of Construction & Backfill Equipment which we understand will describe the salient attributes and functions of the several major types of required underground construction equipment, including the dust reduction and control features.

Design Team Response:

- Will brief board on the construction & Backfill Equipment list when ready

- A similar list will be prepared for ventilation equipment, which will be ready in September.

Board Comment #12 - The Board looks forward to receiving the results of the Design Team's investigation of the alternate fresh air intake system proposed by the Board in Board Report No. 2 which we understand should be completed in the April 1997 time frame. Perhaps a briefing on this subject can be presented at the upcoming 4/24 & 4/25/97 meetings.

Design Team Response:

<u>Development Ventilation System Evaluation</u>

- The design analysis which will document ventilation work is due to discipline check on June 9, 1997
- Work is not yet completed, but sufficient information is available to present the options
- Two primary options, ("A" & "B") are being evaluated

(i) Option A

Intake and Exhaust air streams are carried in ductwork from the bottom of the intake shaft to the working faces, and from the faces back to the surface at the South Ramp Portal

Intake duct volumes exceed exhaust volumes so that airflow is maintained in the drifts

(ii) Option B

Primary airflow is in the drifts, with ductwork used only in locations where excavation is ongoing

Option A: Advantages:

Air can be delivered to the working faces without significant dust exposure. This option has the highest probability of operation within the TLV

Option A: Disadvantages:

- 18 - 20,000 meters of large diameter duct, and 50-60 fans are needed
- Power consumption is considerably higher than Option B
- Operations will be interrupted for TBM movement & re-launch
- Complexity of the system

Option B: Advantages:

- Lower power consumption/less capital expense
- Simple system

Option B: Disadvantages:

- Potential for higher dust loading in intake airstream
- Higher requirement for scrubbing (at dust generation points and along main airways)

Board Comment #13 - The Board does not see how it will be possible to complete the deliverables that were described as necessary and due by June, July, August, and September of this year without first making several important decisions necessary to provide the basis for the schedule, sequence, and priorities for the physical development of the repository (i.e., type of tunnel linings for the Mains and Emplacement Drifts, mapping, types of TBMs to be used, ventilation scheme, and level of assumed funding). The Board encourages early decisions, preferably by the time of the 4/24 & 4/25/97 meetings, if the dates outlined to us for the deliverables to be completed during the balance of 1997 are to be met.

Design Team Response:

The approach to be taken for VA purposes will be to press for the necessary decision, but if it is not possible to obtain the decision in time for the completion of the VA design, to make a reasonable assumption and base the design on that assumption. In the VA documentation, it would be made clear that the design is based on that assumption and might have to be modified if the eventual final decision proves to be different.

Board Comment #14 - Although we concur that the broad-based risk analysis suggested by the Board (see Recommendation #11, Board Report No. 3) can be deferred until mid 1998, interim steps in this process of risk analysis will prove useful to the design, development, and viability assessment efforts underway now. Each interim step will reinforce identifying aspects of the facility in the process of its development that need attention from a risk standpoint.

Design Team Response:

The broad based risk analysis referred to by Comment #14 to Report #4 is presently intended to be deferred until mid 1998.

Board Comment #15 - The Board suggests that concerns stressed in the last briefing with the Board proposed solution in Board Report No. 3 to accommodate Ventilation Raises as long as 30 m might not be satisfactory (because it would result in a low point in the Ventilation Main within the geographical confines of the Emplacement Drifts), could be alleviated by driving a small down-grade drift by drill and blast methods from the low point in the Ventilation Main northwestwardly a sufficient distance to lead any accumulated post closure drainage well away from the Emplacement Drift area.

Design Team Response:

- VA design will show 10 m raises, preliminary analysis indicates this length as adequate.
- A drill & blast excavated drainage decline as proposed will be considered but will require further analysis, including PA assessment

and a determination as to effectiveness of drainage from a single heading.

Board Comment #16 - The Board remains skeptical of the need for requiring construction of repository underground openings to NQA-1 standards, particularly for either the temporary support or the final lining of the Mains and Ramps. A more complete statement of our views on this subject appeared in paragraph 3 at page 21 of Board Report No. 3 and need not be repeated here.

Design Team Response:

The approach that will be taken in discussions with the Nuclear Regulatory Commission will be a 2-step approach:

First Step - Try to eliminate the requirements entirely.

Second Step - If the first step fails, attempt to secure a "graded approach" to the standards. That is, an approach where the more time consuming and obviously unnecessary parts of the standards be relaxed while maintaining other parts of the standards.

Board Comment #17 - Imposition of a PEL as low as 0.10 mg/m^3 for total respirable dust as a design standard for future repository construction will unnecessarily burden the planning and construction effort and will result in a tremendous cost penalty for the construction of the repository facility. The Board believes that the PEL for sequential advancing reaches of future tunnel headings can more reasonably be determined by a procedure similar to that illustrated by Exhibits 4 through 7 of this report. We believe such a procedure would be appropriate in light of the ACGIH commentary on the nature of Threshold Limit Values (TLVs) and consideration of the reality that the future repository construction will involve a gigantic diverse series of separated tunnel reaches as opposed to a single confined area typical in surface industrial work environments.

Design Team Response:

There was no formal written response from the Design Team to this comment. Charles Parker stated orally that it had never been suggested that the design standard be set as low as 0.10 mg/m^3. Thomas McManus stated that "it is our overall desire to lower silica concentrations in air samples to <u>as low as feasible</u> (underline added) through effective engineering controls. (See response to Question #4 of Board Comment #18.)

Board Comment #18 - The Board requests briefings by appropriate experts from the scientific community to answer the following questions in the respirable dust area:

- Would the cristobalite and quartz constituents be expected to be higher for the respirable dust portion of total airborne dust than for the balance of the dust, or would one expect these constituents to be uniformly distributed?
- Can the cristobalite and quartz contents of the repository host rock be more accurately and more quickly determined by analysis of samples of the host rock itself rather than by X-Ray Diffraction methods of respirable dust?
- What level of accuracy can one expect from the X-Ray Diffraction determinations of cristobalite and quartz contents of respirable dust by the X-Ray Diffraction method utilized thus far at the ESF?

Are the cristobalite and quartz percentages reported in the 64 samples taken ahead of Deck 12 after October 7 shown in Board Exhibit 8 real, or does this data simply reflect that there was not enough respirable dust detected to determine its mineral constituents?

Design Team Response:

Question 1: As with any nonhomogeneous materials, the native rock will have varying concentrations of cristobalite, quartz and other minerals from location to location. When mining activities are performed, rock is broken and fractured into dusts of varying sizes, including respirable particles less than 10 microns in size.

The M&O has no specific data, nor have we found a literature reference, to indicate that silica polymorphs in dust vary in concentration based on particle size alone. The concentration is more likely related to the original concentration in the rock, and does not physically or chemically change through the mechanical means routinely employed in mining and tunneling. The concentration of certain silica materials notably amorphous silicates such as diatomaceous earth, can be changed into cristobalite by intense heating, such as through vulcanism. However, this is the only notable method to convert one form of silica to another.

While a concentration gradient by particle size if it exists maybe of some curiosity, it really has no bearing on the health effects of exposure to silica, when all we are concerned with is the exposure to deep alveolar lung deposition of fine respirable particles. In this case, analysis of the respirable particulate for their silica content is the most important health consideration, and this is why it is measured during routine compliance monitoring.

Question 2: No, and more important, current OSHA and technical guidance on the subject from NIOSH requires that the silica content be determined through the analysis of air samples for compliance purposes. There is no OSHA requirement or any other agency recommendation to take bulk samples for this purpose.

Question 3: The current sampling and analytical error (SAE) for the NIOSH 7500 X-ray diffraction (XRD) method used by OSHA is 0.2 or 20%. The relative error is the same for both bulk sample and air sample analysis as the method is identical with the exception of collection methods.

While this SAE is not as good as desired, it is the best currently available for the type of work being done at YMP, and fulfills our regulatory requirement.

According to Mike C. Rose, Analytical Chemist for the OSHA Salt Lake Technical Center, "X-ray diffraction is the most universal method for the measurement of quartz in mineral dusts and industrial matrices." Mr. Rose also quoted that "X-ray diffraction is the method used by OSHA for compliance and consultation analyses and by MSHA for metal and non-metal mining. "It is also the consensus method recommended by the Chemical Manufacturers Association (CMA) Crystalline Silica Panel."

Question 4: From an OSHA compliance standpoint, all of these samples are valid, and the lack of overexposures in this partial sample set was used as justification to discontinue respirator use forward of the TBM Deck 12 curtain. These results show that the dust filtration system installed has been very effective in reducing dust levels for a portion of the TBM. Similar effective controls are needed in all areas of the tunnel and TBM to eliminate other employees from the burden of respirators.

We have also noted that higher dust loadings are more likely to produce detectable cristobalite and quartz levels. This has to do with the detection limits for cristobalite and quartz, which are approximately 30 micrograms per sample for accurate quantiation. It is our overall desire to lower silica concentration in air samples to as low as feasible through effective engineering controls. The set of samples selected by the Board to examine, focuses on the one area where this desire has been a success.

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May 22, 1997

Wesley E. Barnes
YMSCO Project Manager
U. S. Department of Energy
Yucca Mountain Site Characterization Office, M/S 523
1551 Hillshire Dr., Suite A
Las Vegas, Nevada 89134

Dear Mr. Barnes,

Enclosed is a final copy of the Yucca Mountain Project Repository Design Consulting Board Report No. 4. This report pertains to the briefings and consultations held in Las Vegas on February 20 - 21, 1997.

Very truly yours,

S. H. Bartholomew

S. H. Bartholomew
For the Board

cc: Stephen Brocoum (DOE) w/enclosure
L. Dale Foust (TRW) w/ enclosure
Richard Snell (TRW) w/ enclosure

YUCCA MOUNTAIN PROJECT

REPOSITORY DESIGN CONSULTING BOARD

REPORT NO. 4

May 1997

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EXECUTIVE SUMMARY

This report first reviews the chronology and briefing information received by the Repository Design Consulting Board during meetings with the Repository Design Team on 2/20 and 2/21/97. A verbatim statement of the 20 specific Board recommendations listed in Board Report No. 3 and the Design Team's responses to each is included in the Appendix to this report. The context for the Board commentary and recommendations contained in this report was established by the Design Team's responses to the Board's previous recommendations.

This report first notes Dr. Steven Brocoum's characterization of the Viability Assessment document for future guidance of the Board and Design Team. Also noted are Richard Snell's remarks to the Board on the Design Team's perspective on Viability Assessment Design and Engineering/Science Community/Performance Assessment Group interfaces.

Board commentary in this Board Report No. 4 commences with the Board's reaction to several areas in the briefing received on Repository Staging and Schedule. Specific Board concerns involve several details of the Design Team's development phasing sketches and Emplacement Drift sequence sketches. This report also emphasizes a general Board concern that, although efforts to date are a broad based first step, the Repository Construction & Staging Plan must be developed in greater detail in the near future.

This report then discusses Board views on the possible configuration of cross-block drifts to be utilized for repository Performance Assessment purposes. The report particularly makes the point that the chances of distorting the data obtained due to thermal interference from Performance Drift cooling will be greatly decreased by limiting the number of drifts to the minimum possible and utilizing long directional-drilled boreholes from the drifts for containing the measuring sensors. This report also contains the Board recommendation that two cross-block drifts be driven as soon as possible to be used first to provide additional mapping opportunities and to define the western limit of the repository, and then to eventually serve as Performance Assessment Drifts during repository operation. This report also contains the Board recommended configuration and location for these first two drifts as well as how, if more Performance Assessment Drifts are later found to be necessary during repository operation, they can be driven by TBM methods from the same access as utilized by the southernmost of the initial drifts driven and, thus, without interfering with continuing repository operation. Finally, the point is made that the location and configuration of the Performance Assessment Drifts should be such that they can be excavated by TBM methods.

In other areas of performance monitoring, this report expresses several Board questions regarding Emplacement Drift ventilation air quality monitoring, safe handling of contaminated air in the event of a leaking Waste Package, and requests re-examination and additional briefing from the Design Team concerning these matters.

The report then presents Board commentary on Design Team responses to previous Board comments contained in Board Report No. 3. Most of this commentary is to the general effect that many of these issues appear to be approaching closure, in most cases with Board and Design Team concurrence. Several important issues are mentioned on which the Design Team has not yet had time to respond, or for which the Board has concerns with the substance of the Design Team response. An example of the former involves the general ventilation concept to be adopted for the repository development phase. An example of the latter includes Board concern for the need for several decisions to provide the basis for the schedule, sequencing, and priorities for the physical development of the repository, in turn necessary to complete a number of Design Team contract deliverables due in June, July, August, and September of this year.

The Board is particularly concerned with the need for development of a schedule of activities that must be completed prior to receiving the construction license for the repository. This report makes the point that timely completion of these activities will have a far greater impact on the eventual cost of the development than almost any issue to be faced during actual construction operations. This report cites a 1978 study by the National Academy of Science to the effect that the institutional factors related to funding and the political decision making process, among others, added the greatest cost and the most frequently caused delay.

This report reiterates that the Board would like to see a firm sequence of construction activities and the primary details of the approach to be taken before agreeing to the adequacy of the proposed schedule and any accompanying equipment lists, etc. As these decisions are firmed up, comments on the physical development schedule can then be made. However, this report confirms the Board's opinion at this time that with proper advance planning the first 8 or 9 Emplacement Drifts can be ready for the emplacement of waste within 5 years of the beginning of the repository construction.

This report reiterates that the Board remains skeptical of the need of requiring construction of repository underground openings to NQA-1 standards, particularly for either the temporary support or the final lining of the Mains and Ramps. The Board's position on this issues remains as stated in Board Report No. 3.

This reports concludes with the discussion of the Board's independent assessment of the ESF experience with the problem of respirable dust found to contain cristobalite and quartz (silicon dusts known to be harmful to underground workers). After listing and discussing the briefing information received to date and studying data obtained from the large number of respirable dust samples collected during ESF construction, the report states the Board's conclusion that, although the concern with respirable dust containing harmful constituents is very real, application of the philosophy for assessing the health risk and the regulatory standards adopted for the ESF tunnel construction are unnecessarily conservative for application to the construction of the actual repository. The report further states our opinion that if this approach is applied to the repository construction without modification, it will unnecessarily burden the planning and construction effort and will result in a tremendous cost penalty for the construction of the facility.

The report also contains the Board's suggested approach to setting appropriate standards for limiting quantities of respirable dust to be met during repository construction. Such standards are required for the use of the Design Team in planning the ventilation scheme and engineering controls to assure a safe air quality in various work areas of the repository during construction. This report also poses four additional questions relative to the assessment of the respirable dust risk that we believe will aid in the eventual resolution of the problem.

This report closes with a listing on page 25 of 18 specific comments and/or recommendations related to the foregoing issues.

A total of 8 exhibits pertaining to the respirable dust discussion is included in this report.

BRIEFING CHRONOLOGY AND INFORMATION RECEIVED

2/20/97 Introductory Remarks

Dr. Stephen Brocoum briefly addressed the Board prior to the formal briefing sessions. He emphasized that the Viability Assessment document was not intended to be the "decision" regarding the acceptability of Yucca Mountain as the repository site but rather was intended to be information provided to the decision makers in order to provide a continuum for effective debate. The actual decision will not be made until 2001 per the provisions of the Nuclear Waste Policy Act. The Viability Assessment document is also linked to the interim storage issue. Its contents and format will be defined by project personnel. The Board was referred to a document containing the remarks made by Dr. Dreyfus to the Nuclear Waste Technical Review Board on October 9, 1996.

Dr. Brocoum defined four separate divisions of the Viability Assessment document and emphasized that all four must be consistent with and compliment each other. They were:

- Repository Design - To be well enough defined to clearly explain the project and to serve for costing purposes.
- Total System Performance Assessment (TSPA) - A comprehensive assessment of performance for the repository.
- License Application Plan - To define how much work remains to be accomplished prior to license application and what it will cost to accomplish.
- Total Life Cycle Cost Estimate - Defining the total cost of the repository from inception until it is closed.

A companion document entitled "Project Integrated Safety Assessment (PISA) is to be completed in September of 1998 also. This document is intended to be a source document for answering various questions likely to be asked concerning the construction and operation of the repository.

Dr. Brocoum also indicated his general agreement with the Board's proposal contained in our letter of February 13, 1997 for the formation and operation of an expanded board to be entitled the "Mined Geologic Disposal System (MGDS) Consulting Board".

Richard Snell then addressed the Board under the following general headings.

General Discussion

- Engineering and Integration Project Status - The Phase I design was scheduled to be complete by 9/97. Issues effecting this task include determining what performance requirements must be met, what kinds of issues are involved, etc. The design is still being carried forward under the NRC charter for a 70,000 MT Repository, 10% of which is military waste, but a request has been made by EPA to accept additional waste with different characteristics (not presently in the 70,000 MT allowance). Since the Environmental Impact Statement (EIS) has to address what other kinds of waste might eventually have to be included, the Design Team is required to furnish data to the drafters of the EIS even though the repository is not presently being designed for waste in excess of the original 70,000 MT.

- Responsiveness to the Consulting Board - Difficult questions can be anticipated from all directions. The Board is performing a valuable function by raising these questions at an early point in time. The Design Team is endeavoring to be as responsive as possible to the Board's questions.

- Design Team Resources - Design Team resources are limited and the necessity to meet contract commitments for project deliverables may delay answers to specific board questions. When this appeared likely, Mr. Snell suggested that the Design Team and the Board discuss the problem and agree on a future date when time will permit a responsive answer.

- Priorities - The Design Team is charged with two distinct kinds of requirements. First, how to isolate waste for a 10,000 year period (this is the primary design requirement.). Second, how to deal with pre-closure safety issues. Since precedents exist, less immediate effort is necessary for this second task.

Perspective on Viability Assessment (VA) Design

- Issues Resolution - An original list of 13 Viability Assessment issues has now been expanded to approximately 20 issues. The current plan is to resolve these by 3/97. If options exist, they need to be identified. Design is to go forward on presently preferred options even though others could eventually become necessary.

- June Review - A two-day design review is planned for 6/97. This is intended to be a relatively high level review for the purpose of identifying risks and how they are to be met. Also considered will be a typical list of "what ifs" and how they will be dealt with. Also, it is intended that the team develop a rough idea of total project costs. The bottom line is to answer the question, "Are we on the right track?"

- Phase 1 Design Completion and Performance Assessment Interface - Phase 1 Design completion is scheduled for 9/97. It is intended that issues raised during the June Review will be responded to in the completed Phase 1 Design.

- Viability Assessment Submittal - The VA document is scheduled to be submitted in 8/98. The design level reflected at this time will be more detailed than for the Phase 1 Design.

Engineering/Science/Performance Assessment Interface

The Performance Assessment Group needs about 1 year to run their models on information the Design Team produces. The Performance Assessment Group has to produce their portion of the TSPA document previously discussed. To perform their task, they also need input from the Science Group. The Design Team is not waiting until completion of the Phase 1 Design in 9/97 to furnish data to the Performance Assessment Group - it is going to them now as it is developed.

- Adequacy of Data - The concern here is whether the source data is adequate. Is enough known about the PA conclusions to assure the design is on track (this is a "moving target" because standards and applicable time frames keep changing).

- NWTRB Views - The NWTRB's previous understanding on groundwater infiltration has changed. Also, there is still concern over the stratigraphy and other geotechnical characteristics of the repository block (particularly concerning the lower western part of the block). The NWTRB wants horizontal cross-block drifts at this time. They have so testified before Congress.

2/20/97 Detailed Briefing

The Board then received a general briefing on the Performance Confirmation Program from Richard C. Wagner supported by a 9-page handout accompanied by a separate 3-page list of assumptions entitled "Control Design Assumption Rationale Sheet". Mr. Wagner explained that this list of assumptions is what the Design Team is designing to.

Robert Saunders then made a presentation on Repository Sub-Surface Design Sub-Surface Construction and Development Sequence supported by a 16-page handout. The handout contained a 2-page bar-chart schedule and 3 phasing layouts entitled "Phase 1, Phase 2, and Phase 3, respectively." Also included was a separate layout illustrating Emplacement Drift construction. All of this material was intended as the Design Team response to Board Comment #9 contained in Repository Board Report #3.

Charles Parker, Manager Safety and Health, M&O Contractor then made a presentation on Respirable Dust Standards supported by a 14-page handout and a separate 11-page tabulation containing air sample readings between the dates of March 27, 1996 and November 6, 1996 taken at various points in the ESF tunnel. He explained the statistical program used to analyze these readings and the general concept utilized to calculate a Permissible Exposure Level (PEL) for the respirable dust portion of a dust containing cristobalite and quartz. Mr. Thomas McManus of Environmental Health Services (EHS) also spoke to the Board.

Daniel McKenzie then made a presentation to the Board on Repository Design to Support Performance Confirmation supported by an 11-page handout entitled "Appendix D - Key Performance Confirmation Parameters For Design" dated November 22, 1996.

Robert Saunders then made a second presentation to the Board containing Design Team Responses to Board Comments #3, #4, #5, #6, #7, #9, #11, #13, #14, & #15, all from Repository Board Report #3. This presentation was supported by a 17-page handout and a layout of both the north and south ends of the repository each accompanied by separate sheets showing surface topography.

Daniel McKenzie then made a presentation containing Responses to Board Comments #8, #10, and #12 from Board Report #3. His presentation was supported by a 7-page handout.

Rick Nolting completed the formal briefing session by making a presentation to the Board responding to Board Comments #17, #18, #19, and #20, all from Board Report #3. The presentation was supported by a 16-page handout.

At some point during the briefing session, the Board received a Statement for the Record presented to the U.S. Nuclear Regulatory Commission by Daniel Dryfus on September 4, 1996 and a document number BAB00000-01717-2200-00005 Rev 06 containing, among other things a "Requirement 7" for a M&O instruction for the use of water in the ESF tunnel.

2/21/97

The Board conferred privately during the morning and then met with representatives of the Design Team and other M&O and DOE personnel at a 1:00 p.m. debriefing session. The Board orally presented our preliminary views following the previous day's briefing. More complete responses supplementing the Board's oral remarks are contained in this following Repository Board Report No. 4.

Materials Received At 2/20 & 2/21/97 Briefings

The following materials received at the 2/20 & 2/21/97 briefings are included in the Appendix to this report:

- Sign-up sheet of attendees
- Summary of verbatim Design Team Responses to Board Recommendations contained in Board Report No. 3

Board Internal Meeting on 3/6/97

The Board met for one day on 3/16/97 for the purpose of further internal discussion preparatory to the submittal of this Board Report No. 4.

REPOSITORY STAGING AND SCHEDULE

The Board received a briefing from Robert Saunders under the general title "Subsurface Construction and Development Sequence". Our comments, under the following subheadings, follow.

Bar Chart Schedules & Phase I, II, III, Sketches

The bar graph schedules provided to the Board during the briefing on 2/20 seem too detailed in some respects while in other respects they didn't clearly and concisely outline a construction plan. Certainly, many decisions now in process of being made will have a major effect on how the final approach to the development is decided and implemented. Until these decisions are made, it will be difficult to be more specific than to present a very generalized outline. For example, several aspects of the schedules provided, based on the durations used, lead one to assume the use of precast concrete segmented liners in the Emplacement Drifts. That, in turn, would assume a minimal amount of geologic mapping during the Emplacement Drift excavation operation, if any. Decisions on these matters are not yet firm.

In the Phase I layout, we see no need for the 5.5 m TBM disasssembly chamber as shown on the sketch. The TBM, of course, must be designed to permit it to be backed up to the east access tunnel. Also, the ventilation plan is not clearly presented and should be detailed to a greater degree. Consideration should be given to utilizing rock bolts and shotcrete where temporary support is required for work and assembly or disassembly of a TBM or other equipment or facilities (the turnouts and start chambers, for instance).

In the Phase II sketch, the Board again feels that the 5.5 m TBM disassemble chambers are unnecessary as is the 7.62 m TBM disassembly chamber at the north end of the exhaust main.

In the Phase III sketch, it is noted that side dump muck cars are shown as traveling to the surface from the West Main tunnel to discharge material. Alternately, they should also be able to discharge material in the East Main at one of the muck transfer points.

Emplacement Drift Construction Sequence

As presented, several issues are unclear to the Board. We note on the last sketch of the handout the optional location of scrubber units at the ends of a fully excavated Emplacement Drift near the East and West Mains. It is unclear if they are intended to clean the air from the roadheaders developing the turnouts for the Emplacement Drifts as well as air from the 5.5 m TBM engaged in excavating the full length of the Emplacement Drift. More detail would help explain what is intended and/or how the operation is expected to work.

It is also noted that several Emplacement Drifts are identified for material storage. While the Board understands there may be instances when rail car loads of material must be held prior to installation for several hours up to a day or two, it will be much more efficient to schedule material into the construction as it is needed in order to eliminate the need for rehandling the material underground. It must be emphasized that careful planning for logistics will be imperative throughout the construction and operating life of this facility.

The sketches provided to the Board are a very broad-based first step in developing a construction staging plan that can be utilized for developing cost and schedule parameters for the facility. This construction and staging plan must be developed in greater detail.

PERFORMANCE DRIFT CONSTRUCTION

In Comment #10 of Board Report No. 3, we suggested that we be briefed on the functions required to be served by the Performance Confirmation Drifts so that we would have an understanding of what they involved and how they were expected to be utilized. We wanted this understanding in order to consider substituting their early construction in lieu of our original recommendation for early construction of selected Emplacement Drifts.

At the 2/20/97 briefing, the Board received a detailed briefing from Richard Wagner on Performance Confirmation Requirements and a further extensive briefing by Dan McKenzie entitled Repository Design to Support Performance Confirmation. Our comments resulting from these briefings follow.

Specific Performance Confirmation Requirements

The briefings explained the general nature of Performance Confirmation (PC) requirements, and a range of alternatives which have been considered for providing access for necessary testing and monitoring. These alternatives include various layouts of drifts mostly located above the repository horizon, usually E-W drifts but possibly some N-S drifts. These concepts also included a variety of long borings from the drifts, which were to contain various instrumentation to monitor behavior around and above the Emplacement Drifts.

The Board cannot comment on specific performance confirmation requirements or the merits of the various alternative layouts of drifts or borings from the standpoint of what might be necessary or best to meet performance confirmation requirements. How to best meet the performance confirmation requirements is outside of our range of expertise. We can, however, offer the following comments concerning general concepts and constructability issues.

Performance Drift Construction

The limiting cases illustrated in our briefing material included a very large number of drifts crossing above the repository block, and represent construction activity possibly into the range of 10% to 20% of the actual repository construction. This would be a huge undertaking, which we hope will not be needed.

The concepts presented typically involved constructing a PC drift a short distance above the repository horizon, and continuously cooling it prior to repository closure in order to provide a tolerable working environment for the instrumentation. The graphs showing preliminary analysis of thermal effects of these cooled drifts seem to show that the simple presence of the cooled drifts has a major disturbing influence on temperature distribution above the repository. This suggests that any measurements made near the PC drifts would not be a valid indication of repository behavior which develops away from the drifts. This in turn suggests it may be necessary to use a smaller number of drifts in order to minimize PC drift disturbance effects, with most instrumentation placed in long boreholes extending far from the disturbed zone around the PC drifts.

One alternative concept in the briefing material was based on use of steeply inclined access ramps excavated by roadheader off of the East Main, with PC drifts excavated across the repository by roadheader also. We do not recommend further consideration of this approach. The steep ramp access and long drifts excavated by roadheader would be a tremendously slow and expensive method of achieving PC access. We favor layouts which permit TBM excavation

Early Performance Drift Excavation

Based on the briefing material presented and ensuing discussion, it is the Board's position that a minimum of two east-west cross-block drifts be driven by TBM as early as possible. The cross-block drifts would meet the same objectives we previously recommended be attained by early excavation of selected Emplacement Drifts (see Board Recommendation #1, Board Report No. 2.) and could then be utilized later as PC drifts. We suggest the first drift extend from the North Access Tunnel westerly above and across the repository to the area where the west boundary of the repository is now expected to be located. The second drift could be driven similarly from the existing South Access Ramp. Again, the data from this effort would help verify the location of the west boundary of the repository at points along its length near its two ends. Data on the specific detail of the geology across the width of the repository would be verified and any major features specifically located. In addition to the detailed geology mapping that would be achieved, facilities for any added testing deemed necessary would be available in a carefully controlled environment.

It is expected that at least a northern performance drift will be important as a location from which instrumentation can be installed to monitor the early performance of the first few emplacement drifts and the surrounding rock mass. It may not be necessary to construct many additional performance drifts if the initial performance of the repository against the baseline is stable and confirms the original scientific and engineering conclusions. If many performance drifts are developed, the thermal characteristics of the repository could be affected, and this should be taken into consideration as plans for these features progress. If it is eventually concluded that additional PC drifts are needed, they can best be excavated during repository operation by TBM from a north-south tunnel extension off of the same breakout from the South Ramp that was utilized for the second of the two early drifts we are recommending.

OTHER PERFORMANCE MONITORING PLANS

In addition to the briefing materials presented for Performance Confirmation monitoring, Dan McKenzie presented briefing material relating to monitoring Emplacement Drift air quality under the title "Strategy #5 Monitoring Emplacement Drift Air". Our comments regarding this briefing material follow.

Monitoring Emplacement Drift Air Quality

If the emplacement drift air samples are acquired from continuous low volume ventilation flow as shown in Figure 7.4-2 entitled "Emplacement Drift Air Monitory Arrangement 1", any off-normal leaks from the Emplacement Drifts may conceivably contaminate the Ventilation Main if the Ventilation Raise seal does not react quickly enough. The Board had recommended in Report No. 2, Comment #9, that a permanent vent line be provided in the Ventilation Main to contain airborne contamination caused by a leaking waste package to avoid contaminating the entire Ventilation Main. At that time, the Board understood that the normal air flow through the Emplacement Drifts would considerably exceed a volume required for monitoring and that, in event of a leaking WP, this entire flow would be switched to the "contaminant" vent line located within the Ventilation Main. The Design Team responded at that time that they agreed and would consider this concept further as part of the ventilation design and PC program. The arrangement depicted by Figure 7.4-2 does not reflect this concept.

Nor does the arrangement shown in Figure 16 of the briefing material reflect the Board's original understanding of intended normal continuous emplacement drift air flow. Has the Design Team re-thought and changed the original concept?

If the Emplacement Drift air flow is now only intended to consist of air samples acquired by sampling via the sample tubes and pump arrangement as shown in Figure 16 then conceivably the exhaust main tunnel could be considerably smaller than 7.62 m diameter. How could an Emplacement Drift be "cooled down" under the concept of Figure 16? Could sufficient air flow be generated through the sampling tubes? And if the "cooling down" were required because the emplacement drift was contaminated, how could the contaminated air flow be isolated? We think that further discussion of the entire issue of the intended degree of air flow through Emplacement Drifts in both normal and off-normal situations and how contaminated air will be isolated would be worthwhile for future briefings.

COMMENTARY ON DESIGN TEAM RESPONSE TO VARIOUS BOARD COMMENTS IN BOARD REPORT NO. 3

During the 2/20/97 briefing, various Design Team presenters responded to 17 of the 20 board comments/recommendations contained in Board Report No. 3. The verbatim Design Team responses are listed in the Appendix to this report. Following our review of the Design Team response, we offer additional comments as follows.

Response to Board Comments #1 & #2

These board comments related to the establishment of an air quality design standard for the ventilation system for future repository construction. They were made in response to an earlier Design Team presentation by Dan McKenzie at the 12/5/96 briefing session prior to the submittal of Board Report No. 3.

At the 2/20/97 briefing sessions, there was no explicit response to these recommendations although Charles Parker presented his perspective on measures taken to protect workers from harmful exposures to respirable dust during ESF construction. Since the time of Mr. Parker's presentation, the Board has requested and received considerable additional material on this subject. Our present position, based on our analysis of all material received, is contained in a separate section of this Board Report No. 4.

Response to Board Comments #3, #4, #5, & #6

The Board is pleased to note the Design Team's general agreement with these comments, all relating to dust containment features on TBM's and roadheaders, water sprays and fogging nozzles on conveyors, conveyor enclosures, and full-tunnel cross section dust curtains with scrubber units. At this point, it appears to us that acceptable dust levels in the tunnel and in the machine areas may be obtained during the repository excavation by implementing the use of standard engineered solutions such as dust shields on the TBM, water sprays, conveyor enclosures, and the like. We look forward to reviewing in July 97 the "Preliminary List of Construction & Backfill Equipment" which we understand will describe salient attributes and functions of the construction equipment including dust reduction and control features.

Response to Board Comment #7

This Board comment was to the effect that we strongly felt the alternative fresh air intake system previously suggested in Board Report No. 2 be promptly investigated and preliminary design undertaken. We understand the Design Team's response to be that due to the necessity to concentrate on work required to meet the schedule for required deliverables under the M&O contract, consideration of this question must be temporarily deferred but that we could expect a considered response in an April 1997 time frame. We consider this response entirely reasonable and look forward to the presentation of the Design Team's views on this matter.

Response to Board Comment #8

The Board comment concerned redundancy in Exhaust Fan installation. We are pleased to learn from the Design Team response that the design of the Exhaust Fan installation will be reviewed in light of an internal and external "design basis event" study. Our primary concern was the possibility of loss of the Exhaust Fan system during an unplanned event or emergency.

Response to Board Comment #9

This comment was to the effect that we believe a Development Plan by Phases for the Construction of the Repository should be established for viability assessment purposes without delay. The Design Team response at the time of the 2/20/97 briefing was contained in Robert Saunder's presentation entitled Repository Subsurface Design Subsurface Construction and Development Sequence.

In reviewing this presentation, we feel that a great deal of the foundation data has yet to be assembled. It will be extremely difficult to complete the deliverables that were described as necessary and due by June, July, August, and September of this year without making several decisions necessary to provide the basis for the schedule, sequence, and priorities for the physical development of the repository.

Additional to the concern expressed in Board Comment #9, it is essential that the schedule of activities that must be completed prior to receiving the construction license be developed. The timely accomplishment of these activities will have far greater impact on the cost of the development than almost any issue to be faced during the construction process. Several years ago the national Academy of Science did a study of major transportation projects in the U.S. The study was intended to help determine the issues that had the greatest cost impact on very large public projects. In each case, the institutional factors relating to funding and the political decision making process, among others, added the greatest cost and most frequently caused delay. The study is entitled *"Better Management of Major Underground Construction Projects"* dated 1978 and may prove of interest. This project is far larger than most and is particularly susceptible to this type of delay and adverse cost consequence.

Only after a firm decision on the various features of the facility have been made (i.e., type of tunnel lining, mapping, type of TBM, ventilation scheme, and level of assumed funding) can firm program and construction schedules be developed. The Board would like to see a firm sequence of construction activities and the primary details of the approach to be taken before agreeing to the adequacy of the schedule with any accompanying equipment lists. As these decisions are firmed up, comments on the physical development schedule can be made. There is no doubt that the first 8 or 9 emplacement drifts can be developed within 5 years of beginning construction. However, we cannot comment on the intended sequence of work until several decisions on the elements outlined above have been made.

The Board encourages early decision, preferably by the April 1997 Board meeting, if the dates outlined to us for deliverables to be completed during the balance of 1997 are to be met.

Response to Board Comment #10

This comment requested Board briefing on the functions required to be served by the Performance Confirmation Drifts. The Board was very adequately briefed on this matter at the 2/20/97 briefing and we regard this matter closed.

Response to Board Comment #11

The Board had suggested that a broad-based risk analysis be carried out in the near future considering a variety of unplanned events during repository construction and operation. We further suggested the Development Plan by Phases for Construction of the Repository presented in Board Report No. 3 could be used to provide the background construction situations for conducting the risk analysis.

The Board was pleased to learn at the 2/20/97 briefing that a broad-based risk analysis is planned to be carried out in 1998. This is important and we agree with the principle of deferring the analysis until that time frame. However, as discussed during our meetings on 2/20 and 2/21/97, interim steps in this process of risk analysis will prove useful to the design, development, and viability assessment underway now. Each interim step will reinforce identifying aspects of the facility and the process of its development that need attention from a risk standpoint.

Response to Board Comment #12

In response to this Board comment concerning the importance of a decision on the necessary extent of geologic mapping, we understand the

Design Group agrees that this is a key issue upon which many aspects of repository design depend. We understand a decision on this issue is expected to be made by April 1997.

Response to Board Comments #13, #14, & #15

Board Comments #13 and #14 related to the vertical separation between the Emplacement Drifts and the Ventilation Main and to how the Ventilation Main configuration could be adjusted in the event that the vertical clearance between the Emplacement Drifts and the Ventilation Main needed to be increased beyond the Board recommended 10 m. The Design Team response was that the recommended 10 m separation appeared to be satisfactory and that this conclusion would be verified by analysis addressing both the thermal and ground stability concerns. The Design Team furtner agreed that changes to Ventilation Main gradients can be made to accommodate slightly longer Ventilation Raises if necessary. A further comment was made that the Board proposed solution in Board Report No. 3 to accommodate a Ventilation Raise as long as 30 meters might not be satisfactory because it would result in a low point in the Ventilation Main within the geographical confines of the Emplacement Drifts. This was considered undesirable from a post-closure drainage standpoint.

We concur with the present Design Team view on the proposed 10 m ventilation raise length. In regard to the perceived post-closure drainage problem resulting from the Board proposed grade modifications in the event the Ventilation Main had to be lowered, we suggest the concern could be alleviated by simply driving a small down-grade drift by drill and blast methods from the low point in the Ventilation Main northwestward a sufficient distance to lead any accumulated drainage well away from the Emplacement Drift area. Would this not alleviate any post-closure drainage concerns?

Board Comment #15 was to the effect that the intersection between the Ventilation Main and the South Perimeter Main should be kept as close as possible to the location set for the Development Shaft. The Design Team response agreed, stating further that current design seeks to optimize shaft locations and to minimize lengths of connecting drifts consistent with the subsurface configuration and suitable surface topography for shaft collar location. We concur with the Design Team response and regard this issue closed.

Response to Board Comment #16

This comment was to the effect that the Board remains skeptical of the need for requiring construction of repository underground openings to NQA-1 standards, particularly for either the temporary support or the final lining of the

Mains and Ramps. The Design Team offered no response to this comment and we do not know their current view. Our viewpoint on this issue remains as stated in Board Report No. 3.

Response to Board Comments #17, #18, #19, & #20

Rick Nolting, Repository Lead Geotechnical Engineer responded to these comments at the 2/20/97 briefing, all of which concerned issues of tunnel lining and support methods. There seems to be general agreement between the Board and the Design Team on most of these issues. Plans are being made to conduct various studies recommended by the Board, such as laboratory studies of various properties of concrete mixes. The Board is encouraged to learn that current indications are that the use of normal types of steel reinforcing bars and fibers in the concrete will probably be acceptable.

These issues seem to be coming to closure at present. We assume that the Board will be kept aware of progress, and of any new issues which may arise.

RESPIRABLE DUST CONCERNS

Board Position Expressed in Board Report No. 3

At the 12/5/96 briefing session prior to the submittal of Board Report No. 3, the Board was informed by the Design Team that a design standard for air quality for future repository construction had been set at a PEL of 0.10 mg/m^3 for total respirable dust based on a statistical analysis of a number of air samples taken during ESF tunnel construction. We were also informed at that time that the upper and lower PEL for total respirable dust calculated on the basis of the probable level of quartz and cristobalite mineral thought to be present in the host repository rock was an upper PEL of 0.246 mg/m^3 and a lower PEL of 0.170 mg/m^3. Further, we understood at that time that based on a statistical analysis of a number of air samples taken throughout ESF tunnel construction that the design standard was set at 0.100 mg/m^3 due to variation in mineral constituents in the repository and "the conservatism inherent in the methodology used to regulate exposure." We were further informed that "dust exposure levels this low are without precedent and will likely require unprecedented measures for effective control."

We further understood at that time that the decision to establish this very low design standard reflected a DOE decision to establish more conservative criteria than OSHA required for underground work in order to ensure at the 95 percent confidence level that OSHA values are never exceeded. We stated that we did not understand why underground work at Yucca Mountain should be subject to PEL values more strict than normal OSHA requirements and that imposing such a standard adds a design requirement for future repository construction that will adversely impact potential construction methods and system layouts, schedule, and project costs. We questioned whether such a low PEL is necessary or appropriate and recommended that this issue be revisited.

2/20/97 Respirable Dust Briefing

Following receipt of the draft Board Report No. 3, the Board was briefed by Charles Parker, Manager, Safety and Health, M&O Contractor. Supporting handout material stated that "The DOE requires contractors to use the lowest of either the limits advocated by ACGIH and NIOSH, or OSHA and that the former were lower limits. These limits, or Threshold Limit Values (TLVs), were stated to be:

- Total Respirable Dust - 3.0 mg/m^3
- Quartz - 0.10 mg/m^3

- Cristobalite - 0.05 mg/m^3
- Tridymite - 0.05 mg/m^3

It was then explained that the approach utilized for the ESF tunnel was to establish a PEL value (that when exceeded would require respirator use) based on analysis of a large number of air samples obtained at different dates and different locations throughout the ESF tunnel construction.

The Board was furnished 11 pages of air sample readings that we understand to be the base data analyzed to calculate the PEL value. At the bottom of the 11th page an annotated handwritten comment appeared to the effect that the PEL @ 95% Confidence Level is 0.132 mg/m^3 based on 31.476% cristobalite content and 10.8% quartz content in the air samples.

We have verified that the 0.132 mg/m^3 value was calculated on the basis of the formula:

$$PEL = \frac{1}{\dfrac{\%\ \text{Cristobalite}}{100 \times 0.05\ \text{mg/m3}} + \dfrac{\%\ \text{Quartz}}{100 \times 0.10\ \text{mg/m3}} + \dfrac{\%\ \text{Balance of Dust}}{100 \times 3.0\ \text{mg/m3}}}$$

Clearly, the value that one calculates for the PEL for a particular work area will depend on the percentages of cristobalite and quartz that one concludes is actually present in the respirable dust within that work area. The approach taken apparently was to consider the entire ESF tunnel as one common work area and to determine what was considered to be the appropriate values for cristobalite and quartz percentages to properly characterize that very large area.

It was then explained that in this analysis the cristobalite and quartz percentage values were determined by application of a statistical program called LOGAN (a log-normal analysis) resulting in the determination of the 31.47% cristobalite content and the 10.8% quartz content, respectively. This meant that out of the 381 air samples obtained throughout the ESF program, the cristobalite percentage was measured as high as 31.476% in only 5% of the total samples. Similarly, out of the 381 samples, the quartz percentage was measured as high as 10.8% in only 5% of them. However, by study of the data, the Board finds that the particular samples containing the high quartz percentages were different samples than those containing the high cristobalite percentages.

It was explained that when the total respirable dust level sampled in a work area is below the PEL standard calculated above, the employer can be certain to be in compliance with air quality standards at least 95% of the time and that if the sampled total respirable dust level exceeds the calculated standard, there is a potential for non-compliance.

The philosophy of the LOGAN program is explained on page 30 of a report prepared for Mr. Parker by Thomas McManus of Environmental Health Services dated June 10, 1996 which states

> "LOGAN classifies exposures through log-normal analysis of the industrial hygiene data set entered into the computer program. The intent of the application is to enhance professional judgment and decision making regarding the interpretation of industrial hygiene data. In application the LOGAN program will report that exposures are acceptable when there is less than a 5% statistical chance for an overexposure."

In summary, we understand that the approach taken was first to characterize the total ESF tunnel as containing 31.5% cristobalite on the basis of the highest 5% of all cristobalite measurements made regardless of their location in the tunnel, and to characterize the total ESF tunnel as containing 10.8% quartz on the basis of the highest 5% of quartz measurements taken regardless of location in the tunnel. However, the Board finds that the values of the cristobalite and quartz percentages measured in the other 95% of the air samples taken were so much lower than the upper 5% that the mean value for percent cristobalite was only 9.24% and the mean value for quartz was only 2.81%.

Board Concern with the ESF Approach

The Board first performed an independent analysis of the air sample data furnished by Charles Parker on 2/20/97. Our analysis is shown on Exhibit 1 (pages 1 - 9) included in this report. We note the variation in cristobalite and quartz percentage measurements, even in those taken in the same place in the tunnel on the same day. For instance, 5 cristobalite measurements taken on 4/2/96 in the TBM Dance Floor area varied from 0% to 12% while quartz percentage measurements varied from 0% to 5.6%. This suggests to us that the X-Ray Diffraction analysis of the air filter samples may not be an exact science. We would appreciate receiving briefing information from a person familiar with this analysis process that will indicate the range of accuracy that can be reasonably be expected. On this account alone, we question the reasonableness of basing the PEL calculation on a relatively few very high readings when the vast majority of the readings were far less.

To further study this situation, we have included computer plots illustrating the variation of the cristobalite and quartz percentage measurements, all developed from the data furnished by Mr. Parker and shown on Board Exhibit

1. Board Exhibit 2 shows the variation in cristobalite percentage while Board Exhibit 3 shows the variation in quartz percentage. Referring to Exhibit 2, the large disparity between the mean value for cristobalite of 9.24% and the LOGAN 95 percentile value of 31.5% used in the ESF PEL calculation is very apparent. The variation in quartz percentage is shown on Board Exhibit 3. Again, the disparity between the mean value of 2.81% and the LOGAN 95 percentile value of 10.8% used in the ESF PEL calculation is similarly apparent.

We also question the validity of the ESF method of pairing up the results of high cristobalite percentages with high quartz percentages without regard to the fact that these high percentages do not occur in the same air samples (i.e., samples with high cristobalite percentages may contain low quartz percentages and samples with high quartz percentages may contain low cristobalite percentages). Reference to page 9 of Board Exhibit 1 underscores this point. Using mean values for purposes of illustration, the PEL determined by the ESF method based on a cristobalite percentage of 9.47 and a quartz percentage of 2.88 is 0.40 mg/m^3 while the mean value of the PELs calculated for each individual air sample is 1.51 mg/m^3, nearly four times greater. Clearly, the ESF method results in calculated PELs much lower than the actual PELs of the air samples themselves.

A more fundamental Board concern is that we do not believe the LOGAN 5%/95% criteria of establishing compliance with respirable air standards can be reasonably applied to underground construction operations involving tunnels of great length (in the case of the ESF tunnel nearly 5 miles). We are not concerned with the use of the ACGIH Threshold Limit Values (TLVs). They appear to be very near to similar limits established by OSHA, and we understand that current DOE policy directs the use of these limits. If current DOE policy required the use of the LOGAN approach, we would recommend that the policy be changed. We suspect that the method was developed for stationary industrial work sites when workers are relatively immobile in a fairly confined work area and, for some of these situations, we can understand how the method could be appropriate. However, a long underground development is an entirely different matter. Board members have never encountered the use of this criteria and we know of no other underground operation anywhere where it has ever been applied.

The TLVs are time-weighted averages. The 1995 - 1996 ACGIH publication on Threshold Limit Values defines a Threshold Limit Value - Time-Weighted Average on page 2 as

> "The time-weighted average concentration for a normal 8-hour work day and a 40-hour work week, to which nearly all workers may be repeatedly exposed, day after day, without adverse effect."

The ACGIH publication goes on to state on page 4 that

> "TWAs permit excursions above the TLV provided they are compensated by equivalent excursions below the TLV - TWA during the work day",

and that

> "It may be permissible to calculate the average concentration for a work week rather than for a work day."

In the case of a work area as large and varied as a tunnel where workers are highly mobile, the exposure of a worker to the highest 5% of respirable dust risk detected anywhere in the tunnel for any significant period of time is a virtual impossibility. In view of the above cited commentary in the ACGIH standards themselves, we believe that use of the highest 5% of the possible exposure profile in the entire underground development is unreasonable.

Another result of the use of ESF LOGAN method, which to the Board seems illogical, is to regulate compliance with air quality standards in a discrete part of the tunnel based on values of percent cristobalite and percent quartz far higher than the values of these mineral constituents actually measured in that particular part of the tunnel. To illustrate this point, the Board separated out all air samples from Mr. Parker's list taken between the dates of 3/27/96 and 4/10/96 in the TBM work area ahead of Deck 12. From this list of samples, we deleted all of those where no cristobalite whatsoever was detected due to our concern that these zero cristobalite measurements may have resulted from respirable dust samples so small that the mineral constituents might not have been accurately determined. We were reluctant to accept these samples as evidence that no cristobalite was present. We then analyzed the 30 remaining air samples in a manner identical to the analysis performed on the full 359 air samples from Mr. Parker's list. The result of our analysis appear as Board Exhibit 4 in this report. A number of facts from this analysis are readily apparent:

- The 30 cristobalite measurements were very tightly grouped with a mean of 11.4% and a standard deviation of only 2.6%. The highest cristobalite measurement was 19.5%, the lowest 5.9%.

- The mean of the quartz readings was 5.8% with a standard deviation of 4.4%. The highest quartz reading was 17.8% and the lowest was zero.

- The mean value of the 30 calculated PELs, each calculated on the cristobalite and quartz percentages in each discrete air sample, was

0.340 mg/m^3 with a standard deviation of 0.086 mg/m^3. This is a comparatively tight distribution.

A computer generated plot of the cristobalite distribution appears as Board Exhibit 5. The quartz distribution is Board Exhibit 6 and the calculated PEL distribution is shown as Board Exhibit 7.

As the Board understands the present ESF regulatory policy, respirator use would be required whenever the actual measured respirable dust content exceeded 0.10 mg/m^3 even though, in this case for the TBM work area, the lowest of the individual PELs based on actual cristobalite and quartz contents in the area was nearly twice this value and the mean of the PELs was over 3 times this value. It should be noted that the highest cristobalite value measured in this work area during the period reported is considerably less than the 31.5% upon which the 0.1 mg/m^3 PEL was calculated while the mean of the cristobalite values measured in the area during the period was approximately one-third of the 31.5% value.

In view of the variation in cristobalite and quartz measurements (which the Board suspects may be due in large part to inherent inaccuracies in the X-Ray Diffraction process), it seems to the Board that use of the mean value of 0.34 mg/m^3 would have been far more logical for determining when respirators were required in view of the ACGIH commentary on the nature of the TLVs upon the which the PEL is calculated.

It should be further noted that even if the Board recommended PEL of 0.34 mg/m^3 had been the regulatory standard for total respirable dust for the TBM and trailing gear work area ahead of Deck 12 during this period, all of the total dust measurements taken (reflected in Col. 1 on Board Exhibit 5) indicate that the permissible PEL would have been exceeded, in some cases greatly so. Corrective action was clearly required. Based on the reports that we have received, it is clear that the actions taken between April and October 1996 resulted in significant improvement in air quality forward of Deck 12, principally due to the installation of the HEPA scrubber unit at Deck 12.

The results of 64 air quality measurements made ahead of Deck 12 after October 7 when the HEPA scrubber was in service are reported on Board Exhibit 9 (page 1 & 2). These measurements indicated a dramatic improvement in air quality. Total respirable dust was reduced from the average value prior to the installation of the HEPA scrubber reflected on Board Exhibit 5 of 1.04 mg/m^3 to a mean value after the installation of the scrubber of 0.15 mg/m^3, a reduction of approximately 85%. According to the information received by the Board, the cristobalite percentage reported for each of the 64 samples was zero and the quartz percentage reported for the 64 samples was zero with the exception of a 4.4% value reported on 10/15/96 and an 8.6% value reported on 10/23/96. Yet, by application of the present ESF criteria of a 0.10 mg/m^3 PEL, the TBM operation was out of compliance for 36 of the 64 air samples taken even though no cristobalite was detected in any of them and levels of quartz were detected in only two of them. In the Board's opinion, this represents an over regulation and is not reasonable. On the other hand, if the 0.34 mg/m^3 figure for the PEL, as developed on Exhibit 4 had been used as the criteria, the TBM operation after October 7 would have been out of compliance for only 2 of the 64 air quality samples taken. Of course, if the reported percentages of cristobalite and quartz for the 64 samples are real (zero and near zero, respectively), there were no occasions after October 7 when the TBM operation was out of compliance.

Current Board Position on Appropriate PEL Standard for Design of the Ventilation System for Future Repository Construction

Imposition of a PEL as low as 0.10 mg/m^3 for total respirable dust as a design standard for future repository construction will unnecessarily burden the planning and construction effort and will result in a tremendous cost penalty for the construction of the facility. We believe that the PEL for sequential advancing reaches of future tunnel headings can more reasonably be determined by a procedure along the lines illustrated by Exhibits 4 through 7 of this report. To us, this seems appropriate in the light of the ACGIH commentary on the nature of Threshold Limit Values (TLVs) and consideration of the reality that the future repository construction will involve a gigantic diverse series of separated tunnel reaches rather than a single confined area typical of surface industrial work environments.

It should be noted on Figure 7 that even if one adopted the LOGAN philosophy and used the PEL at the 5 percentile level (reflecting the 95% percentile of the exposure risk), the PEL value would be 0.24 mg/m^3, a far more reasonable value than 0.10 mg/m^3.

Additional Questions

There are several questions in this area that we would like to see answered in future briefings:

- Would the cristobalite and quartz constituents be expected to be higher for the respirable dust portion of total airborne dust than for the balance of the dust, or would one expect these constituents to be uniformly distributed?

- Can the cristobalite and quartz contents of the repository host rock be more accurately and more quickly determined by analysis of samples of the host rock rather than by X-Ray Diffraction methods of respirable dust?

- What level of accuracy can one expect from the X-Ray Diffraction determinations of cristobalite and quartz content of respirable dust by the X-Ray Diffraction method utilized thus far at the ESF?

- Are the cristobalite and quartz percentages reported in the 64 samples taken ahead of Deck 12 after October 7 shown in Board Exhibit 8 real, or does this data simply reflect that there was not enough respirable dust detected to determine its mineral constituents?

SUMMARY OF BOARD COMMENTS AND RECOMMENDATIONS

1. The Board sees no need for the 5.5 m TBM disassembly chambers shown on the Phase I and Phase II sketches accompanying the briefing presentation "Subsurface Construction and Development Sequence". The Board's concept is that the 5.5 m TBMs be designed for easy partial disassembly so that they can be quickly backed up through the installed support to the East Main.

2. The Board does not understand the intended ventilation concept for the "Subsurface Construction and Development Sequence" presented to us. We request that the intended concept be explained in greater detail at future briefings.

3. The Board does not understand the intended function of the scrubber units shown at the end of a fully excavated Emplacement Drift near the East and West Mains on the Emplacement Drift construction sequence sketch accompanying the "Subsurface Construction and Development Sequence" presentation. We need additional explanation for what is intended and/or how the operation is expected to work.

4. The Board does not favor the planned utilization of excavated Emplacement Drifts for storage of construction material. Careful logistic planning should minimize the need for underground storage and rehandling.

5. Although the development sketches provided to the Board are a broad-based first step in developing a construction plan for costing and scheduling purposes, the Board encourages the development of a more comprehensive and detailed construction plan in the near future.

6. The limiting cases illustrated in the briefing material for Performance Drift construction involved driving a large number of drifts above and across the repository block, representing construction activity into the range of 10% - 20% of the balance of repository construction. The Board discourages such a concept for providing access for performance confirmation purposes and hopes a way can be found to provide the necessary access without embarking on such a huge construction undertaking.

7. The thermal studies presented to the Board of Performance Drift Confirmation cooling to achieve a tolerable working environment for instrumentation suggests such a major disturbing influence on temperature distribution above the repository that PC measurements would not be a

valid indication of repository behavior. This indicates to the Board the desirability of using a smaller number of PC Drifts in order to minimize disturbance effects with most instrumentation located in long boreholes extending beyond the disturbed cooled zone around the PC Drifts.

8. The Board recommends against any further consideration of excavating Performance Confirmation Drifts by roadheader methods. We favor layouts that permit TBM excavation.

9. The Board recommends that a minimum of 2 east-west cross block drifts be driven by TBM methods as soon as possible. These cross block drifts would meet the same objectives to be obtained by the previously recommended early excavation of selected Emplacement Drifts. We suggest the first drift extend from the North Ramp westerly above and across the repository to the area where the west boundary of the repository is now expected to be located. We recommend the second drift extend similarly from the existing South Ramp. These cross block drifts can later be used for performance confirmation purposes. If it is eventually concluded that additional PC Drifts are needed, they can best be excavated during repository operation by TBM methods from a north-south tunnel extension off of the same breakout from the South Ramp as that utilized for the second of the recommended two early drifts.

10. The Board requests that the issues of the intended degree of air flow through Emplacement Drifts in both normal and off-normal situations, air quality monitoring arrangements, and how contaminated air will be isolated be revisited in future briefings.

11. The Board looks forward to reviewing after July 1997 the preliminary list of Construction & Backfill Equipment which we understand will describe the salient attributes and functions of the several major types of required underground construction equipment, including the dust reduction and control features.

12. The Board looks forward to receiving the results of the Design Team's investigation of the alternate fresh air intake system proposed by the Board in Board Report No. 2 which we understand should be completed in the April 1997 time frame. Perhaps a briefing on this subject can be presented at the upcoming 4/24 & 4/25/97 meetings.

13. The Board does not see how it will be possible to complete the deliverables that were described as necessary and due by June, July, August, and September of this year without first making several important decisions necessary to provide the basis for the schedule, sequence, and priorities for the physical development of the repository (i.e., type of tunnel linings for

the Mains and Emplacement Drifts, mapping, types of TBMs to be used, ventilation scheme, and level of assumed funding). The Board encourages early decisions, preferably by the time of the 4/24 & 4/25/97 meetings, if the dates outlined to us for the deliverables to be completed during the balance of 1997 are to be met.

14. Although we concur that the broad-based risk analysis suggested by the Board (see Recommendation #11, Board Report No. 3) can be deferred until mid 1998, interim steps in this process of risk analysis will prove useful to the design, development, and viability assessment efforts underway now. Each interim step will reinforce identifying aspects of the facility in the process of its development that need attention from a risk standpoint.

15. The Board suggests that concerns stressed in the last briefing with the Board proposed solution in Board Report No. 3 to accommodate Ventilation Raises as long as 30 m might not be satisfactory (because it would result in a low point in the Ventilation Main within the geographical confines of the Emplacement Drifts), could be alleviated by driving a small down-grade drift by drill and blast methods from the low point in the Ventilation Main northwestwardly a sufficient distance to lead any accumulated post closure drainage well away from the Emplacement Drift area.

16. The Board remains skeptical of the need for requiring construction of repository underground openings to NQA-1 standards, particularly for either the temporary support or the final lining of the Mains and Ramps. A more complete statement of our views on this subject appeared in paragraph 3 at page 21 of Board Report No. 3 and need not be repeated here.

17. Imposition of a PEL as low as 0.10 mg/m^3 for total respirable dust as a design standard for future repository construction will unnecessarily burden the planning and construction effort and will result in a tremendous cost penalty for the construction of the repository facility. The Board believes that the PEL for sequential advancing reaches of future tunnel headings can more reasonably be determined by a procedure similar to that illustrated by Exhibits 4 through 7 of this report. We believe such a procedure would be appropriate in light of the ACGIH commentary on the nature of Threshold Limit Values (TLVs) and consideration of the reality that the future repository construction will involve a gigantic diverse series of separated tunnel reaches as opposed to a single confined area typical in surface industrial work environments.

18. The Board requests briefings by appropriate experts from the scientific community to answer the following questions in the respirable dust area:

- Would the cristobalite and quartz constituents be expected to be higher for the respirable dust portion of total airborne dust than for the balance of the dust, or would one expect these constituents to be uniformly distributed?

- Can the cristobalite and quartz contents of the repository host rock be more accurately and more quickly determined by analysis of samples of the host rock itself rather than by X-Ray Diffraction methods of respirable dust?

- What level of accuracy can one expect from the X-Ray Diffraction determinations of cristobalite and quartz contents of respirable dust by the X-Ray Diffraction method utilized thus far at the ESF?

- Are the cristobalite and quartz percentages reported in the 64 samples taken ahead of Deck 12 after October 7 shown in Board Exhibit 8 real, or does this data simply reflect that there was not enough respirable dust detected to determine its mineral constituents?

SIGNATURE PAGE

The foregoing Report No. 4 of the Yucca Mountain Project Repository Design Consulting Board is submitted this 22nd day of May 1997.

S. H. Bartholomew
s/ S. H. Bartholomew

Ronald E. Heuer
s/ Ronald E. Heuer

J K Lemley
s/ Jack K. Lemley

Larry Snyder
s/ Larry Snyder

EXHIBITS

Board Analysis of 359 Air Samples From ESF Tunnel (Data from Charles Parker 2/20/97)

Sample No.	Date	Location	Col. 1 Total Dust mg/m3	Col. 2 Cristo-balite mg/m3	Col. 3 Quartz mg/m3	Col. 4 Cristo-balite %/100	Col. 5 Quartz %/100	Col. 6 PNOC %/100	Col. 7 Col. 4/ 0.050	Col. 8 Col. 5/ 0.100	Col. 9 Col.6/ 3.000	Col. 10 Col. 7 + Col. 8 + Col. 9	Col. 11 PEL = 1/Col. 10 mg/m3
EHS1	Mar. 27, 1996	Consultant	0.180	0.080	0.000	0.444	0.000	0.556	8.880	0.000	0.185	9.065	0.110
EHS2	Mar. 27, 1996	Consultant	0.150	0.060	0.000	0.400	0.000	0.600	8.000	0.000	0.200	8.200	0.122
gd1	Mar. 27, 1996	Tunnel Dance Floor	0.470	0.045	0.016	0.096	0.034	0.870	1.920	0.340	0.290	2.550	0.392
gd2	Mar. 27, 1996	Deck 14	0.340	0.057	0.000	0.168	0.000	0.832	3.360	0.000	0.277	3.637	0.275
ntl-101	Apr. 2, 1996	Tunnel Dance Floor	1.200	0.120	0.056	0.100	0.047	0.853	2.000	0.470	0.284	2.754	0.363
ntl-104	Apr. 2, 1996	Tunnel Dance Floor	0.370	0.072	0.056	0.195	0.151	0.654	3.900	1.510	0.218	5.628	0.178
ntl-105	Apr. 2, 1996	Deck 13	0.370	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
ntl-102	Apr. 2, 1996	Forward Deck	0.820	0.081	0.035	0.099	0.043	0.858	1.980	0.430	0.286	2.696	0.371
ntl-103	Apr 2, 1996	Tunnel Mechanic	1.500	0.160	0.070	0.107	0.047	0.846	2.140	0.470	0.282	2.892	0.346
ntl-16-01	Apr. 2, 1996	Portal	0.063	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
ntl-16-04	Apr. 2, 1996	Loci Driver	0.570	0.052	0.000	0.091	0.000	0.909	1.820	0.000	0.303	2.123	0.471
ntl-16-03	Apr. 2, 1996	Telect 12	0.310	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
ntl-16-03	Apr. 2, 1996	Tunnel Mechanic	1.600	0.190	0.100	0.119	0.063	0.818	2.380	0.630	0.273	3.283	0.305
ntl-05	Apr. 2, 1996	TCrow	0.850	0.080	0.065	0.094	0.076	0.830	1.880	0.760	0.277	2.917	0.343
ntl-04	Apr. 2, 1996	Dance Floor	0.630	0.055	0.000	0.087	0.000	0.913	1.740	0.000	0.304	2.044	0.489
ntl-02	Apr. 2, 1996	Dance Floor	0.410	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
ntl-03	Apr. 2, 1996	Dance Floor	0.780	0.069	0.000	0.088	0.000	0.912	1.760	0.000	0.304	2.064	0.484
ntl-110	Apr. 3, 1996	T2	0.910	0.094	0.040	0.103	0.044	0.853	2.060	0.440	0.284	2.784	0.359
ntl-109	Apr. 3, 1996	Forward Deck	1.800	0.220	0.084	0.122	0.047	0.831	2.440	0.470	0.277	3.187	0.314
ntl-106	Apr. 3, 1996	Tdf-miner	1.600	0.180	0.085	0.113	0.053	0.834	2.260	0.530	0.278	3.068	0.326
ntl-107	Apr. 3, 1996	Tutil-miner	0.890	0.047	0.000	0.053	0.000	0.947	1.060	0.000	0.316	1.376	0.727
ntl-108	Apr. 3, 1996	Tobs-df	1.500	0.170	0.078	0.113	0.052	0.835	2.260	0.520	0.278	3.058	0.327
ntl-16-07	Apr. 3, 1996	T12	0.350	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
ntl-16-11	Apr. 3, 1996	T12	0.190	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
ntl-16-09	Apr. 3, 1996	T12	0.400	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
ntl-16-10	Apr. 3, 1996	T14	0.100	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
ntl-16-08	Apr. 3, 1996	T14	0.320	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
ntl-22-08	Apr. 3, 1996	A5	0.590	0.062	0.000	0.105	0.000	0.895	2.100	0.000	0.298	2.398	0.417
ntl-22-10	Apr. 3, 1996	A6	0.820	0.090	0.051	0.110	0.062	0.828	2.200	0.620	0.276	3.096	0.323
ntl-22-09	Apr. 3, 1996	T3	0.730	0.064	0.000	0.088	0.000	0.912	1.760	0.000	0.304	2.064	0.484
ntl-12-113	Apr. 4, 1996	A5-coredir	0.580	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
ntl-12-114	Apr. 4, 1996	A5-corelrhlp	0.340	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
ntl-12-116	Apr. 4, 1996	2840 Meters	0.250	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
ntl-16-16	Apr. 4, 1996	Cal Oper ?	0.520	0.036	0.000	0.069	0.000	0.931	1.380	0.000	0.310	1.690	0.592
ntl-16-15	Apr. 4, 1996	Shifter	1.000	0.110	0.087	0.110	0.087	0.803	2.200	0.870	0.268	3.338	0.300
ntl-22-13	Apr. 4, 1996	T2 op-cab-outside	1.000	0.140	0.098	0.140	0.098	0.762	2.800	0.980	0.254	4.034	0.248
ntl-22-16	Apr. 4, 1996	T2abv-conv-hopper	1.400	0.160	0.073	0.114	0.052	0.834	2.280	0.520	0.278	3.078	0.325
ntl-22-11	Apr. 4, 1996	Tfwdddk	2.000	0.240	0.110	0.120	0.055	0.825	2.400	0.550	0.275	3.225	0.310
ntl-22-15	Apr. 4, 1996	Tdf-miner	1.500	0.200	0.071	0.133	0.047	0.820	2.660	0.470	0.273	3.403	0.291
ntl-22-14	Apr. 4, 1996	Tdf-miner	1.600	0.220	0.082	0.138	0.051	0.811	2.760	0.510	0.270	3.540	0.282

Board Analysis of 359 Air Samples From ESF Tunnel (Data from Charles Parker 2/20/97)

Sample No.	Date	Location	Col. 1 Total Dust mg/m3	Col. 2 Cristo-balite mg/m3	Col. 3 Quartz mg/m3	Col. 4 Cristo-balite %/100	Col. 5 Quartz %/100	Col. 6 PNOC %/100	Col. 7 Col. 4/ 0.050	Col. 8 Col. 5/ 0.100	Col. 9 Col.6/ 3.000	Col. 10 Col. 7 + Col. 8 + Col. 9	Col. 11 PEL = 1/Col. 10 mg/m3
ntl-12-120	Apr. 5, 1996	Tmech-scrubber	2.200	0.240	0.120	0.109	0.055	0.836	2.180	0.550	0.279	3.009	0.332
ntl-12-121	Apr. 5, 1996	T12up-Surv platfm	0.610	0.064	0.000	0.105	0.000	0.895	2.100	0.000	0.298	2.398	0.417
ntl-12-119	Apr. 5, 1996	T4up	1.100	0.120	0.067	0.109	0.061	0.830	2.180	0.610	0.277	3.067	0.326
ntl-12-118	Apr. 5, 1996	Telect-all over	0.630	0.043	0.000	0.068	0.000	0.932	1.360	0.000	0.311	1.671	0.599
ntl-12-117	Apr. 5, 1996	Tmg-miner	0.610	0.042	0.000	0.069	0.000	0.931	1.380	0.000	0.310	1.690	0.592
ntl-16-19	Apr. 5, 1996	Tfwddk-miner-lt	0.760	0.075	0.078	0.099	0.103	0.798	1.980	1.030	0.266	3.276	0.305
ntl-16-20	Apr. 5, 1996	Tfwddk-miner-rt	1.500	0.160	0.099	0.107	0.066	0.827	2.140	0.660	0.276	3.076	0.325
ntl-16-23	Apr. 5, 1996	Tminer-lower	1.400	0.140	0.075	0.100	0.054	0.846	2.000	0.540	0.282	2.822	0.354
ntl-16-21	Apr. 5, 1996	Tminer-lower	1.100	0.150	0.084	0.136	0.076	0.788	2.720	0.760	0.263	3.743	0.267
ntl-16-22	Apr. 5, 1996	Tminer-lower	0.520	0.049	0.035	0.094	0.067	0.839	1.880	0.670	0.280	2.830	0.353
ntl-22-20	Apr. 5, 1996	2800 (lt rib to Alc5)	0.980	0.110	0.180	0.112	0.184	0.704	2.240	1.840	0.235	4.315	0.232
ntl-22-22	Apr. 5, 1996	A5-junc main & shaft	0.880	0.120	0.059	0.136	0.067	0.797	2.720	0.670	0.266	3.656	0.274
ntl-22-21	Apr. 5, 1996	2813	0.460	0.050	0.000	0.109	0.000	0.891	2.180	0.000	0.297	2.477	0.404
ntl-22-19	Apr. 5, 1996	2850	0.470	0.037	0.000	0.079	0.000	0.921	1.580	0.000	0.307	1.887	0.530
ntl-22-18	Apr. 5, 1996	2900	0.360	0.038	0.000	0.106	0.000	0.894	2.120	0.000	0.298	2.418	0.414
ntl-12-126	Apr. 8, 1996	T2-above belt transf	0.410	0.070	0.000	0.171	0.000	0.829	3.420	0.000	0.276	3.696	0.271
ntl-12-127	Apr. 8, 1996	T2-oper cab-top	0.980	0.120	0.070	0.122	0.071	0.807	2.440	0.710	0.269	3.419	0.292
ntl-12-123	Apr. 8, 1996	Telect-all over	0.490	0.054	0.000	0.110	0.000	0.890	2.200	0.000	0.297	2.497	0.401
ntl-12-124	Apr. 8, 1996	Telect-all over	0.740	0.060	0.000	0.081	0.000	0.919	1.620	0.000	0.306	1.926	0.519
ntl-12-125	Apr. 8, 1996	Tsurveyor-all over	0.520	0.048	0.000	0.092	0.000	0.908	1.840	0.000	0.303	2.143	0.467
ntl-16-28	Apr. 8, 1996	T1ObsDk	0.760	0.078	0.070	0.103	0.092	0.805	2.060	0.920	0.268	3.248	0.308
ntl-16-27	Apr. 8, 1996	T1rt side	0.920	0.100	0.073	0.109	0.079	0.812	2.180	0.790	0.271	3.241	0.309
ntl-16-25	Apr. 8, 1996	T2rt side	0.640	0.038	0.042	0.059	0.066	0.875	1.180	0.660	0.292	2.132	0.469
ntl-16-29	Apr. 8, 1996	Tfwddk-lt side	0.280	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
ntl-16-26	Apr. 8, 1996	Tfwdddk-rt side	1.100	0.130	0.077	0.118	0.070	0.812	2.360	0.700	0.271	3.331	0.300
ntl-22-25	Apr. 8, 1996	T1up-nxt conv 1	0.780	0.099	0.041	0.127	0.053	0.820	2.540	0.530	0.273	3.343	0.299
ntl-22-26	Apr. 8, 1996	T2low-nxt emerg butt	0.640	0.074	0.047	0.116	0.073	0.811	2.320	0.730	0.270	3.320	0.301
ntl-22-24	Apr. 8, 1996	T2rt rib-nxt elect box	0.800	0.072	0.000	0.090	0.000	0.910	1.800	0.000	0.303	2.103	0.475
ntl-22-27	Apr. 8, 1996	T3low-shelving nxt F	0.780	0.085	0.046	0.109	0.059	0.832	2.180	0.590	0.277	3.047	0.328
ntl-22-28	Apr. 8, 1996	T3mech	0.640	0.069	0.044	0.108	0.069	0.823	2.160	0.690	0.274	3.124	0.320
ntl-12-131	Apr. 9, 1996	Tdf-lt-side	1.000	0.120	0.081	0.120	0.081	0.799	2.400	0.810	0.266	3.476	0.288
ntl-12-132	Apr. 9, 1996	T4up-frt scrubbers	0.900	0.130	0.160	0.144	0.178	0.678	2.880	1.780	0.226	4.886	0.205
ntl-12-128	Apr. 9, 1996	T14 mech	1.500	0.190	0.140	0.127	0.093	0.780	2.540	0.930	0.260	3.730	0.268
ntl-12-130	Apr. 9, 1996	T1-cutterhead-wld	4.300	0.580	0.420	0.135	0.098	0.767	2.700	0.980	0.256	3.936	0.254
ntl-12-129	Apr. 9, 1996	T4&rear-miner	1.900	0.270	0.180	0.142	0.095	0.763	2.840	0.950	0.254	4.044	0.247
ntl-16-32	Apr. 9, 1996	0	0.014	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
ntl-16-31	Apr. 9, 1996	1000	0.020	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
ntl-16-35	Apr. 9, 1996	2000	0.100	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
ntl-16-33	Apr. 9, 1996	3000	0.420	0.040	0.043	0.095	0.102	0.803	1.900	1.020	0.268	3.188	0.314
ntl-16-34	Apr. 9, 1996	4000	0.380	0.049	0.088	0.129	0.232	0.639	2.580	2.320	0.213	5.113	0.196
ntl-22-33	Apr. 9, 1996	Tdf-rt rib	1.600	0.220	0.150	0.138	0.094	0.768	2.760	0.940	0.256	3.956	0.253

Board Analysis of 359 Air Samples From ESF Tunnel (Data from Charles Parker 2/20/97)

Sample No.	Date	Location	Col. 1 Total Dust mg/m3	Col. 2 Cristo-balite mg/m3	Col. 3 Quartz mg/m3	Col. 4 Cristo-balite %/100	Col. 5 Quartz %/100	Col. 6 PNOC %/100	Col. 7 Col. 4/ 0.050	Col. 8 Col. 5/ 0.100	Col. 9 Col.6/ 3.000	Col. 10 Col. 7 + Col. 8 + Col. 9	Col. 11 PEL = 1/Col. 10 mg/m3
ntl-22-32	Apr. 9, 1996	Tfwddk-rt-side	1.100	0.120	0.091	0.109	0.083	0.808	2.180	0.830	0.269	3.279	0.305
ntl-22-30	Apr. 9, 1996	Tdf-miner	2.500	0.290	0.170	0.116	0.068	0.816	2.320	0.680	0.272	3.272	0.306
ntl-22-31	Apr. 9, 1996	Tdf-miner	2.700	0.380	0.230	0.141	0.085	0.774	2.820	0.850	0.258	3.928	0.255
ehs 7	Apr. 9, 1996	T14 + 100m	0.290	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
ehs 10	Apr. 9, 1996	T14 + 50	0.270	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
ehs 6	Apr. 9, 1996	1000	0.030	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
ehs 3	Apr. 9, 1996	2000	0.250	0.023	0.000	0.092	0.000	0.908	1.840	0.000	0.303	2.143	0.467
ehs 2	Apr. 9, 1996	2000	1.210	0.012	0.000	0.010	0.000	0.990	0.200	0.000	0.330	0.530	1.887
ehs 1	Apr. 9, 1996	2000	0.170	0.140	0.000	0.824	0.000	0.176	16.480	0.000	0.059	16.539	0.060
ehs 8	Apr. 9, 1996	2800	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
ntl-12-139	Apr. 10, 1996	0	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
ntl-12-138	Apr. 10, 1996	1000	0.110	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
ntl-12-137	Apr. 10, 1996	2000	0.370	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
ntl-12-136	Apr. 10, 1996	3000	0.260	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
ntl-12-135	Apr. 10, 1996	4000	0.510	0.055	0.061	0.108	0.120	0.772	2.160	1.200	0.257	3.617	0.276
ntl-16-41	Apr. 10, 1996	Telect (where?)	0.240	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
ntl-16-39	Apr. 10, 1996	Tmech (where ?)	0.840	0.056	0.082	0.067	0.098	0.835	1.340	0.980	0.278	2.598	0.385
ntl-16-37	Apr. 10, 1996	Oiler-throughout tunn	0.230	0.000	0.042	0.000	0.183	0.817	0.000	1.830	0.272	2.102	0.476
ehs 20	Apr. 10, 1996	Tdf	0.840	0.075	0.000	0.089	0.000	0.911	1.780	0.000	0.304	2.084	0.480
ntl-16-38	Apr. 10, 1996	T5miner-rear drill dk	0.480	0.033	0.000	0.069	0.000	0.931	1.380	0.000	0.310	1.690	0.592
ntl-16-40	Apr. 10, 1996	Tfwddk-miner	1.700	0.040	0.045	0.024	0.026	0.950	0.480	0.260	0.317	1.057	0.946
ehs 17	Apr. 10, 1996	2000	0.310	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
ehs 19	Apr. 10, 1996	2488	0.340	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
ehs 14	Apr. 10, 1996	2800	0.550	0.045	0.000	0.082	0.000	0.918	1.640	0.000	0.306	1.946	0.514
ehs 13	Apr. 10, 1996	2900	0.000	0.000	0.000	0.376	0.000	0.624	7.520	0.000	0.208	7.728	0.129
ehs 11	Apr. 10, 1996	3000	0.170	0.064	0.000	0.105	0.000	0.895	2.100	0.000	0.298	2.398	0.417
ehs 16	Apr. 10, 1996	4512	0.430	0.045	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
ntl-22-36	Apr. 10, 1996	0	0.110	0.000	0.000	0.162	0.000	0.838	3.240	0.000	0.279	3.519	0.284
ehs 22	Apr. 10, 1996	1000	0.130	0.021	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
ntl-22-39	Apr. 10, 1996	1000	0.160	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
ehs 21	Apr. 10, 1996	1000	0.090	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
ehs 23	Apr. 10, 1996	2000	0.230	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
ntl-22-40	Apr. 10, 1996	2000	0.280	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
ehs 25	Apr. 10, 1996	2000	0.300	0.020	0.011	0.067	0.037	0.896	1.340	0.370	0.299	2.009	0.498
ehs 28	Apr. 10, 1996	2800	0.290	0.034	0.000	0.177	0.000	0.823	3.540	0.000	0.274	3.814	0.262
ehs 27	Apr. 10, 1996	2800	0.500	0.029	0.019	0.058	0.038	0.904	1.160	0.380	0.301	1.841	0.543
ntl-22-37	Apr. 10, 1996	3000	0.370	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
ntl-22-38	Apr. 10, 1996	4000	0.420	0.048	0.000	0.114	0.000	0.886	2.280	0.000	0.295	2.575	0.388
ehs 30	Apr. 10, 1996	4460	0.270	0.017	0.000	0.063	0.000	0.937	1.260	0.000	0.312	1.572	0.636
ehs 29	Apr. 10, 1996	4460	0.310	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
ehs 40	Apr. 11, 1996	T14	0.560	0.030	0.000	0.054	0.000	0.946	1.080	0.000	0.315	1.395	0.717

Board Analysis of 359 Air Samples From ESF Tunnel (Data from Charles Parker 2/20/97)

Sample No.	Date	Location	Col. 1 Total Dust mg/m3	Col. 2 Cristo-balite mg/m3	Col. 3 Quartz mg/m3	Col. 4 Cristo-balite %/100	Col. 5 Quartz %/100	Col. 6 PNOC %/100	Col. 7 Col. 4/ 0.050	Col. 8 Col. 5/ 0.100	Col. 9 Col.6/ 3.000	Col. 10 Col. 7 + Col. 8 + Col. 9	Col. 11 PEL = 1/Col. 10 mg/m3
ehs 31	Apr. 11, 1996	T14	0.860	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
ehs 39	Apr. 11, 1996	Tmg	0.440	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
ehs 38	Apr 11, 1996	Tmg	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3 000
ehs 34	Apr 11, 1996	T14 + 50 m	0.710	0.050	0.000	0.070	0.000	0.930	1.400	0.000	0.310	1.710	0 585
ehs 33	Apr. 11, 1996	T14 + 50 m	0.640	0.047	0.000	0.073	0.000	0.927	1.460	0.000	0.309	1.769	0 565
ehs 32	Apr. 11, 1996	T14 + 50 m	0.580	0.035	0.000	0.060	0.000	0.940	1.200	0.000	0.313	1.513	0.661
ehs 35	Apr. 11, 1996	2900	0.440	0.036	0.019	0.082	0.043	0.875	1.640	0.430	0.292	2.362	0.423
ehs 36	Apr. 11, 1996	2900	0 980	0.024	0.000	0.024	0.000	0.976	0.480	0.000	0.325	0.805	1.242
ehs 37	Apr. 11, 1996	2900	0.710	0.055	0.020	0.077	0.028	0.895	1.540	0.280	0.298	2.118	0.472
gd 4	Apr. 17, 1996	1000	0.070	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3 000
gd 2	Apr 17, 1996	2000	0.140	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3 000
gd 1	Apr. 17, 1996	2100	0 560	0.030	0.000	0.054	0.000	0.946	1.080	0.000	0.315	1.395	0.717
gd 3	Apr. 17, 1996	2800	0.180	0.024	0.000	0.133	0.000	0.867	2.660	0.000	0.289	2.949	0 339
gd5	Apr. 17, 1996	4460	0 270	0.052	0.000	0.193	0.000	0.807	3.860	0.000	0.269	4 129	0 242
gd-03	Apr. 23, 1996	2100		0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3 000
gd-02	Apr. 23, 1996	2800		0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-04	Apr. 23, 1996	2800		0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3 000
gd-05	Apr. 23, 1996	4460		0.060	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3 000
gd-06	Apr. 23, 1996	4460		0.060	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
msha-183	Apr. 25, 1996	ESF PAD FE loader	0.540	0.000	0.022	0.000	0.041	0.959	0.000	0.410	0.320	0.730	1.370
msha-177	Apr. 25, 1996	miner	0.520	0.000	0.018	0.000	0.035	0.965	0.000	0.350	0.322	0.672	1.489
k-2	Apr. 28, 1996	k	0.210	0.020	0.000	0.095	0.000	0.905	1.900	0.000	0.302	2.202	0.454
ehs-2	May.1, 1996	T14	0.400	0.044	0.039	0.110	0.098	0.792	2.200	0.980	0.264	3.444	0 290
ehs-1	May.1, 1996	T14	1.910	0.038	0.024	0.020	0.013	0.967	0.400	0.130	0.322	0.852	1.173
gd-05	May.1, 1996	2250	0.340	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3 000
gd-03	May.1, 1996	2790	0.120	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3 000
gd-04	May.1, 1996	2790	0.090	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3 000
gd-01	May.1, 1996	4750	0.310	0.032	0.000	0.103	0.000	0.897	2.060	0.000	0.299	2.359	0 424
gd-02	May.1, 1996	4750	0.310	0.078	0.000	0.252	0.000	0.748	5.040	0.000	0.249	5 289	0.189
mp-01dc	May.15, 1996	2790	0.140	0.020	0.000	0.143	0.000	0.857	2.860	0.000	0.286	3.146	0 318
mp-02al	May.15, 1996	2790	0.220	0.020	0.000	0.091	0.000	0.909	1.820	0.000	0.303	2.123	0 471
mp-03-dc		4460	0.460	0.120	0.020	0.261	0.043	0.696	5.220	0.430	0.232	5.882	0 170
mo-04al		4460	0.590	0.080	0.020	0.136	0.034	0.830	2.720	0.340	0.277	3.337	0 300
mp-05cd	May.15, 1996	5224	0.560	0.090	0.000	0.161	0.000	0.839	3.220	0.000	0.280	3.500	0.286
dc-05al	May.16, 1996	Tmg	0.570	0.110	0.000	0.193	0.000	0.807	3.860	0.000	0.269	4.129	0.242
dc06dc	May.16, 1996	Tmg	0.190	0.060	0.000	0.316	0.000	0.684	6.320	0.000	0.228	6.548	0.153
dc-01al	May.16, 1996	2790	0.530	0.040	0.000	0.075	0.000	0.925	1.500	0.000	0.308	1.808	0.553
dc-02dc	May.16, 1996	2790	0.370	0.090	0.000	0.265	0.000	0.735	5.300	0.000	0.245	5.545	0.180
dc-03al	May.16, 1996	4695	0.670	0.120	0.030	0.179	0.045	0.776	3.580	0.450	0.259	4.289	0 233
dc-04dc	May.16, 1996	4695	0.610	0.040	0.000	0.066	0.000	0.934	1.320	0.000	0.311	1.631	0.613
dc-1	May.22, 1996	<booster #3	0.320	0.091	0.041	0.284	0.128	0.588	5.680	1.280	0.196	7.156	0.140

Board Analysis of 359 Air Samples From ESF Tunnel (Data from Charles Parker 2/20/97)

Sample No.	Date	Location	Col. 1 Total Dust mg/m3	Col. 2 Cristo-balite mg/m3	Col. 3 Quartz mg/m3	Col. 4 Cristo-balite %/100	Col. 5 Quartz %/100	Col. 6 PNOC %/100	Col. 7 Col. 4/ 0.050	Col. 8 Col. 5/ 0.100	Col. 9 Col.6/ 3.000	Col. 10 Col. 7 + Col. 8 + Col. 9	Col. 11 PEL = 1/Col. 10 mg/m3
dc-2	May 22, 1996	<booster #3	0.140	0.104	0.037	0.743	0.264	-0.007	14.860	2.640	-0.002	17.498	0.057
dc-3	May 22, 1996	>booster #3	0.130	0.074	0.000	0.569	0.000	0.431	11.380	0.000	0.144	11.524	0.087
dc-4	May 22, 1996	>booster #3	0.110	0.061	0.000	0.555	0.000	0.445	11.100	0.000	0.148	11.248	0.089
gd-1-al	May 29, 1996	5523	2.250	0.280	0.050	0.124	0.022	0.854	2.480	0.220	0.285	2.985	0.335
gd-2-al	May 29, 1996	5523	0.990	0.120	0.030	0.121	0.030	0.849	2.420	0.300	0.283	3.003	0.333
gd-3-al	May 29, 1996	5439	1.230	0.130	0.030	0.106	0.024	0.870	2.120	0.240	0.290	2.650	0.377
gd-4-al	May 29, 1996	2800	0.600	0.070	0.030	0.117	0.050	0.833	2.340	0.500	0.278	3.118	0.321
gd-5-al	May 29, 1996	2790	0.570	0.090	0.000	0.158	0.000	0.842	3.160	0.000	0.281	3.441	0.291
dc-1	June 11, 1996	Tmg	0.250	0.033	0.024	0.132	0.096	0.772	2.640	0.960	0.257	3.857	0.259
dc-2	June 11, 1996	T14-portal	0.260	0.020	0.000	0.077	0.000	0.923	1.540	0.000	0.308	1.848	0.541
TRW-1	June 11, 1996	Tmg	0.560	0.108	0.000	0.193	0.000	0.807	3.860	0.000	0.269	4.129	0.242
dc-1	June 12, 1996	Tmg	0.130	0.041	0.000	0.315	0.000	0.685	6.300	0.000	0.228	6.528	0.153
TRW-2	June 12, 1996	T14	0.160	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-1	June 25, 1996	3600	0.470	0.069	0.028	0.147	0.060	0.793	2.940	0.600	0.264	3.804	0.263
gd-2	June 25, 1996	2950	0.830	0.135	0.029	0.163	0.035	0.802	3.260	0.350	0.267	3.877	0.258
gd-3	June 25, 1996	3850	1.110	0.133	0.056	0.120	0.050	0.830	2.400	0.500	0.277	3.177	0.315
gd-4	June 25, 1996	5505	0.850	0.091	0.030	0.107	0.035	0.858	2.140	0.350	0.286	2.776	0.360
gd-5	June 25, 1996	5780.000	0.660	0.075	0.029	0.114	0.044	0.842	2.280	0.440	0.281	3.001	0.333
gd-2	July 9, 1996	Alc 5	0.070	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-3	July 9, 1996	2900.000	0.100	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-4	July 9, 1996	3600.000	0.030	0.020	0.000	0.667	0.000	0.333	13.340	0.000	0.111	13.451	0.074
gd-5	July 9, 1996	3850.000	0.120	0.060	0.000	0.500	0.000	0.500	10.000	0.000	0.167	10.167	0.098
DC-1	July 17, 1996		0.420	0.034	0.038	0.081	0.090	0.829	1.620	0.900	0.276	2.796	0.358
DC-1	July 17, 1996		0.640	0.016	0.018	0.025	0.030	0.945	0.500	0.300	0.315	1.115	0.897
DC-2	July 30, 1996		0.220	0.055	0.000	0.250	0.000	0.750	5.000	0.000	0.250	5.250	0.190
GD-1	July 30, 1996		0.400	0.086	0.000	0.215	0.000	0.785	4.300	0.000	0.262	4.562	0.219
DC-1	Aug. 7, 1996		0.270	0.028	0.000	0.104	0.000	0.896	2.080	0.000	0.299	2.379	0.420
DC-2	Aug. 9, 1996		0.300	0.059	0.024	0.197	0.080	0.723	3.940	0.800	0.241	4.981	0.201
DC-3	Aug. 9, 1996		0.200	0.048	0.000	0.240	0.000	0.760	4.800	0.000	0.253	5.053	0.198
DC-4	Aug. 9, 1996		0.350	0.045	0.028	0.129	0.080	0.791	2.580	0.800	0.264	3.644	0.274
DR-1	Aug. 9, 1996		0.580	0.079	0.034	0.136	0.059	0.805	2.720	0.590	0.268	3.578	0.279
Dataram-4	Aug. 13, 1996		0.480	0.130	0.000	0.271	0.000	0.729	5.420	0.000	0.243	5.663	0.177
DC-1	Aug. 13, 1996		0.900	0.021	0.080	0.023	0.089	0.888	0.460	0.890	0.296	1.646	0.608
DC-2	Aug. 13, 1996		0.990	0.000	0.101	0.000	0.102	0.898	0.000	1.020	0.299	1.319	0.758
DC-3	Aug. 13, 1996		1.220	0.031	0.126	0.025	0.103	0.872	0.500	1.030	0.291	1.821	0.549
Dc-4	Aug. 13, 1996		1.140	0.040	0.158	0.035	0.139	0.826	0.700	1.390	0.275	2.365	0.423
dc-1	Sept. 17, 1996	28.00	0.040	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
dc-3	Sept. 17, 1996	21.00	0.030	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
dc-4	Sept. 17, 1996	21.00	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
dc-5	Sept. 17, 1996	28.40	0.070	0.048	0.017	0.686	0.243	0.071	13.720	2.430	0.024	16.174	0.062
dc-7	Sept. 17, 1996	21.00	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000

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Sample No.	Date	Location	Col. 1 Total Dust mg/m3	Col. 2 Cristo-balite mg/m3	Col. 3 Quartz mg/m3	Col. 4 Cristo-balite %/100	Col. 5 Quartz %/100	Col. 6 PNOC %/100	Col. 7 Col. 4/ 0.050	Col. 8 Col. 5/ 0.100	Col. 9 Col.6/ 3.000	Col. 10 Col. 7 + Col. 8 + Col. 9	Col. 11 PEL = 1/Col. 10 mg/m3
dc-8	Sept. 17, 1996	Alc 5	0.110	0.037	0.000	0.336	0.000	0.664	6.720	0.000	0.221	6.941	0.144
dc-9	Sept. 17, 1996	28.42	0.280	0.018	0.000	0.064	0.000	0.936	1.280	0.000	0.312	1.592	0.628
dc-10	Sept. 17, 1996	Alc 5	0.130	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
dc-1	Sept. 18, 1996	28.40	0.120	0.031	0.016	0.258	0.133	0.609	5.160	1.330	0.203	6.693	0.149
dc-5	Sept. 18, 1996	28.40	0.130	0.041	0.000	0.315	0.000	0.685	6.300	0.000	0.228	6.528	0.153
dc-6	Sept. 18, 1996	28.40	0.230	0.018	0.000	0.078	0.000	0.922	1.560	0.000	0.307	1.867	0.536
dc-9	Sept. 18, 1996	Alc 5	0.140	0.030	0.000	0.214	0.000	0.786	4.280	0.000	0.262	4.542	0.220
dc-11	Sept. 18, 1996	Alc 5	0.140	0.000	0.066	0.000	0.471	0.529	0.000	4.710	0.176	4.886	0.205
dc-A	Sept. 18, 1996	28.00	0.110	0.027	0.055	0.245	0.500	0.255	4.900	5.000	0.085	9.985	0.100
dc-B	Sept. 18, 1996	28.00	0.110	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
dc-C	Sept. 18, 1996	21.00	0.170	0.050	0.000	0.294	0.000	0.706	5.880	0.000	0.235	6.115	0.164
dc-D	Sept. 18, 1996	21.00	0.110	0.000	0.034	0.000	0.309	0.691	0.000	3.090	0.230	3.320	0.301
dc-E	Sept. 18, 1996	21.00	0.250	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
EHS-01	Sept. 19, 1996	6352.61	1.600	0.218	0.038	0.136	0.024	0.840	2.720	0.240	0.280	3.240	0.309
EHS-2	Sept. 19, 1996	5242.61	1.050	0.086	0.023	0.082	0.022	0.896	1.640	0.220	0.299	2.159	0.463
EHS-3	Sept. 19, 1996	5352.61	1.290	0.211	0.023	0.164	0.018	0.818	3.280	0.180	0.273	3.733	0.268
EHS-4	Sept. 19, 1996	5242.61	1.090	0.102	0.025	0.094	0.023	0.883	1.880	0.230	0.294	2.404	0.416
EHS-5	Sept. 19, 1996	5242.61	1.120	0.152	0.021	0.136	0.019	0.845	2.720	0.190	0.282	3.192	0.313
DR-9/19	Sept. 19, 1996	Alc 5	0.099	0.010	0.007	0.101	0.071	0.828	2.020	0.710	0.276	3.006	0.333
DR-9/20	Sept. 20, 1996	6247.97	0.780	0.091	0.026	0.117	0.033	0.850	2.340	0.330	0.283	2.953	0.339
EHS-1	Sept. 23, 1996	6376.09	0.960	0.087	0.000	0.091	0.000	0.909	1.820	0.000	0.303	2.123	0.471
EHS-2	Sept. 23, 1996	6376.09	1.020	0.143	0.049	0.140	0.048	0.812	2.800	0.480	0.271	3.551	0.282
EHS-3	Sept. 23, 1996	6376.09	1.080	0.142	0.034	0.131	0.031	0.838	2.620	0.310	0.279	3.209	0.312
gd-5	Sept. 24, 1996	28.00	0.180	0.041	0.000	0.228	0.000	0.772	4.560	0.000	0.257	4.817	0.208
gd-6	Sept. 24, 1996	28.00	0.340	0.017	0.000	0.050	0.000	0.950	1.000	0.000	0.317	1.317	0.759
gd-9	Sept. 24, 1996	28.00	0.400	0.060	0.017	0.150	0.043	0.807	3.000	0.430	0.269	3.699	0.270
gd-A	Sept. 24, 1996	28.42	0.110	0.061	0.017	0.555	0.155	0.290	11.100	1.550	0.097	12.747	0.078
gd-B	Sept. 24, 1996	28.42	0.130	0.070	0.000	0.538	0.000	0.462	10.760	0.000	0.154	10.914	0.092
gd-1	Sept. 25, 1996	28.40	0.414	0.128	0.000	0.309	0.000	0.691	6.180	0.000	0.230	6.410	0.156
gd-2	Sept. 25, 1996	28.40	0.442	0.128	0.000	0.290	0.000	0.710	5.800	0.000	0.237	6.037	0.166
gd-3	Sept. 25, 1996	28.40	0.342	0.100	0.000	0.292	0.000	0.708	5.840	0.000	0.236	6.076	0.165
gd-4	Sept. 25, 1996	28.40	0.428	0.128	0.000	0.299	0.000	0.701	5.980	0.000	0.234	6.214	0.161
gd-5	Sept. 25, 1996	28.40	0.414	0.114	0.000	0.275	0.000	0.725	5.500	0.000	0.242	5.742	0.174
gd-6	Sept. 25, 1996	28.00	0.065	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-7	Sept. 25, 1996	28.00	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-8	Sept. 25, 1996	28.00	0.032	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-9	Sept. 25, 1996	28.00	0.032	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-10	Sept. 25, 1996	28.00	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
k-3	Oct. 7, 1996	TBM-Dk-12 Air filter	0.219	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
k-5	Oct. 7, 1996	TBM-Dk 12 inside Cl	0.017	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
k-4	Oct. 7, 1996	TBM-DK 12 inside Cl	0.057	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000

Board Analysis of 359 Air Samples From ESF Tunnel (Data from Charles Parker 2/20/97)

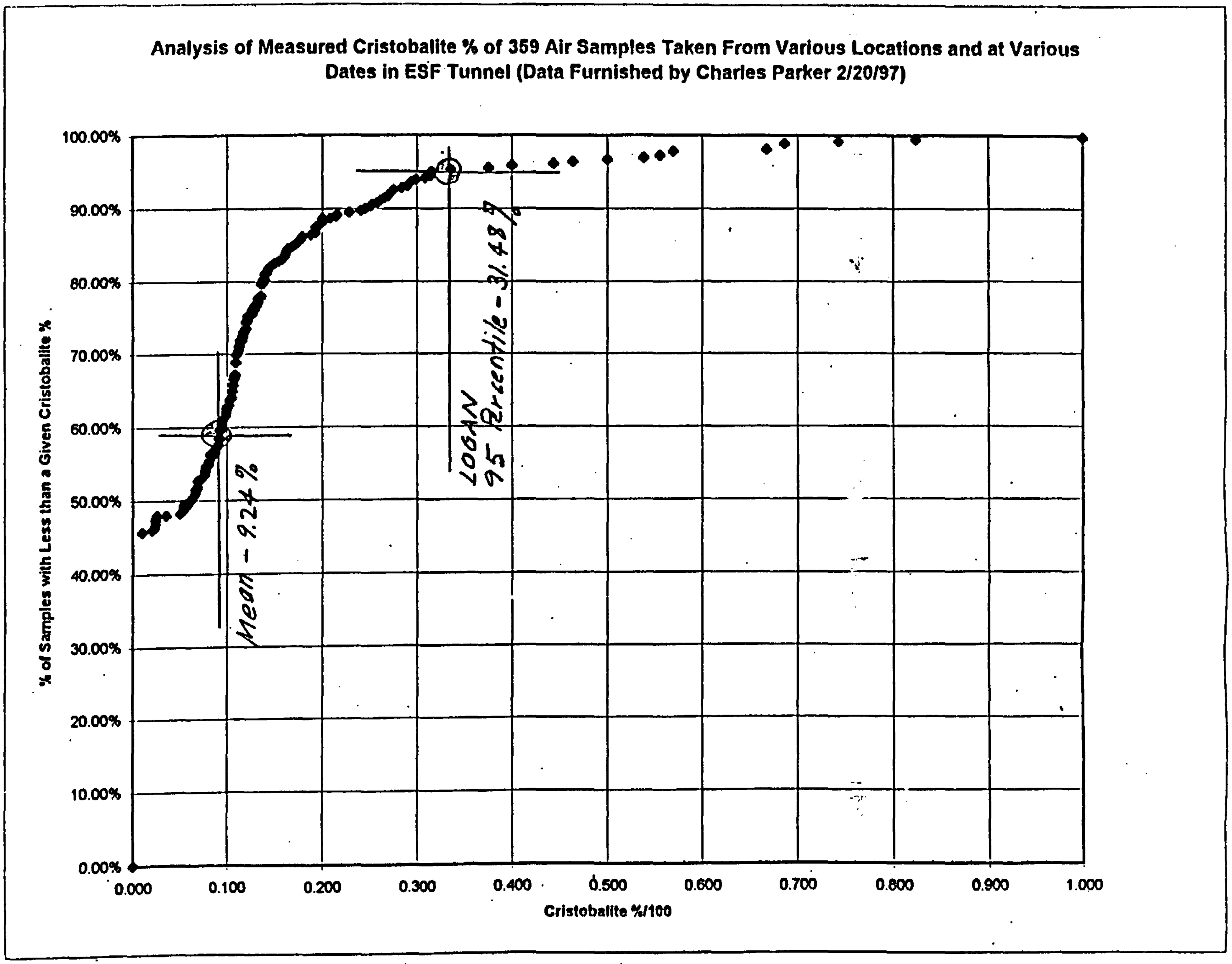
Sample No.	Date	Location	Col. 1 Total Dust mg/m3	Col. 2 Cristo-balite mg/m3	Col. 3 Quartz mg/m3	Col. 4 Cristo-balite %/100	Col. 5 Quartz %/100	Col. 6 PNOC %/100	Col. 7 Col. 4/ 0.050	Col. 8 Col. 5/ 0.100	Col. 9 Col.6/ 3.000	Col. 10 Col. 7 + Col. 8 + Col. 9	Col. 11 PEL = 1/Col. 10 mg/m3
k-2	Oct. 7, 1996	TBM-Dk 1 spt struct	0.201	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
k-1	Oct. 7, 1996	TBM-dk12 outside cl	0.038	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-5	Oct. 8, 1996	28.40	1.120	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-10	Oct. 8, 1996	Alc 5	0.070	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-8	Oct. 8, 1996	29.00	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-7	Oct. 8, 1996	29.00	0.150	0.030	0.000	0.200	0.000	0.800	4.000	0.000	0.267	4.267	0.234
gd-6	Oct. 8, 1996		0.020	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-2	Oct. 8, 1996	27.90	0.180	0.020	0.000	0.111	0.000	0.889	2.220	0.000	0.296	2.516	0.397
gd-4	Oct. 8, 1996	28.40	0.130	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-3	Oct. 8, 1996	28.40	0.120	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-1	Oct. 8, 1996	27.90	0.100	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
k-2	Oct. 8, 1996	29.50	0.013	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
k-1	Oct. 8, 1996	27.50	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-5	Oct. 9, 1996	28.40	0.090	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-9	Oct. 9, 1996	Alc 5	0.070	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-8	Oct. 9, 1996	Alc 5	0.070	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-7	Oct. 9, 1996	29.00	0.020	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-6	Oct. 9, 1996	29.00	0.080	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-4	Oct. 9, 1996	28.40	0.080	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-3	Oct. 9, 1996	28.40	0.020	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-2	Oct. 9, 1996	27.90	0.080	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-1	Oct. 9, 1996	27.90	0.070	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-5	Oct. 10, 1996	28.40	0.020	0.020	0.000	1.000	0.000	0.000	20.000	0.000	0.000	20.000	0.050
gd-9	Oct. 10, 1996	Alc 5	0.080	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-7	Oct. 10, 1996	29.00	0.040	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-6	Oct. 10, 1996	29.00	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-8	Oct. 10, 1996	Alc 5	0.010	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-4	Oct. 10, 1996	28.40	0.010	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-3	Oct. 10, 1996	28.40	0.040	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-2	Oct. 10, 1996	27.90	0.010	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-1	Oct. 10, 1996	27.90	0.090	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
k-4	Oct. 15, 1996	TBM Dk1 Oper. Cab	0.224	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
k-3	Oct. 15, 1996	TBM-Mechanic	0.256	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
k-2	Oct. 15, 1996	TBM-dk 1 Drill Rock	0.109	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
k-1	Oct. 15, 1996	TBM-dk5 dril rockbolt	0.063	0.000	0.044	0.000	0.698	0.302	0.000	6.980	0.101	7.081	0.141
gd-1	Oct. 15, 1996	28.40	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-2	Oct. 15, 1996	28.40	0.090	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-3	Oct. 15, 1996	28.40	0.110	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-4	Oct. 15, 1996	Alc 5	0.160	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-5	Oct. 15, 1996	Alc 5	0.170	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
k-3	Oct. 16, 1996	TBM-dk1 supt	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000

Board Analysis of 359 Air Samples From ESF Tunnel (Data from Charles Parker 2/20/97)

Sample No.	Date	Location	Col. 1 Total Dust mg/m3	Col. 2 Cristo-balite mg/m3	Col. 3 Quartz mg/m3	Col. 4 Cristo-balite %/100	Col. 5 Quartz %/100	Col. 6 PNOC %/100	Col. 7 Col. 4/ 0.050	Col. 8 Col. 5/ 0.100	Col. 9 Col.6/ 3.000	Col. 10 Col. 7 + Col. 8 + Col. 9	Col. 11 PEL = 1/Col. 10 mg/m3
k-1	Oct. 16, 1996	TBM-dk14	0.040	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
k-2	Oct. 16, 1996	TBM-dk12-in CR	0.042	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
k-2	Oct. 21, 1996	TBM-dk12 TBM side	0.091	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
k-1	Oct. 21, 1996	TBM-dk12 TBM side	0.087	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
k-2	Oct. 21, 1996	TBM-dk12 TBM side	0.311	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
k-1	Oct. 21, 1996	TBM-dk12 TBM side	0.157	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-8	Oct. 22, 1996		0.170	0.034	0.000	0.200	0.000	0.800	4.000	0.000	0.267	4.267	0.234
gd-7	Oct. 22, 1996		0.200	0.028	0.000	0.140	0.000	0.860	2.800	0.000	0.287	3.087	0.324
k-2	Oct. 22, 1996	TBM MG opr	0.169	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
k-1	Oct. 22, 1996	TBM-dk14 util. install	0.281	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-6	Oct. 22, 1996		0.110	0.051	0.000	0.464	0.000	0.536	9.280	0.000	0.179	9.459	0.106
gd-5	Oct. 22, 1996	Alc 5 01 21	0.010	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-1	Oct. 22, 1996	27 90	0.030	0.020	0.000	0.667	0.000	0.333	13.340	0.000	0.111	13.451	0.074
gd-3	Oct. 22, 1996	Alc 5 00 07	0.070	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-2	Oct. 22, 1996	28 40	0.070	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-4	Oct. 22, 1996	Alc 5 00 16	0.020	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
k-1	Oct. 23, 1996	TBM-dk12 TBM side	0.230	0.000	0.086	0.000	0.374	0.626	0.000	3.740	0.209	3.949	0.253
k-2	Oct. 23, 1996	TBM dk12 TBM side	0.208	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
k-2	Oct. 24, 1996	TBM-dk5 lost elect	0.113	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
k-1	Oct. 24, 1996	TBM-dk5 lost elect	0.118	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
k-2	Oct. 25, 1996	Alc 7 Mucker oper.	0.268	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
k-1	Oct. 25, 1996	Alc 7 Alp Mnr Opr	0.228	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
k-1	Oct. 26, 1996	Alc 7 50+50 rt rib	0.395	0.031	0.000	0.078	0.000	0.922	1.560	0.000	0.307	1.867	0.536
k-1	Oct. 26, 1996	Alc 7 Alp Mnr spott	0.402	0.037	0.000	0.092	0.000	0.908	1.840	0.000	0.303	2.143	0.467
k-2	Oct. 27, 1996	Alc 7 lt rib beh alp	0.361	0.035	0.121	0.097	0.335	0.568	1.940	3.350	0.189	5.479	0.183
k	Oct. 27, 1996	Alc 7 Alp. Mnr opr	0.774	0.082	0.084	0.106	0.109	0.785	2.120	1.090	0.262	3.472	0.288
k-2	Oct. 28, 1996	Alc 7 50+62 rt rib	0.229	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-5	Oct. 29, 1996	29 00	0.110	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-3	Oct. 29, 1996	28.40	0.110	0.030	0.000	0.273	0.000	0.727	5.460	0.000	0.242	5.702	0.175
k-2	Oct. 29, 1996		1.013	0.093	0.069	0.092	0.068	0.840	1.840	0.680	0.280	2.800	0.357
gd-4	Oct. 29, 1996	29 00	0.160	0.030	0.030	0.188	0.188	0.624	3.76)	1.880	0.208	5.848	0.171
gd-2	Oct. 29, 1996	28.40	0.140	0.000	0.000	0.000	0.000	1.000	0.00)	0.000	0.333	0.333	3.000
gd-1	Oct. 29, 1996	27.90	0.210	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
k-1	Oct. 29, 1996	Alc 7 Alp mnr opr	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-2	Oct. 30, 1996	28.40	0.230	0.040	0.000	0.174	0.000	0.826	3.480	0.000	0.275	3.755	0.266
gd-4	Oct. 30, 1996	29 00	0.250	0.040	0.000	0.160	0.000	0.840	3.200	0.000	0.280	3.480	0.287
gd-3	Oct. 30, 1996	28.40	0.260	0.070	0.000	0.269	0.000	0.731	5.380	0.000	0.244	5.624	0.178
k-1	Oct. 30, 1996	TBM kd6 lt rail	0.050	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-1	Oct. 30, 1996	27 90	0.240	0.050	0.000	0.208	0.000	0.792	4.160	0.000	0.264	4.424	0.226
k-2	Oct. 30, 1996	TBM dk6 rt rail	0.049	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-5	Oct. 30, 1996	29.00	0.260	0.040	0.000	0.154	0.000	0.846	3.080	0.000	0.282	3.362	0.297

Board Analysis of 359 Air Samples From ESF Tunnel (Data from Charles Parker 2/20/97)

Sample No.	Date	Location	Col. 1 Total Dust mg/m3	Col. 2 Cristo-balite mg/m3	Col. 3 Quartz mg/m3	Col. 4 Cristo-balite %/100	Col. 5 Quartz %/100	Col. 6 PNOC %/100	Col. 7 Col. 4/ 0.050	Col. 8 Col. 5/ 0.100	Col. 9 Col.6/ 3.000	Col. 10 Col. 7 + Col. 8 + Col. 9	Col. 11 PEL = 1/Col. 10 mg/m3
k-4	Oct. 30, 1996	TBM dk7 inside rail	0.057	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
lm-5	Oct. 30, 1996	29.00	0.120	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
k-3	Oct. 30, 1996	TBM kd6 outside rail	0.046	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
lm-6	Oct. 30, 1996	28.40 DR	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
k-2	Oct. 31, 1996	TBM dk6 outside rail	0.054	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
lm-4	Oct. 31, 1996	29.00	0.290	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
lm-3	Oct. 31, 1996	28.40	0.130	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
lm-2	Oct. 31, 1996	28.40	0.100	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
lm-1	Oct. 31, 1996	27.90	0.150	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
k-1	Oct. 31, 1996	TBM dk7 inside rt rail	0.058	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
lm-3	Nov 1, 1996	28.40	0.070	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
lm-4	Nov. 1, 1996	29.00	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
lm-5	Nov. 1, 1996	29.00	0.090	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
k-1	Nov. 1, 1996	TBM dk8 outside rail	0.101	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
lm-1	Nov 1, 1996	27.90	0.090	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
k-2	Nov. 1, 1996	TBM dk8 inside rail	0.119	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
k-3	Nov. 1, 1996	TBM dk9 outside rail	0.093	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
k-4	Nov. 1, 1996	TBM dk9 rt inside rail	0.102	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
lm-2	Nov. 1, 1996	28.40	0.140	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
k-3	Nov. 4, 1996	TBM dk-6 rt rib	0.064	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
k-4	Nov. 4, 1996	TBM dk5 rt rib	0.096	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
k-1	Nov. 4, 1996	TBM dk 8 rt rib	0.068	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
k-2	Nov. 4, 1996	TBM dk7 rt rib	0.078	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-2	Nov. 6, 1996	28.40	0.140	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-5	Nov. 6, 1996	29.00	0.140	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-3	Nov. 6, 1996	28.40	0.340	0.060	0.000	0.176	0.000	0.824	3.520	0.000	0.275	3.795	0.264
gd-4	Nov. 6, 1996	29.00	0.090	0.060	0.000	0.667	0.000	0.333	13.340	0.000	0.111	13.451	0.074
k-2	Nov. 6, 1996	TBM-Dk7 rt rib	0.148	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
k-1	Nov. 6, 1996	TBM-DK8 rt rib	0.032	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
k-3	Nov. 6, 1996	TBM-Dk6 rt rib	0.108	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
k-4	Nov. 6, 1996	TBM-Dk5 rt rib	0.166	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
gd-1	Nov. 6, 1996	27.90	0.110	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.333	0.333	3.000
		Mean	0.43827	0.04487	0.01870	0.09239	0.02811	0.87950	-	-	-	-	1.51286
		Stand. Dev.	0.51080	0.06582	0.04167	0.14083	0.07113	0.16563	-	-	-	-	1.32500
		PEL Calc. Based on Means as Input				0.09239	0.02811	0.87950	1.84780	0.28106	0.29317	2.42203	0.41288
		95th Percentile (LOGAN Determination)				0.31476	0.10800	0.57723	6.29520	1.08000	0.19241	7.56761	0.13214



Analysis of Measured Cristobalite % of 359 Air Samples Taken From Various Locations and at Various Dates in ESF Tunnel (Data Furnished by Charles Parker 2/20/97)
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
% of Samples with Less than a Given Cristobalite %
0.000
0.100
0.200
0.300
0.400
0.500
0.600
0.700
0.800
0.900
1.000
Cristobalite %/100
Mean - 9.24%
LOGAN
95 Percentile - 31.48%

39

Exhibit 2

Analysis of Measured Quartz % of 359 Air Samples Taken From Various Locations and at Various Dates in ESF Tunnel (Data Furnished by Charles Parker 2/20/97)

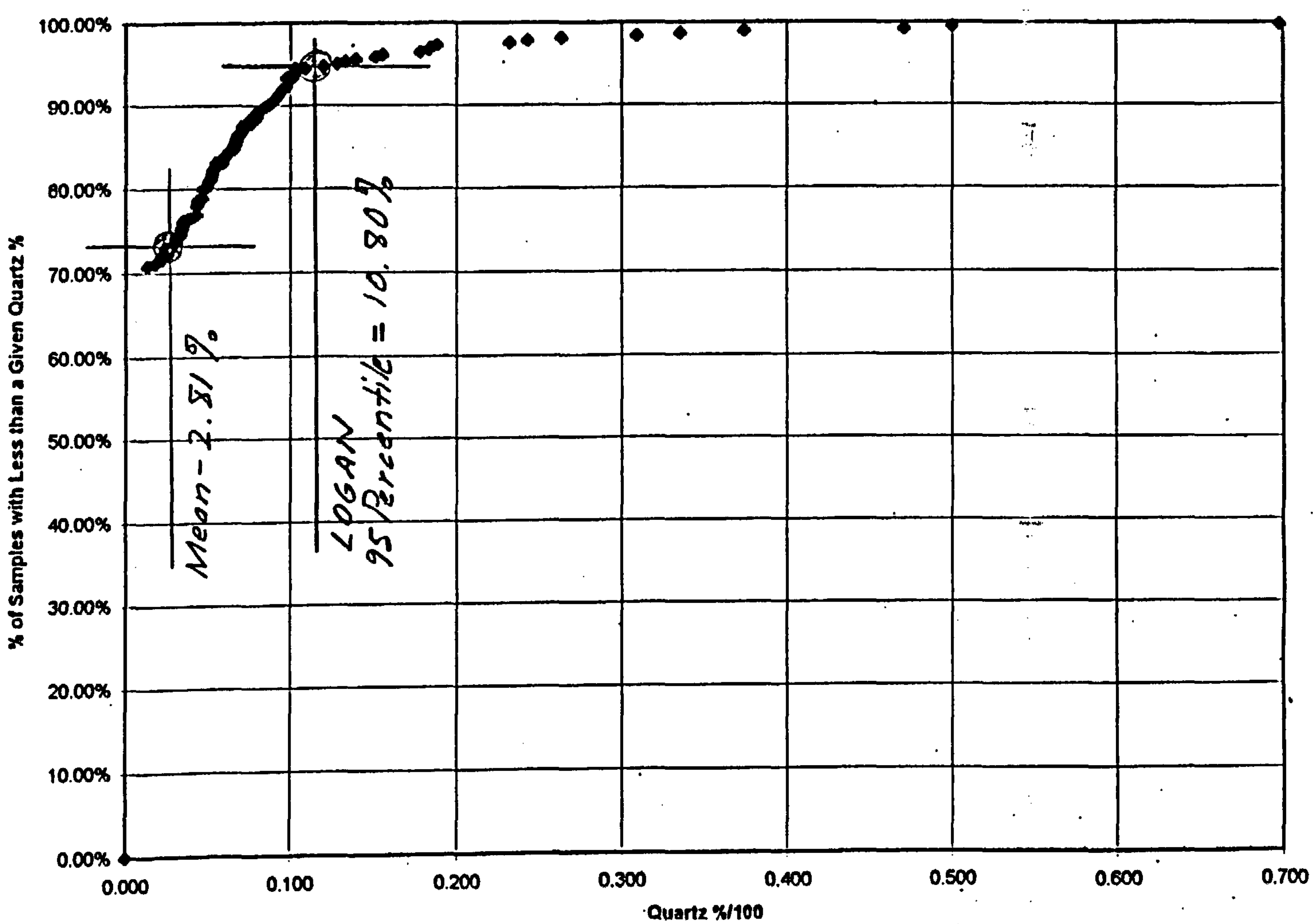
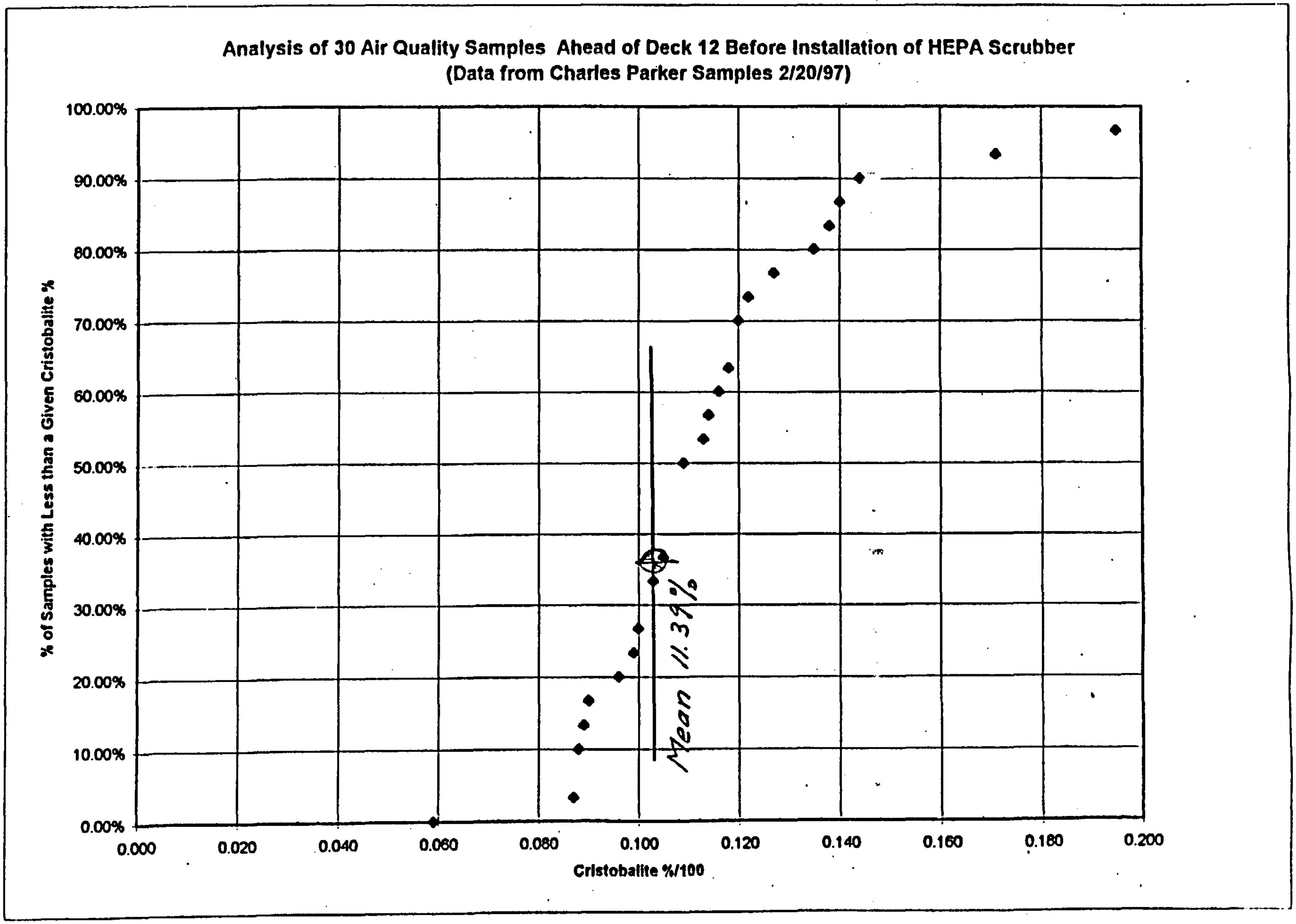


Exhibit 3

Analysis of 30 Air Quality Samples Ahead of Deck 12 Before Installation of HEPA Scrubber
(Data from Charles Parker Samples 2/20/97)

Sample No.	Date	Location	Col. 1 Total Dust mg/m3	Col. 2 Cristo-balite mg/m3	Col. 3 Quartz mg/m3	Col. 4 Cristo-balite %/100	Col. 5 Quartz %/100	Col. 6 PNOC %/100	Col. 7 Col. 4/ 0.050	Col. 8 Col. 5/ 0.100	Col. 9 Col.6/ 3.000	Col. 10 Col. 7 + Col. 8 + Col. 9	Col. 11 PEL = 1/Col. 10 mg/m3
gd1	Mar. 27, 1996	Tunnel Dance Floor	0.470	0.045	0.016	0.096	0.034	0.870	1.920	0.340	0.290	2.550	0.392
ntl-101	Apr. 2, 1996	Tunnel Dance Floor	1.200	0.120	0.056	0.100	0.047	0.853	2.000	0.470	0.284	2.754	0.363
ntl-104	Apr. 2, 1996	Tunnel Dance Floor	0.370	0.072	0.056	0.195	0.151	0.654	3.900	1.510	0.218	5.628	0.178
ntl-102	Apr. 2, 1996	Forward Deck	0.820	0.081	0.035	0.099	0.043	0.858	1.980	0.430	0.286	2.696	0.371
ntl-04	Apr. 2, 1996	Dance Floor	0.630	0.055	0.000	0.087	0.000	0.913	1.740	0.000	0.304	2.044	0.489
ntl-03	Apr. 2, 1996	Dance Floor	0.780	0.069	0.000	0.088	0.000	0.912	1.760	0.000	0.304	2.064	0.484
ntl-110	Apr. 3, 1996	T2	0.910	0.094	0.040	0.103	0.044	0.853	2.060	0.440	0.284	2.784	0.359
ntl-108	Apr. 3, 1996	Tobs-df	1.500	0.170	0.078	0.113	0.052	0.835	2.260	0.520	0.278	3.058	0.327
ntl-22-09	Apr. 3, 1996	T3	0.730	0.064	0.000	0.088	0.000	0.912	1.760	0.000	0.304	2.064	0.484
ntl-22-13	Apr. 4, 1996	T2 op-cab-outside	1.000	0.140	0.098	0.140	0.098	0.762	2.800	0.980	0.254	4.034	0.248
ntl-22-16	Apr. 4, 1996	T2abv-conv-hopper	1.400	0.160	0.073	0.114	0.052	0.834	2.280	0.520	0.278	3.078	0.325
ntl-22-11	Apr. 4, 1996	Tfwdddk	2.000	0.240	0.110	0.120	0.055	0.825	2.400	0.550	0.275	3.225	0.310
ntl-12-121	Apr. 5, 1996	T12up-Surv platfm	0.610	0.064	0.000	0.105	0.000	0.895	2.100	0.000	0.298	2.398	0.417
ntl-12-119	Apr. 5, 1996	T4up	1.100	0.120	0.067	0.109	0.061	0.830	2.180	0.610	0.277	3.067	0.326
ntl-12-126	Apr. 8, 1996	T2-above belt transf	0.410	0.070	0.000	0.171	0.000	0.829	3.420	0.000	0.276	3.696	0.271
ntl-12-127	Apr. 8, 1996	T2-oper cab-top	0.980	0.120	0.070	0.122	0.071	0.807	2.440	0.710	0.269	3.419	0.292
ntl-16-28	Apr. 8, 1996	T1ObsDk	0.760	0.078	0.070	0.103	0.092	0.805	2.060	0.920	0.268	3.248	0.308
ntl-16-27	Apr. 8, 1996	T1rt side	0.920	0.100	0.073	0.109	0.079	0.812	2.180	0.790	0.271	3.241	0.309
ntl-16-25	Apr. 8, 1996	T2rt side	0.640	0.038	0.042	0.059	0.066	0.875	1.180	0.660	0.292	2.132	0.469
ntl-16-26	Apr. 8, 1996	Tfwdddk-rt side	1.100	0.130	0.077	0.118	0.070	0.812	2.360	0.700	0.271	3.331	0.300
ntl-22-25	Apr. 8, 1996	T1up-nxt conv 1	0.780	0.099	0.041	0.127	0.053	0.820	2.540	0.530	0.273	3.343	0.299
ntl-22-26	Apr. 8, 1996	T2low-nxt emerg butto	0.640	0.074	0.047	0.116	0.073	0.811	2.320	0.730	0.270	3.320	0.301
ntl-22-24	Apr. 8, 1996	T2rt rib-nxt elect box	0.800	0.072	0.000	0.090	0.000	0.910	1.800	0.000	0.303	2.103	0.475
ntl-22-27	Apr. 8, 1996	T3low-shelving nxt F	0.780	0.085	0.046	0.109	0.059	0.832	2.180	0.590	0.277	3.047	0.328
ntl-12-131	Apr. 9, 1996	Tdf-lt-side	1.000	0.120	0.081	0.120	0.081	0.799	2.400	0.810	0.266	3.476	0.288
ntl-12-132	Apr. 9, 1996	T4up-frt scrubbers	0.900	0.130	0.160	0.144	0.178	0.678	2.880	1.780	0.226	4.886	0.205
ntl-12-130	Apr. 9, 1996	T1-cutterhead-wld	4.300	0.580	0.420	0.135	0.098	0.767	2.700	0.980	0.256	3.936	0.254
ntl-22-33	Apr. 9, 1996	Tdf-rt rib	1.600	0.220	0.150	0.138	0.094	0.768	2.760	0.940	0.256	3.956	0.253
ntl-22-32	Apr. 9, 1996	Tfwddk-rt-side	1.100	0.120	0.091	0.109	0.083	0.808	2.180	0.830	0.269	3.279	0.305
ehs 20	Apr. 10, 1996	Tdf	0.840	0.075	0.000	0.089	0.000	0.911	1.780	0.000	0.304	2.084	0.480
		Mean	1.03567	0.12017	0.06657	0.11387	0.05780	0.82833	2.27733	0.57800	0.27611	3.13144	0.34036
		Stand. Dev.	0.71111	0.09886	0.07926	0.02639	0.04382	0.06248	0.52789	0.43817	0.02083	0.83278	0.08644

Exhibit 4


Analysis of 30 Air Quality Samples Ahead of Deck 12 Before Installation of HEPA Scrubber
(Data from Charles Parker Samples 2/20/97)
% of Samples with Less than a Given Cristobalite %
Cristobalite %/100
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
0.000
0.020
0.040
0.060
0.080
0.100
0.120
0.140
0.160
0.180
0.200
Mean 11.39%

42

Exhibit 5

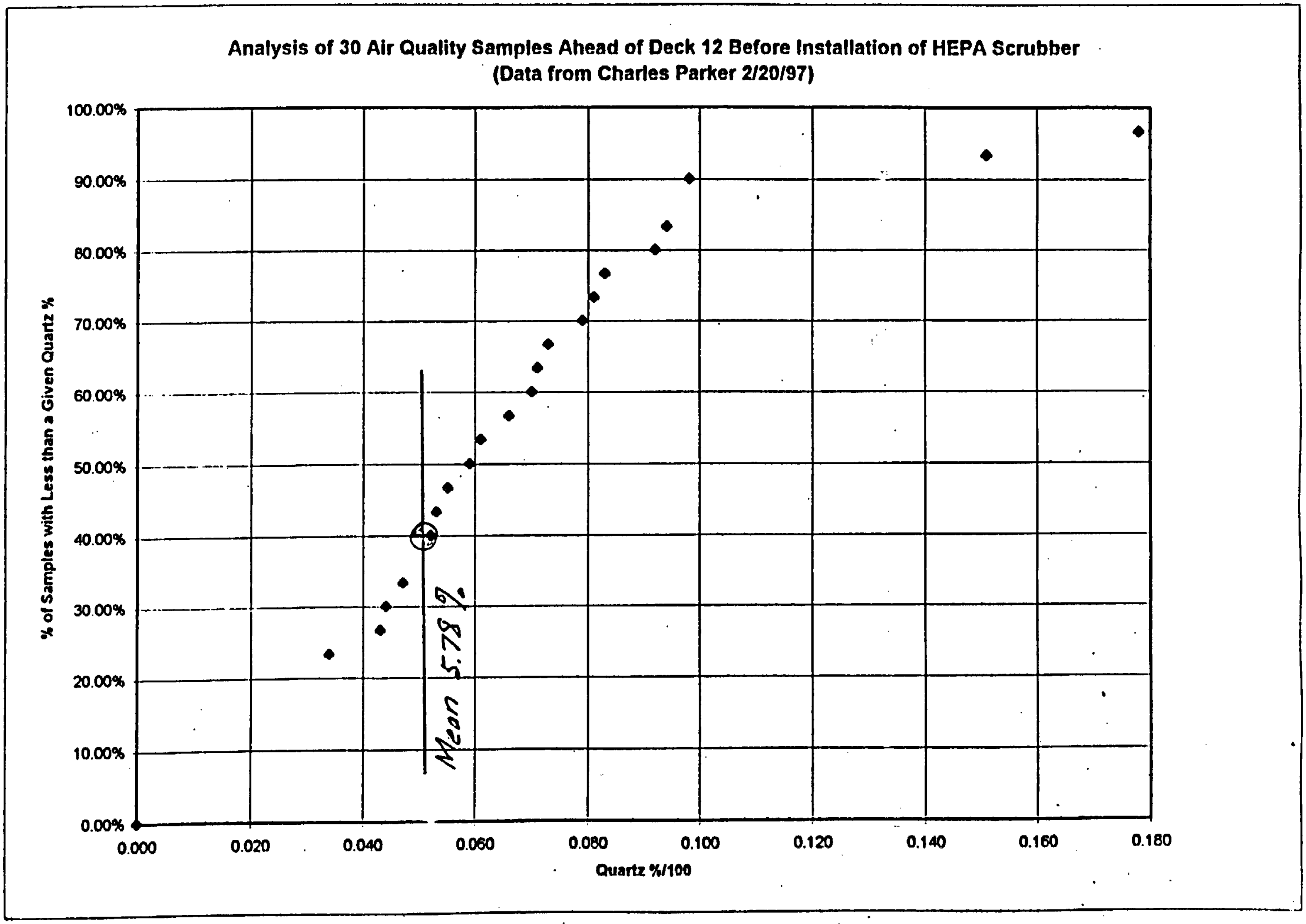

Analysis of 30 Air Quality Samples Ahead of Deck 12 Before Installation of HEPA Scrubber
(Data from Charles Parker 2/20/97)
% of Samples with Less than a Given Quartz %
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
0.000
0.020
0.040
0.060
0.080
0.100
0.120
0.140
0.160
0.180
Quartz %/100
Mean 5.78%

Exhibit 6

Analysis of 30 Air Quality Samples Ahead of Deck 12 Before Installation of HEPA Scrubber
(Data from Charles Parker Samples 2/20/97)

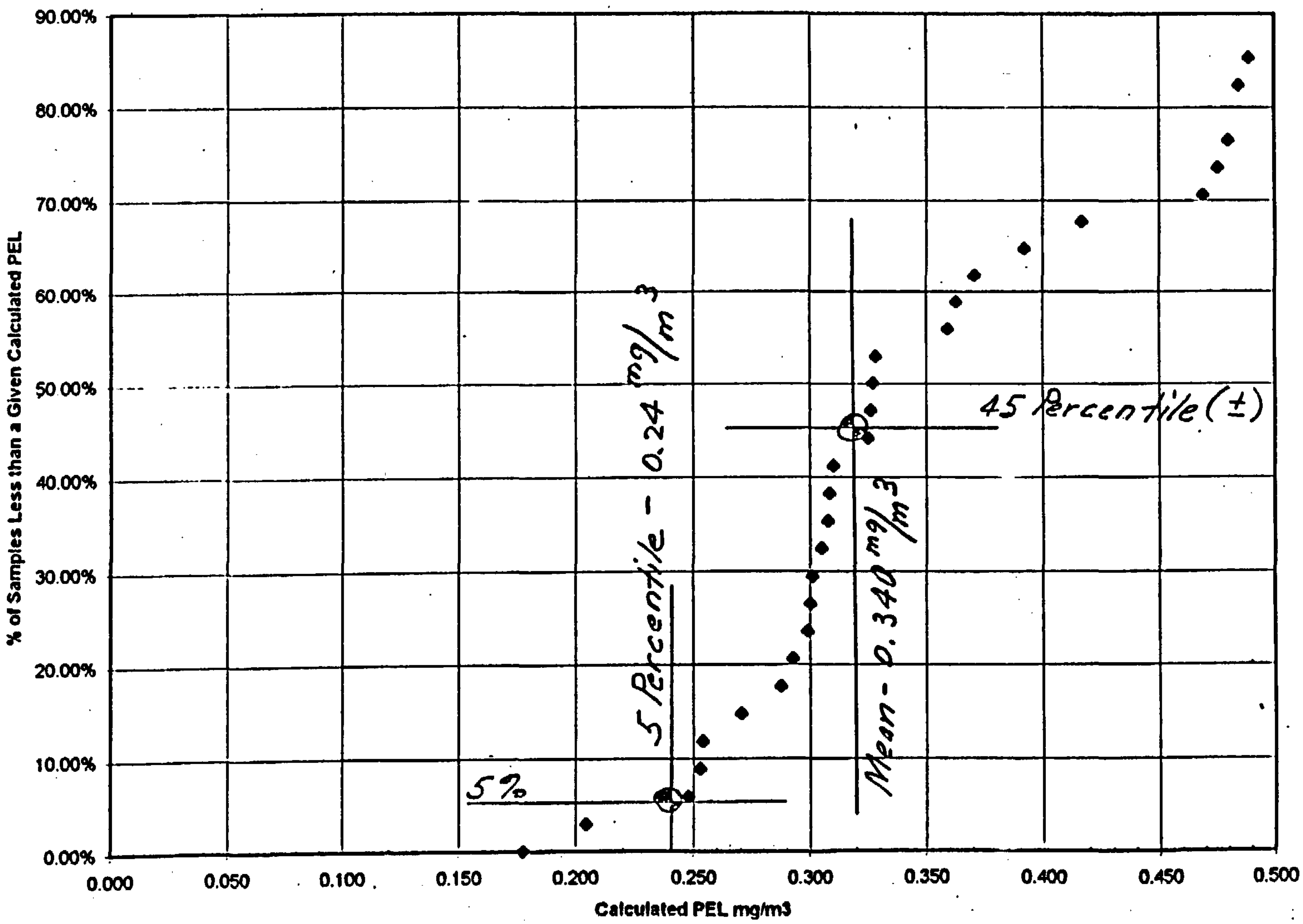


Exhibit 7

64 Air Quality Samples Taken Ahead of TBM Deck 12
After Installation of HEPA Scrubber

Sample No.	Date	Location	Col. 1 Total Dust mg/m3	Col. 2 Cristo-balite mg/m3	Col. 3 Quartz mg/m3
k-3	Oct. 7, 1996	TBM-Dk-12 Air filter	0.219	0.000	0.000
k-5	Oct. 7, 1996	TBM-Dk 12 inside Clea	0.017	0.000	0.000
k-4	Oct. 7, 1996	TBM-DK 12 inside Clea	0.057	0.000	0.000
k-2	Oct. 7, 1996	TBM-Dk 1 spt struct	0.201	0.000	0.000
k-4	Oct. 15, 1996	TBM Dk1 Oper. Cab	0.224	0.000	0.000
k-2	Oct. 15, 1996	TBM-dk 1 Drill Rockbolt	0.109	0.000	0.000
k-1	Oct. 15, 1996	TBM-dk5 dril rockbolt	0.063	0.000	0.044
k-3	Oct. 16, 1996	TBM-dk1 supt	0.000	0.000	0.000
k-2	Oct. 16, 1996	TBM-dk12-in CR	0.042	0.000	0.000
k-2	Oct. 21, 1996	TBM-dk12 TBM side	0.091	0.000	0.000
k-1	Oct. 21, 1996	TBM-dk12 TBM side	0.087	0.000	0.000
k-2	Oct. 21, 1996	TBM-dk12 TBM side	0.311	0.000	0.000
k-1	Oct. 21, 1996	TBM-dk12 TBM side	0.157	0.000	0.000
k-1	Oct. 23, 1996	TBM-dk12 TBM side	0.230	0.000	0.086
k-2	Oct. 23, 1996	TBM-dk12 TBM side	0.208	0.000	0.000
k-1	Oct. 30, 1996	TBM kd6 lt rail	0.050	0.000	0.000
k-2	Oct. 30, 1996	TBM dk6 rt rail	0.049	0.000	0.000
k-4	Oct. 30, 1996	TBM dk7 inside rail	0.057	0.000	0.000
k-3	Oct. 30, 1996	TBM kd6 outside rail	0.046	0.000	0.000
k-2	Oct. 31, 1996	TBM dk6 outside rail	0.054	0.000	0.000
k-1	Oct. 31, 1996	TBM dk7 inside rt rail	0.058	0.000	0.000
k-1	Nov. 1, 1996	TBM dk8 outside rail	0.101	0.000	0.000
k-2	Nov. 1, 1996	TBM dk8 inside rail	0.119	0.000	0.000
k-3	Nov. 1, 1996	TBM dk9 outside rail	0.093	0.000	0.000
k-4	Nov. 1, 1996	TBM dk9 rt inside rail	0.102	0.000	0.000
k-3	Nov. 4, 1996	TBM dk-6 rt rib	0.064	0.000	0.000
k-4	Nov. 4, 1996	TBM dk5 rt rib	0.096	0.000	0.000
k-1	Nov. 4, 1996	TBM dk 8 rt rib	0.068	0.000	0.000
k-2	Nov. 4, 1996	TBM dk7 rt rib	0.078	0.000	0.000
k-2	Nov. 6, 1996	TBM-Dk7 rt rib	0.148	0.000	0.000
k-1	Nov. 6, 1996	TBM-DK8 rt rib	0.032	0.000	0.000
k-3	Nov. 6, 1996	TBM-Dk6 rt rib	0.108	0.000	0.000
k-4	Nov. 6, 1996	TBM-Dk5 rt rib	0.166	0.000	0.000
k-1	Nov. 14, 1996	TBM dk1 79.00	0.170	0.000	0.000
k-2	Nov. 14, 1996	TBM dk1 79.01	0.200	0.000	0.000
k-3	Nov. 14, 1996	TBM dk2 78.90	0.060	0.000	0.000
k-4	Nov. 14, 1996	TBM dk2 78.91	0.120	0.000	0.000
k-1	Nov. 15, 1996	TBM dk 1 rt side	0.100	0.000	0.000
k-2	Nov. 15, 1996	TBM dk 1 lt side	0.130	0.000	0.000
k-1	Nov. 16, 1996	TBM dk 1 lt side	0.270	0.000	0.000
k-2	Nov. 16, 1996	TBM DF	0.370	0.000	0.000
k-3	Nov. 16, 1996	TBM dk2 rt side	0.250	0.000	0.000
k-4	Nov. 16, 1996	TBM DF	0.390	0.000	0.000
k-1	Nov. 18, 1996	TBM DF lt side	0.030	0.000	0.000
k-2	Nov. 18, 1996	TBM DF lt side	0.210	0.000	0.000
k-3	Nov. 18, 1996	TBM DF rt side	0.230	0.000	0.000
k-4	Nov. 18, 1996	TBM DRD rt side	0.230	0.000	0.000
k-4	Nov. 20, 1996	TBM DF lt side	0.340	0.000	0.000
k-18	Dec. 13, 1996	TBM Dk3 rt side	0.340	0.000	0.000
k-19	Dec. 13, 1996	TBM Dk3 rt side	0.340	0.000	0.000
k-20	Dec. 13, 1996	TBM Dk3 rt side	0.330	0.000	0.000
k-21	Dec. 14, 1996	TBM Dk3 rt side	0.330	0.000	0.000
k-22	Dec. 14, 1996	TBM Dk3 rt side	0.250	0.000	0.000

64 Air Quality Samples Taken Ahead of TBM Deck 12
After Installation of HEPA Scrubber

			Col. 1	Col. 2	Col. 3
			Total	Cristo-	
Sample			Dust	balite	Quartz
No.	Date	Location	mg/m3	mg/m3	mg/m3
k-23	Dec. 14, 1996	TBM Dk3 rt side	0.310	0.000	0.000
k-24	Dec. 16, 1996	TBM Dk3 rt side	0.030	0.000	0.000
k-25	Dec. 16, 1996	TBM Dk3 rt side	0.050	0.000	0.000
k-26	Dec. 16, 1996	TBM Dk3 rt side	0.110	0.000	0.000
k-27	Dec. 16, 1996	TBM DF	0.260	0.000	0.000
k-28	Dec. 16, 1996	TBM DF	0.270	0.000	0.000
k-30	Dec. 16, 1996	TBM Dk 12 inside	0.240	0.000	0.000
k-3	Jan. 15, 1997	TBM Obs	0.060	0.000	0.000
k-3	Jan. 15, 1998	TBM Obs portal	0.100	0.000	0.000
k-3	Jan. 15, 1998	TBM DF rt side	0.060	0.000	0.000
k-3	Jan. 15, 1998	TBM DF lt side	0.080	0.000	0.000
		Mean	0.153	0.000	0.002
		SD	0.105	0.000	0.012

APPENDIX

LIST OF ATTENDEE AT THE REPOSITORY CONSULTING BOARD
MEETING OF FEBRUARY 20 AND 21, 1997.

Name	Affiliation	Telephone #
Hemendra N. Kalia	M&O/Los Alamos	(702) 295-4734
Kalyan Bhattacharyya	M&O/MK	(702) 794-1872
Alden Segrest	M&O/Duke	(702) 794-1924
Victor Dulock	M&O/TRW	(702) 295-4808
Jaime Gonzalez	DOE	(702) 794-5454
Richard Snell	M&O/Fluor Daniel	(702) 295-5168
Raymond W. Durante	Member, Repository Consulting Board	(703) 276-8444
Jack Lemley	Member, Repository Consulting Board	(208) 345-5226
S. H. Bartholomew	Chairman, Repository Consulting Board	(916) 894-7411
Ron Heuer	Member, Repository Consulting Board	(815) 675-2003
Larry L. Snyder	Member, Repository Consulting Board	(303) 420-1544
Tim Sullivan	DOE	(702) 794-5589
Rick Nolting	M&O/MK	(702) 794-1833
Ralph Dresel	M&O/MK	(702) 794-5115
Robert Saunders	M&O/MK	(702) 794-1865
Douglas McAffee	M&O/MK	(702) 295-9656
Jim Gardiner	DOE	(702) 794-1320
R. L. Craun	DOE	(702) 794-1320
R. K. McFarland	Nuclear Waste Technical Review Board	(703) 235-4473
Robert V. Barton	DOE	(702) 794-1455
Stephan Brocoum	DOE	(702) 794-1359
Paul Harrington	DOE	(702) 794-5415
Dennis R. Williams	DOE	(702) 794-1417
Keith Lobo	Booze Allen Hamilton	(702) 794-5424
Richard C. Wagner	M&O	(702) 295-3935
Charles Parker	M&O	(702) 295-4807
Thomas T. McManus	EHS, Inc.,	(702) 645-1521
Russell Baumeister	DOE	(702) 794-5448

SUMMARY OF DESIGN TEAM RESPONSE TO RECOMMENDATIONS CONTAINED IN BOARD REPORT #3

As presented in the February 20, 1997 briefing, the Design Team's response to earlier board comments contained in Board Report #3 is summarizes as follows:

Board Comment #1 - The respirable dust PEL should be established at no more than OSHA standards with the weighted value of the PEL calculated upon mineralogy composition determined from cores taken from broad based sampling of the existing ESF and all future repository excavations. This sampling should be undertaken immediately to assemble a comprehensive data base to establish the mineralogy of the repository host rock.

Design Team Response:

No Response Received.

Board Comment #2 - Extensive data should also be immediately obtained to determine the existing dust level, and the mineralogy of the dust, for atmospheric conditions existing at the surface of Yucca Mountain. Sampling should occur at every location where intake air will eventually be obtained at the elevation at which the intake air will be drawn. The purpose of such tests is to establish the quantities of silica based elements present in atmospheric dust and whether initial scrubbing of intake air would be practical and beneficial.

Design Team Response:

No Response Received.

Board Comment #3 - All new TBMs to be furnished for future repository work should be furnished with state-of-the-art dust shields completely isolating the cutterhead as well as effective dust hood coverings for the TBM and trailing conveyors to trap as much dust as possible so that it can be passed through scrubbers and discharged thru exhaust air ducts to the surface.

Board Comment #4 - Tunnel conveyors to be installed in the future for repository construction should be fitted out with water sprays and fogging nozzles at all locations where dust is likely to be generated, such as transfer points, etc. Water sprays should also be fitted at intervals throughout the conveyor lengths to continually dampen the top surface of material on the conveyors.

Board Comment #5 - Full enclosures for all tunnel conveyors to be installed in the future should be completely designed, but not procured or installed until, and only until, found in actual early repository construction to be necessary to isolate respirable dust. The design of such enclosures should provide fogging nozzles to maintain a humid atmosphere within the enclosure as well as fire and/or smoke detectors.

Board Comment #6 - Roadheaders procured for future repository construction should be fitted out with state-of-the-art features to trap and contain dust. Also, thought should be given to the design and use of full-tunnel cross-section dust curtains with scrubber units similar in concept to the installation presently being used on the trailing gear of the ESF TBM. The Board envisions that such units would be located immediately downstream of the roadheader work area between the roadheader operation and the portal, and that the scrubbed air withdrawn from the work area would be discharged into the full-tunnel cross-section in the direction of air flow to the portal. If necessary, such units could also be located periodically between the extended work areas and the South Portal to clean up return air flow in the tunnel before passing it along in the direction of the portal.

Design Team Response to Board Comments #3, #4, #5, & #6:

Subsurface HVAC Design - FY 97 Tasks:

- Overall Development and Emplacement Ventilation Systems Analysis (Aug. 1997)
- Emplacement Exhaust Shaft HEPA Filters Analysis (HEPA filters & adsorption units) (Aug. 1997)
- Airflow Control Analysis (Emplacement drift doors, PC monitoring system, and emplacement/development airlocks) (Aug. 1997)
- Preliminary List of Ventilation Equipment (Sept. 30, 1997)
- GA Drawings: i) Overall ventilation system, including airflow diagrams, ii) ventilation doors and airlock arrangements, iii) exhaust shaft fans and adsorption units and HEPA filter systems (Sept. 30, 1997)

- We are in general agreement with the Board's recommendations for reducing and controlling dust emissions.

- Analyses currently in progress will address state-of-the-art features to contain and control respirable dust from repository TBMs, roadheaders, and other construction equipment, and to reduce dust emissions and dust levels in the subsurface openings.

- The ventilation design analyses currently in preparation will address air doors, air curtains, and air scrubbing systems for construction activities as suggested.

- The ventilation systems will be designed "in depth" with contingency provisions for unexpected conditions.

- The *Preliminary List of Construction & Backfill Equipment* (due July 31, 1997) will describe salient attributes and functions of the construction equipment (such as TBMs and roadheaders), including dust reduction and control features on the construction equipment.

- The *Preliminary List of Ventilation Equipment* (due Sept. 30, 1997) will describe primary and secondary ventilation equipment.

Board Comment #7 - The Board strongly feels that the alternative fresh air intake system previously suggested in Board Report No. 2 (which suggestion is reiterated in this Board Report No. 3) be promptly investigated and preliminary design undertaken. Note that the suggested Development Plan by Phases for construction of the repository described later in this report includes utilization of this method of fresh air supply.

Design Team Response:

- The analyses will address alternative approaches for ventilating the subsurface construction activities. The thrust of these analyses is to establish a baseline for the overall ventilation strategy and primary airflow arrangements that will satisfy program requirements and construction needs.

- The analyses will address the Board's suggestion for a ducted intake and exhaust air system.

- The analyses will also examine various alternatives for fresh air and exhaust air intakes as recommended by the Board.

- The Board's suggestions for covered conveyors, airlocks, and air curtains will be addressed in the analyses.

Board Comment #8 - We reiterate our previous recommendation for provision of redundancy in the repository exhaust air fan installation (as further amplified in this present report).

Design Team Response:

As discussed during the December meeting, the design incorporates both 100% redundancy of fans and motors as well as backup, site generated power. Two sets of HEPA filters are also provided to allow simultaneous filtration and filter change out.

The conceptual general arrangement of the fan/filter installation, however, showed both fans side-by-side with a single filter building housing both sets of filters. We have workscope this FY to address the layout of the surface ventilation facility. An alternative layout, showing separation of the fans, can be developed.

A detailed evaluation of potential internal and external design basis events is required in order to determine the relative risks associated with the fan installation. Such an analysis will provide the basis for requirements on the amount of redundancy and the need for protective measures, including physical separation.

Board Comment #9 - A Development Plan by Phases for the Construction of the Repository be established for Viability Assessment purposes without delay. To this end, we suggest that a major thrust in the discussion at Board Meeting No. 4 be focused on review of the suggested plan by phases included in this Report No. 3.

Design Team Response:

- Subsurface Development Design - FY 97 Tasks:
  - Determination of Available Emplacement Volume Analysis (Jun. 1997)
  - Thermal Load Management Analysis (May 1997)
  - Subsurface Repository Layout Configuration Analysis (Jun. 1997)
  - Subsurface Repository Layout Coordinate Geometry Analysis (Jun. 1997)
  - Subsurface Construction & Development Analysis (Jun. 1997)

- Subsurface Construction & Operations Schedule Analysis (Jun. 1997)

- Preliminary List of Construction & Backfill Eouipment (July 31, 1997)

- GA Drawings: i) site volume and emplacement boundaries, ii) thermal management and emplacement schedule, iii) layout arrangement, iv) construction methods and equipment, and v) construction and development schedule (July 31, 1997)

- Cost Estimates

- The subsurface design scope is structured to address and integrate all pertinent design parameters including constructability, construction and development sequence & schedule, emplacement strategy, emplacement method and equipment, retrieval strategy and method, ventilation (for all phases of repository construction and operations), PC monitoring, and general operability and maintenance (again, for all phases of construction and operations).

- The subsurface construction and development sequence and schedule is based on the sketches presented to the Board last year.

- The repository subsurface development plan closely parallels the phased approach suggested by the Board.

Construction and Development Plan:

- Prior to Dec. 31, 2004, prepare construction drawings, specifications, work plans and procedures, procure services of constructor, procure and assemble construction equipment, clear site and erect key construction facilities ready to start work.

- Commence pre-emplacement construction Jan. 1, 2005, and finish by Dec. 31, 2009.

- Commence waste emplacement Jan. 1, 2010.

- Development phase starts Jan. 1, 2010 and runs concurrently with emplacement until construction of subsurface facilities completed.

Construction and Development Sequence:

- Excavate early cross block drifts to establish western boundary of the block and place North Ramp CIP concrete lining.
- Excavate 7.62 m TBM perimeter mains from South Ramp to North Ramp, back up TBM and excavate North Ramp Extension
- Excavate stubs for ventilation shafts and commence shaft excavations as soon as tunneling operation in perimeter mains will permit.
- Move 7.62 m TBM and excavate the Exhaust Main starting at south end.
- Install tunnel CIP concrete lining in perimeter mains as tunneling finishes.
- Excavate emplacement drift turnouts and commence emplacement drift TBM excavation at the north end of block initially with a single TBM. Need 8 - 10 drifts for start of emplacement.
- Finish emplacement drifts as excavation completed (i.e., vent raises, gantry track, controls, power supply, monitoring systems, doors, etc.).
- Finish East and West Mains concurrently with finishing of emplacement drifts (emplacement track, utilities, control and monitoring systems, airlocks, etc.).
- Once first 4 drifts excavated introduce 2nd TBM.
- Develop blocks of 15 to 20 emplacement drifts to keep construction well ahead of the emplacement operations.

Board Comment #10 - The Board should be briefed on the functions required to be served by the Performance Confirmation Drifts suggested at Board Meeting No. 2 so that we will have an understanding of what they involve and how they are expected to be utilized in order to consider substituting their early construction in lieu of our present recommendation for early construction of initial Emplacement Drifts.

Design Team Response:

This subject was covered in detail in a briefing prior to the discussion of individual comments. Any questions remaining can be addressed at this time.

Board Comment #11 - A broad based risk analysis should be carried out in the near future, considering a variety of unplanned events during repository construction and operation to resolve a number of safety issues including, for example, the need for the ability to reverse general air flow patterns in both the repository and development side during emergency situations, whether full-tunnel section fire doors in addition to air locks are needed, and if so, where they should be located. The Development Plan by Phases for Construction of the Repository discussed later in this report can be used to provide the background construction situations for conducting this risk analysis.

Design Team Response:

- We agree with suggestion for the broad based risk analysis and integration of the results with the overall subsurface design. Such analysis is required by the program and will be performed once the layout and ventilation designs are firmer (probably in FY 98).
- Although the scope of work currently in progress does not cover a broad risk analysis, the analyses in progress will address certain unplanned events, such as fires.
- The design analyses will address reversibility of the fans, and installation of airlocks and fire doors for fire and smoke control.

Board Comment #12 - A decision should be made without further delay on the degree of mapping that is to be done during excavation of all repository underground openings.

Design Team Response:

A mapping issue was discussed in the previous briefings. Any remaining questions may be addressed at this time.

Board Comment #13 - A decision should be made without delay setting the vertical separation distance between the Ventilation Main and the Emplacement Drifts.

Board Comment #14 - If the separation distance referred to in recommendation 13 is greater than 10 m, we recommend this requirement be accommodated by grade changes to the north end of the Ventilation Main and to the South Perimeter Main along the lines of Exhibit 2 included in this report.

Design Team Response to Board Comments #13 & #14:

- From a practical construction, layout, and ground support perspective, 10 m ventilation raises appear satisfactory. The vertical separation between the ventilation main and the emplacement drifts will be verified by analysis addressing both thermal and ground stability concerns.

- Agree, that some changes to tunnel gradients can be made to accommodate slightly longer ventilation raises if necessary.

- Tunnel gradients must accommodate equipment capabilities and drainage.

Board Comment #15 - The intersection between the Ventilation Main and the South Perimeter Main should be kept as close as possible to the location that is set for the Development Shaft (or vice versa) to minimize the length of the connecting adits.

Design Team Response:

- Agree, current design seeks to optimize shaft locations and to minimize length of connecting drifts consistent with subsurface configuration and suitable surface topography for shaft collar location.

Board Comment #16 - The Board remains skeptical of the need for requiring construction of repository underground openings to NQA-1 standards, particularly for either the temporary support or final lining of the Mains and Ramps.

Design Team Response:

No Response Received.

Board Comment #17 - We continue to favor the use of a pre-cast concrete segmented lining for the Emplacement Drifts and are pleased with the progress of the design work in this direction. We continue to believe that the most important design criteria should be the ability of these linings to tolerate imposed strain under the most severe loading conditions contemplated, rather than consideration of the compressive thrust calculated to exist in the lining.

Design Team Response:

We agree. Our basic approach to the lining design remains one of designing for an imposed strain and using a strain criterion to determine the acceptability of lining performance.

A "drift stability" design analysis, in preparation, presents the approach and calculations for the design of the emplacement drift ground support.

Board Comment #18 - We expect the actual controlling design concern for load carrying ability of the segmented lining to be the compressive loads to be transmitted across longitudinal joints between segments within a ring, generated by the thermal loading case. Another concern will be the ability of the haunches on the Emplacement Drift invert (whether pre-cast or subsequently cast-in-place) to carry the large loads imposed by a gantry carrying a waste package. Although the design for Viability Assessment must demonstrate solutions to these problems, we do not believe it necessary or appropriate at this stage to attempt to optimize such features as exact geometry of the expansion joint, final internal reinforcement details at segment ends, handling methods, pick up points, etc. Many alternative details for solving these problems have been satisfactorily used on previous tunnels. We recommend that for Viability Assessment purposes the Design Team illustrates typical examples of what is possible and acceptable for such details. For example, calculations can be made to demonstrate that adequate shear failure resistance at longitudinal segment joints and adequate handling strengths can be achieved using a type of reinforcement judged by the Design Team to be satisfactory, considering thermal loading effects, differential thermal expansion, etc. However, we recommend that the actual design details of the final product be either left to construction engineering personnel of the repository construction contractor, or developed in collaboration with the repository construction contractor.

Design Team Response:

1) A current "invert segment analysis" examines TBM and gantry/waste package loads. Results show that the precast concrete invert, including haunches, is satisfactory for these operational loads.

2) For ground support design, emphasis is on the development of a "reference" or typical design solution, not a detailed or completely optimized approach.

3) "Drift stability" and "constructability" analyses, in preparation, are evaluating suitable concrete segmental lining, cast-in-place lining, and steel lining designs and installation approaches.

Board Comment #19 - The Board believes that prior to License Application the following level of laboratory testing will be necessary:

- Laboratory tests to determine thermal and creep properties of concrete necessary for design analysis.

- Insitu heater test of cast-in-place concrete lining at elevated temperatures. These tests are presently planned, but probably will not be completed until very late in 1998.

- Structural model testing of segment joints (see Exhibits 4, and 5 included with this report) if design analyses indicate that this is a controlling feature of the lining system.

Since the level of design evolvement for Viability Assessment (VA) purposes is considerably less than required for License Application purposes, these tests, although desirable, are probably not necessary for the Viability Assessment.

Design Team Response:

1) We are in the process of setting up a concrete testing program for:

   - Engineering properties at elevated temperatures - primarily strength, modulus, and creep.

   - Geochemical effects - scoping test to examine the process affecting concrete pH.

2) A drift-scale heater test, including a 200 mm concrete lining, will commence this fall, and is planned to run for more than 2 years.

3) Structural model testing, will be considered on the basis of the results of current design analyses and tests on engineering properties.

Board Comment #20 - Although at some stage in the design process it will be necessary to fabricate and test full size pre-cast concrete segments and rings , the Board recommends that such testing be conducted for Viability Assessment purposes only if thermal analysis and design studies presently underway conclude that normal reinforcement systems are not acceptable because of their behavior under long term thermal loading conditions. If the use of segment reinforcement is in doubt, or must be limited, then full segment handling tests, although not necessary for the Viability Assessment, will be necessary for License Application purposes.

Design Team Response:

- Segment reinforcement, both rebar for structural reinforcement and fiber (steel) reinforcement for handling or joint reinforcement, appear acceptable.

- Evaluation continues on the use of rebar and fibers.

- Fiber reinforcement will be included in the concrete lining in the planned drift-scale test.