SUMMARY ANNUAL REPORT

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NYE COUNTY NUCLEAR WASTE REPOSITORY PROJECT OFFICE INDEPENDENT SCIENTIFIC INVESTIGATIONS PROGRAM

GRANT DE-FG08-96NV12027

NYE COUNTY NUCLEAR WASTE REPOSITORY PROJECT OFFICE

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1.0 INTRODUCTION

This annual summary report, prepared by Multimedia Environmental Technology, Inc. (MET) on behalf of Nye County Nuclear Waste Project Office, summarizes the activities that were performed during the period from May 1, 1996 to April 30, 1997. These activities were conducted in support of the Independent Scientific Investigation Program (ISIP) of Nye County at the Yucca Mountain Site (YMS).

The Nye County NWRPO is responsible for protecting the health and safety of the Nye County residents. NWRPO's on-site representative is responsible for designing and implementing the Independent Scientific Investigation Program (ISIP). Major objectives of the ISIP include:

- Investigating key issues related to conceptual design and performance of the repository that can have major impact on human health, safety, and the environment.
- Identifying areas not being addressed adequately by DOE

Nye County has identified several key scientific issues of concern that may affect repository design and performance which were not being adequately addressed by DOE. Nye County has been conducting its own independent study to evaluate the significance of these issues.

The reader is referred to previous reports (NWRPO, 1995; MET, 1995; and MET, 1996) for detailed explanation of these specific concerns.

1.1 SCOPE

This report summarizes the results of monitoring from two boreholes and the Exploratory Study Facility (ESF) tunnel that have been instrumented by Nye County since March and April of 1995. The preliminary data and interpretations presented in this report do not constitute and should not be considered as the official position of Nye County.

1.2 NYE COUNTY'S BOREHOLE AND TUNNEL MONITORING STUDIES

The ISIP presently includes borehole and tunnel instrumentation, monitoring, data analysis, and numerical modeling activities to address the concerns of Nye County.

Figure 1-1 shows the regional setting of Yucca Mountain. Nye County has installed and is currently monitoring pressure and temperature instruments in boreholes UE-25 ONC#1 and USW NRG-4 (Figure 1-2) to evaluate the long-term pneumatic conditions at strategic depths in the subsurface both in response to fluctuations in atmospheric conditions and in response to other possible disturbances resulting from site characterization activities such as ESF tunnel construction. Nye County has also installed instruments to measure temperature, pressure, and humidity within the ESF tunnel to characterize the air being used to ventilate the tunnel which could potentially impact the performance of the repository. Additionally, Nye County collected gas samples from the vadose zone in ONC#1 to establish background conditions. Changes in the chemical compositions of the gases in the vadose zone with time may be used to evaluate the impact of the ESF construction and obtain transport properties of the rock mass at the site. Finally, Nye County is conducting numerical modeling simulations to evaluate factors (including tunnel ventilation) which affect both short-term and long-term pneumatic and moisture conditions in the repository host rock.

1.3 OTHER ACTIVITIES

Nye County has also been evaluating new critical data and information as it becomes available from the DOE's Yucca Mountain Project studies. In the past year, Nye County has observed water usage in the tunnel and its potential impact on the repository horizon and the scientific investigation results. The interpretation of the results of the ^{36}Cl and other environmental and geological isotope studies such as ^{14}C , ^{13}C, and ^{3}H have been the focus of many meetings attended by Nye County which has resulted in several letter reports to DOE during the past year. Some of these communications have resulted in DOE's more focused attention to some of the issues raised by Nye County. Specifically, these issues related to the need for more detailed studies in the ESF tunnel, limiting the use of construction water, and enhanced interpretation of the results of the isotope sampling.

Nye County evaluated procedures and methods used by DOE to conduct air-permeability tests in the unsaturated zone of YMS. As a result of several interactions between Nye County and DOE, satisfactory procedures were developed and used by DOE in more recent testing efforts. The results of these tests were analyzed and reported (Advance Resources International, 1995).

In addition, Nye County has evaluated the saturated zone pumping tests that were performed in the C-Well complex during the past year. Nye County has also been monitoring responses to these pumping tests in the ONC#1 saturated-zone instrumentation.

1.4 PROPOSED FUTURE INVESTIGATIONS

Nye County is planning to perform several investigations in the future to clear some of the issues that were outlined above by installing new wells in both the saturated and unsaturated zones, testing and sampling these wells, and performing data analysis and modeling. These issues are related to the steep gradients in the saturated zone north and west of the site, the potential for dilution in the saturated zone as unsaturated zone moisture enters the saturated zone, the atmospheric and pneumatic boundaries in the Solitario Canyon that might impact the repository performance, and the large-scale transport properties of the fractured formations in both saturated and unsaturated zones.

2.0 INSTRUMENTATION AND MONITORING APPROACH

The ONC#1 borehole was drilled and both ONC#1 and NRG-4 boreholes were instrumented to support the following data collection activities:

1. To monitor the long-term variation of pressure and temperature in hydrogeologic units that may be impacted by the construction of the ESF.
2. To perform vacuum and/or injection pneumatic testing to evaluate the horizontal and, to some extent (unknown), vertical pneumatic conductivity values of the hydrogeologic units packed off by the Westbay Instruments.
3. To sample intervals isolated by packers for environmental isotopes to evaluate the residence time of the gases in the hydrogeologic formations.

The tunnel was instrumented with temperature, pressure, and humidity sensors to monitor pneumatic parameters of the ventilation air necessary to:

1. Assess the impact of this air on the gas composition and water content of the repository formation rock.
2. Permit calculation of large scale bulk permeabilities of the repository host rock between the ESF tunnel and Nye County instrumented boreholes (UE-25 ONC#1 and USW NRG-4).

2.1 BOREHOLE DESCRIPTION

Nye County borehole locations were selected primarily to establish baseline conditions before penetration of the repository host rock by the ESF tunnel and to monitor the effects of the mine ventilation system used in the ESF tunnel on the ambient pneumatic and moisture conditions of the unsaturated zone in the vicinity of the north and south ramps of the ESF tunnel. UE-25 ONC#1 is situated southeast of the repository block and is in the path of the future South Ramp of the ESF tunnel (Figure 1-2). It was also strategically located to be along the main trace of the Bow Ridge Fault system and close enough to DOE's C Well Complex (approximately 800 meters) to serve as a monitoring well during aquifer testing. It was drilled by Nye County in late 1994 and early 1995 using dual wall reverse circulation technology to demonstrate an alternative drilling and sampling method to DOE (NWRPO, 1995).

USW NRG-4 is located northeast of the repository block (Figure 1-2) and is situated about 1100 m from the North Ramp (NR) portal of the ESF tunnel. It was previously drilled by DOE. The ESF tunnel passed within approximately 15 meters of USW NRG-4 in the middle of June 1995. The effects of the tunnel excavation on pneumatic conditions in this instrumented borehole, as well as in UE-25 ONC#1, will be discussed in the following sections.

2.2 BOREHOLE INSTRUMENTATION

Nye County instrumented UE-25 ONC#1 and USW NRG-4 in early 1995 with Westbay Corporation's MOSDAX MP55 system. The MP-55 is a multilevel monitoring device that consists of an access casing with multiple ports or valves that can be opened to the formation. A multilevel packer system integrated into the access tube serves to isolate access ports and retrievable temperature/pressure measurement probes that connect to these access ports. An above ground data logger is used to monitor the temperature/pressure probes. A complete description of this downhole monitoring system and installation procedures in these boreholes are presented in NWRPO (1995).

Fifteen downhole packers were used to isolate major stratigraphic units, a fault zone, and two isolated zones below the water table in UE-25 ONC#1. Figure 2-1 shows the location of 15 packers and 31 measurement ports in relation to stratigraphic units, the Bow Ridge fault zone, and the water table. MOSDAX temperature/sensor probes were installed in 9 of the 31 measurement ports available. It should be noted that the two bottom-most probes in UE-25 ONC#1 are situated below the water table and are monitoring the piezometric potential.

Seven downhole packers and 7 measurement ports were strategically installed in major stratigraphic units in USW NRG-4 as shown in Figure 2-1. MOSDAX temperature/sensor probes were installed in all 7 measurement ports.

2.3 TUNNEL INSTRUMENTATION

An underground climatological monitoring station was installed in August 1995 behind the ESF tunnel boring machine (TBM) to measure the temperature, pressure, and relative humidity of the ventilation air. Figure 2-2 is a schematic drawing that shows the relative position of the instruments. This monitoring station moves with the tunnel boring machine frame. Several other measurement stations have been recently installed by DOE, following the recommendation of Nye County, along the main axis of the tunnel and in radial alcoves to characterize the spatial variation of these parameters in the underground tunnel system.

2.4 CALIBRATION, DATA COLLECTION AND PROCESSING

Nye County NWRPO Quality Assurance (QA) procedures document the detailed methods followed to calibrate instruments (laboratory and field methods), to collect field data and transfer data into a databases, and to analyze and evaluate data through computer programs, including numerical modeling codes. The specific NWRPO QA procedures controlling activities described in this report are as follows:

- *Instrument Calibration and Collection and Processing of Data from Boreholes, Revised Version 1.0* (Applicable to the initial collection and processing of data from April to August, 1995).

- *Instrument Calibration and Collection and Processing of Data from Boreholes. Revised Version 2.0* (Applicable to the collection and processing of data after August, 1995).
- *Instrument Calibration and Collection and Processing of Data from ESF Tunnels.*
- *Computer Modeling and Data Analysis Quality Assurance Procedure.*
- *Gas Sampling and Analysis Quality Assurance Procedure.*

3.0 RESULTS OF FIRST GAS SAMPLING FROM ONC#1

3.1 PURPOSE

The purposes of the gas sampling were to:

- **Estimate the ages of the gases in the vadose zone in ONC #1 and their relationship with the ages of the water obtained from other boreholes at Yucca Mountain that could help evaluate the percolation and recharge at the site.**
- **Understand the transport mechanism governing gaseous migration in the vadose zone at this site.**
- **Evaluate the effect of tunneling on the repository horizon.**

The ESF tunnel has been approaching the area of the ONC#1. The tunnel is a boundary condition for temperature, pressure, humidity, and environmental isotopes. Each of these parameters affect the unsaturated zone in various degrees depending on the properties of the host rock. Environmental chemicals such as fluorocarbons and isotopes such as ^{14}C, ^{13}C, and ^{3}H are introduced by the tunnel as a constant source in the tunnel which contains atmospheric composition. These chemical species enter the unsaturated zone (UZ) with advection of the air as a result of the change in air pressure of the tunnel. These gases are transported in the UZ by advective, dispersive, and diffusive processes. A background condition needs to be established at ONC #1. The change in the chemical composition of the gas with time may be analyzed to evaluate the arrival of these environmental tracers in ONC#1. With adequate data, transport properties of the rock mass between the tunnel and ONC#1 may be evaluated. The volume of rock affected by this test is the largest that has ever been considered to be tested at the site.

3.2 APPARATUS AND SAMPLING PROCEDURES

The sampling apparatus is schematically shown in Figure 3-1. Detailed sampling procedures are outlined in Nye County's Technical Procedure entitled "Gas Sampling Procedures..." dated 11-26-96. A brief description follows.

The Westbay access tube was fitted with a vacuum tight plug (Figure 3-1) during sampling. By applying vacuum in the access tube through this plug, the sampling was performed from selected intervals. The surface attachments consisted of :

- **Tritium sampling unit (TSU).**
- **The Tedlar bag vacuum purging and sampling (TBVPS) unit.**
- **Flow metering unit (FMU).**
- **Vacuum pump (VP).**

The first three units had by-pass valves that were used during purging of the sampling zone. Flow rates in excess of 2 ft^3/min (0.06 m^3/min) were used during purging for 1.5 to more than 2 hours. The duration of flow was calculated to be sufficient to evacuate the entire string, the annulus between the packers, and a radius of at least 2.5 feet into the formation based on an average air-filled porosity of 10 percent. Air-filled porosity of 10 percent is very conservative. Actual air-filled porosity is less than 1 percent for the formations sampled. Therefore, in some cases up to 25 feet radius of the borehole may have been purged prior to sampling.

As soon as the purging process was completed, the by-pass valve for the TSU was shut and air was allowed to flow through the Tritium Microsieve Sampling Cylinder (TMSC). All the TMSCs were weighted, prepared, and sealed in the laboratory. The by-pass valve at the FMU was also closed to allow monitoring flow rate. A minimum of one hour of flow was allowed to occur through the TMSCs at an approximate rate of 1 ft^3/min (0.03 m^3/min). This time duration allowed entrapment of between 50 to 70 grams of water in the molecular sieve (see attachment 1, Tritium Laboratory Report).

Once Tritium sampling was completed, the TMSC was disconnected and shipped to laboratory in a cooler.

Vacuum pumping was continued at the same zone following TMSC removal, but with the shutoff valve (V3) closed and rubber hoses clamped. Evacuation was continued for at least 15 minutes at high flow rates (all by-pass valves open) before sampling for carbon isotopes and fluorocarbons was initiated. A two liter (0.5 gallon) tedlar bag was used for fluorocarbons sampling. For carbon isotopes sampling, a 10 l (2.5 gallon) tedlar bag was used. Both bags were attached to the main flow lines. Sampling and purging of the bags were performed by reversing the pressure difference between the in-line air and the air in the TBVPS in repeated cycles (at least 3 times). The tedlar bags were shipped to laboratory in coolers within 24 hours.

3.3 CHEMICAL SAMPLING ZONES

The Westbay access tube can be opened at nine locations in ONC #1 (Figure 3-2) using sliding sleeves that, once opened, expose slotted sections of the access tube. Each of the six vertical slots in a section is 1.75 in (4.5 cm) long and 0.5 in (1 cm) wide. By opening each one of the sliding sleeves, a packed-off section of the borehole can be sampled by applying vacuum to the inside of the access tube.

For the first sampling event in October 1996, five screens were selected for sampling. The location of these screens are identified by a "GS- " prefix in Figure 3-2. Samples GS-1 and GS-2A were selected to be near the fault zone. Samples GS-3 and GS-4 were selected in the Topopah Springs Welded Unit in two fractured intervals. GS-5 was selected to be in the Tiva Canyon Welded Unit (TCWU) above the Paintbrush Tuff Nonwelded Unit (PTNU).

3.4 PRELIMINARY RESULTS

The results of the first sampling event are shown in Figure 3-3 and the attachments. Fluorocarbon samples were reported non detectable at 0.1 µg/l (17 nano-l/l) which is not surprising since the atmospheric concentrations are reported to be at least an order of magnitude smaller. The reason for the high detection limit was the small size of the sample and the limitation of the laboratory method used. A much lower detection limit will need to be used in the future.

Results of both tritium and carbon isotopes are shown in Figure 3-3 and the values are reported in the attachments. Tritium detection limit was chosen relatively high since the main interest was to detect any bomb pulse which is expected to be in the order of 100 TU. No bomb pulse level was detectable. However, because the sampling sections were more than 20 feet (6 m), discrete pathways may not have been detected. More rigorous sampling will be required to isolate such narrow pathways using tritium as the tracer.

Carbon-14 apparent ages do not support a systematic trend for the ages in the unsaturated zone as expected. It is suspected that GS-4 sample may have been contaminated with the atmospheric air. This is purely based on the young apparent age and the $\delta^{13}C$ value of this sample. Based on $\delta^{13}C$ values atmospheric contamination of all other samples is minimal, if any. The only time that atmospheric air may contact the sample is during removal from the TBVPS; however, the inlet into the bag is very small and the amount of atmospheric air that can be accidentally introduced into the bag is less than 0.1 percent.

Comparison of the data from ONC #1 with those from UZ-1 reveals significant differences and some similarities in the carbon isotope signatures. The isotopic signatures in TCWU are similar between the two boreholes. In ONC #1, the ^{14}C activity is about 10 percent larger than that in UZ-1 at the same vertical distance from the top of the TCWU. Carbon-14 activity in UZ-1 is 33 percent lower than the activity at an equivalent depth in ONC #1 (GS-4 sample). If the value of GS-4 is representative of the conditions in ONC #1, the apparent age of the gas at this level would be about 500 years. This is considerably younger than any apparent age reported for UZ-1 borehole below a depth of 100 feet (30 m). Conversely, the activity of ^{14}C in GS-3 sample is about the same as that in UZ-1. The activity of GS-2A sample is about 15 percent higher than that of the equivalent horizon in UZ-1. This sample is not likely to have been contaminated with the atmosphere due to its much heavier $\delta^{13}C$ (-2.7) ratio than the atmosphere (about -9 at Yucca Mountain). However, laboratory errors cannot be ruled out at this time. A possible explanation may be the proximity of ONC #1 to the Bow Ridge Fault Zone and complex intersection of the fracture network between ONC #1 and the fault zone. Repeated sampling is planned to be conducted to resolve some of these uncertainties.

GS-1 sample is in the Calico Hills Nonwelded Unit and is on the hanging wall of the fault zone. The apparent younger age of this sample is consistent with the data from other boreholes and the conceptual model of Montazer and Wilson (1984). However, the high value of $\delta^{13}C$ (-3.6) has not been reported anywhere at Yucca Mountain. These values are usually associated with the presence of carbonates of marine origin. According to Al Yang of U. S. Geological Survey (personal communication, 1997), the Calico Hills Unit is not known to have abundance of carbonates.

3-5 CONCLUSIONS AND RECOMMENDATIONS

Preliminary results indicate that the sampling method used for obtaining gas samples from ONC #1 is very efficient and produces results that seem to be comparable with results of other UZ sampling techniques that have been used at Yucca Mountain. Further sampling and analysis is required to verify some of the anomalous measurements. It is recommended to sample all of the nine available screens (including two that are in the saturated zone) and analyze for the isotopes and chemical species sampled as part of this report. A much lower detection limit for analysis of fluorocarbons needs to be used. The fluorocarbon results could provide a better means of evaluating the potential impact of any atmospheric contamination on the results of the analysis of the gas samples. A few of the carbon isotope samples should be sent to a different laboratory for comparison of the techniques used in analyzing the samples. Also a modified sampling apparatus may need to be devised to minimize potential for atmospheric contamination.

4.0 SUMMARY OF MONITORING RESULTS

This section briefly describes the results of monitoring pressure and temperature in UE-25 ONC#1 and USW NRG-4. Results of monitoring pressure, temperature, and humidity in the ESF tunnel are also presented in this section. A more comprehensive presentation of the results of monitoring is presented in MET (1996) and are posted on a monthly basin on the Internet (www.nyecounty.com).

4.1 BOREHOLE TEMPERATURE AND PRESSURE DATA

The pressure and temperature in UE-25 ONC#1 and USW NRG-4 have been monitored since April 1995. Temperatures reported for all downhole instruments are fairly stable with occasional deviations from the norm. The atmospheric probe (Probe 0) in each borehole records a wide range of daily and seasonal temperature fluctuations typical of a desert environment. Comparison of the temperature data from atmospheric probes in USW NRG-4 and UE-25 ONC#1 indicates very consistent atmospheric temperature patterns at the two borehole sites.

Pressure fluctuations with time for UE-25 ONC#1 and USW NRG-4 show that pressure responses exhibit trends versus depth that are expected in layered geologic media. That is, there is a general dampening of the magnitude as well as an increasing time-lag in the peaks and valleys of barometric pressure fluctuations as depth increases. The only exception to these trends are data collected from April to August 1995 in UE-25 ONC#1 when the upper portion of the borehole was opened to the atmosphere and in both boreholes after the tunnel penetrated the proposed repository horizon.

Two of the probes in UE-25 ONC#1 (Probes 8 and 9) are below the water table. These probes monitor variation of piezometric level with time.

Comparison of Probe-0 pressure responses at USW NRG-4 and UE-25 ONC#1 indicate nearly identical responses over time when corrected for elevation differences.

Nye County has also received data from unsaturated zone boreholes monitored by the U. S. Geological Survey. These data were analyzed and graphed to compare the data collected by the Yucca Mountain Project (U.S. Geological Survey) with those collected by Nye County. These graphs show that, despite the significant difference in the data collection techniques, there is a close agreement between the averages of the data. The slight differences in the trends and magnitudes are expected due to the position of the boreholes with respect to the natural and man-made boundary conditions.

4.2 ESF TUNNEL TEMPERATURE, PRESSURE, AND HUMIDITY MONITORING DATA

Results of the Nye County's monitoring in the ESF are presented in a series of graphs in MET (1996). Initially, until November 1995, only one set of probes were installed in the ESF tunnel near the tunnel boring machine (TBM). In December of 1995, two additional monitoring stations were installed at the same location in approximately the same plane perpendicular to the tunnel axis but at different distances from the walls of the tunnel. The purpose of the separation of the three sets of probes was to obtain the thermal and vapor concentration gradients in the tunnel perpendicular to the axis of the tunnel. As will be discussed in later sections, these gradients are important in defining the direction and magnitude of the vapor and heat flux in the tunnel. Both temperature and relative humidity data show a period of almost chaotic perturbations followed by a smooth recovery. The perturbations coincide with the tunnel operating days (Monday through Friday). The smooth recoveries correspond to the weekends and holidays. It is noticeable that the values of the temperature and relative humidity of Probe 2, which is in the center of the tunnel, are almost always smaller than the values of the other two probes.

In order to compare the climatic conditions in the ESF tunnel with the atmospheric climatic conditions, data from two weather stations near the ESF portal were obtained from the U.S. Department of Energy. The location of one of the stations (NTS-60) is shown in Figure 1-2. The Sever Wash meteorological station is about one mile east of the ESF tunnel portal (not shown in Figure 1-2).

Detailed correlation and analysis of these data are currently underway by Nye County. A portion of these data was used for preliminary calibration of the model that will be described in Section 6. A cursory review of the graphs indicate that during the first three month of observation, the tunnel temperature and humidity were slightly influenced by the atmospheric conditions. The pressure fluctuations in the tunnel on the other hand have always been synchronous with the atmospheric pressure fluctuations. There is no detectable delay (lag) between the atmospheric and tunnel pressure fluctuations regardless of whether the tunnel ventilation was operating or not. The relative humidity of the atmospheric air is generally between 10 to 15 percent. The relative humidity of the atmospheric air increases generally as a result of decline in temperature. This indicates that the moisture content (or specific humidity) of the atmospheric air is almost always low. This means, regardless of the relative humidity value of the outside air, the atmospheric air that enters the tunnel has a great potential for removing moisture from the rock.

5.0 CALCULATION OF AIR PERMEABILITIES FROM PRESSURE MONITORING DATA

Simulation of the pressure responses before and after the tunnel has provided estimates of the air permeability of the units intersected by the tunnel. Several methods of calculating permeability from these barometric responses have been used. The simplest form was the assumption that before the tunnel influence, the barometric pressure waves travel vertically in a uniform front. This conceptual model has been used by Edwin Weeks of the U.S. Geological Survey at Yucca Mountain and various other sites. However, quasi three-dimensional simulations (MET, 1995) have indicated that substantial amounts of lateral flow of air occurs as a result of complex boundary conditions and heterogeneity in the hydrogeologic formations at the site. Furthermore, the tunnel effects are obviously three-dimensional. Attempts to simulate responses in ONC#1, which is at least 1.5 miles away from the tunnel, with the one-dimensional approach has not been successful.

5.1 BOREHOLE PERMEABILITY CALCULATIONS

Calibration to permeability values alone does not always have a unique solution. It is the overall diffusivity of the system (the dynamic combination of permeability, porosity, saturation, and density) that dictates the responses to barometric fluctuations at any of the boundary conditions. However, in cases where the boundary is connected to the zone of interest (where the probes are situated) through equivalent porous media (such as the connection between the atmospheric boundary and the TCWU), the response is broad and distinctly resembles the fluctuations at the boundary. Where there is more than one connection; such as along faults, the responses to each can be isolated and identified. In some cases, because the response through faults is through a small diffusivity (because of the small effective porosity and large permeability) it produces small ripples superimposed on the broad signals that result from relatively low permeability and large porosity equivalent porous media pathways.

Pressure fluctuations with time in NRG-4 borehole during the month of May 1995 show that the pressure response to atmospheric fluctuations is substantially dampened in probes below the Ptn Unit (Probes 4 to 7). Probe 3 which is near the bottom of the Ptn, is only slightly dampened. It appears that a majority of the dampening occurs in the bottom portion of the Ptn unit where it is believed to have a higher moisture content which results in lower air permeability. On or about May 22, 1995, the ESF tunnel began penetrating the Tiva Canyon vitric zone which is the upper-most part of the Ptn. There is no noticeable change in the response of the pressure probes in NRG-4 at this time.

The pressure fluctuations in NRG-4 borehole during the month of June 1995 showed noticeable deviation from normal trend in all deep probes which began responding almost synchronously to the atmospheric fluctuations as a result of direct pneumatic communication of the ESF tunnel with the fractured Topopah Spring Welded Unit (TSWU). Probe 3 which is in Paintbrush Nonwelded Unit (PTN) continued to maintain a lag in barometric response relative to the other probes. The reason for this lag is that Probe 3 is separated from the tunnel and other affected units by nonwelded tuff both horizontally and vertically. As of the latest data set retrieval, this lag has remained about the same.

Data from NRG-4 in April, before the tunnel interference in June 1995, were used to calculate the permeability of the units isolated by the packers. A one-dimensional model using A-TOUGH computer code was setup for these calculations. The results of the calibration were used to simulate the May 1995 data. It appeared that a one-dimensional simulation of the conditions before the tunnel penetrated the repository host rock was appropriate to estimate the vertical air permeability values. Figure 5-1 is a summary of the results of permeability calculations in NRG-4 for this one dimensional case.

Pressure fluctuation data for November 1995 for well ONC#1 when the ESF tunnel entered the repository horizon and began turning to the south (see Figure 1-2) show a lag time between probe 1 and the atmospheric fluctuations of about 4 hours. The lag time between the atmosphere and the probe 2 responses is 14 hours. Probe 2 responses are almost synchronous with all the lower probes in the unsaturated zone.

Figure 5-2 is a plot of the pressure fluctuation data from January 18 to February 21, 1996. During this period the ESF tunnel was at the repository horizon in the area of Yucca Ridge where several northwest-southeast trending structures have been mapped. This structure probably intersects the Ghost Dance Fault, and is probably pneumatically connected to the Sundance Fault system.

In this figure, the lag times on February first are shown. On this day, the lag time between the atmosphere and Probe 2 is 20 hours and that between atmosphere and Probe 1 is about 1 hour. However, fluctuations in Probe 2 are still synchronous with all the deeper probes. It is noticeable, however, that in late February, the deeper probes began to show small ripples in their fluctuations. In March 1996 data (Figure 5-3) these ripples clearly become stronger. What is most interesting in this figure is that the lag between Probe 2 and deeper probes have become negative. That is, the deeper probes, which are vertically closer to the fault zone intersect ONC#1 at a depth of about 1200 feet. The fault zone in this figure is drawn to indicate the probable interval where it exists in this borehole. The fault is believed to be at a steep angle (NWRPO, 1995). The apparently low angle in this figure is a result of horizontal exaggeration.

In Figure 5-3, it is also notable that probe 1 has maintained its 4 hour lag but probe 2 has a lag of 36 hours from the atmospheric fluctuation. This apparent longer lag is partly due to the long-term atmospheric pressure decline in early March but it could also be due to superposition of other sources of pressure. Closer examination of the data indicates that this negative lag between Probe 2 and the deeper probes has been reoccurring since October 1995. Atmospheric pressure signals are not very strong between July and October 1995. However, comparison of the same strength signal between June 1995 and October 1995 clearly indicates that the negative lag was developed sometime between June and October of 1995. This is the period that the ESF tunnel was advancing closer to ONC#1 borehole in the fractured TSWU. Similar lags can be observed in other boreholes at Yucca Mountain. In particular UZ-4 and UZ-5 in December 95 and May 1996 and NRG-7a in December 95 and May 96 distinctly show this negative lag in probes placed below the Ptn unit.

In order to evaluate the cause of these effects, a one dimensional simulation of the ONC#1 column was setup to calculate the permeability of the instrumented sections. Data from April 1996 were used for this simulation. The column used for this set of simulations is shown in Figure 5-4. The simulated pressures are compared with the measured pressures in Figure 5-5. It was not possible to match the trends for probes below probe 2. Probes 1 and 2 are matched very closely.

To evaluate the potential for influence of the tunnel on the responses, a three-dimensional configuration was setup as shown in figure 5-6. The one dimensional configuration is pictorially shown as a vertical column of cylindrical nodes at the ONC#1 location. The major fractures are shown by vertical planar nodes. The tunnel nodes are shown with horizontal cylindrical nodes. The atmospheric fluctuations are connected to the top of the ONC#1 column and to the beginning of the tunnel. Therefore, communication with the atmosphere is through both a vertical column of hydrogeologic units as well as through the tunnel, Ghost Dance and Sundance Fault systems. Figure 5-7 is a comparison of the observed versus simulated pressures in April 1996. The match is almost perfect with the three-dimensional configuration. This simulation exercise demonstrates that deviation of the pressure from normal trends in the deeper probes in ONC#1 are very likely due to the disturbance of the pressures in the repository horizon by the ESF tunnel.

5.2 LARGE-SCALE PERMEABILITIES

Comparison of the calculated permeability values between Figures 5-1 and 5-4 reveals that the bulk vertical air permeability of the TCWU is slightly smaller at ONC#1 site than at the NRG-4 site. The Ptn unit forms a barrier to barometric pressure transmission in both boreholes. Its effectiveness appears to be largely due to the existence of a low permeability layer near the bottom of the unit. At the NRG-4 site, the Ptn unit is thicker than at the ONC#1 site. This lower air permeability of the bottom layer is probably due to the higher moisture content of the unit in both sites. This layer corresponds with the Topopah Spring crystal rich vitric zone.

The fault zone at the ONC#1 site has a slightly higher permeability than the host rock. In Figure 5-4, the air permeability of the Sundance Fault from the three-dimensional model is also shown. In calibrating this model, it was realized that the equivalent effective porosity of this zone is very small ($\phi = 1 \times 10^{-5}$). This small effective porosity indicates that the pressure transmission occurs along a very distinct path. This path is probably partly through the Ghost Dance, Sundance, and Bow Ridge Faults. Evaluation of the responses in other boreholes at the site is underway by Nye County to better understand this phenomenon.

Comparison of the overall permeability measurements from borehole packer testing shows that the overall permeability values measured in boreholes can be one to two orders of magnitude smaller than those calculated from barometric fluctuations. Montazer (1982) demonstrated this by conducting experiments in boreholes at various sampling sizes. Preliminary analysis of some of the data indicates that the horizontal directional permeability may be as much as two-orders of magnitude smaller than the vertical directional permeability.

6.0 MODELING VENTILATION EFFECTS ON MOISTURE IN REPOSITORY HOST ROCK

The two most important aspects of the Yucca Mountain project are radionuclide isolation and thermal stability of the repository. Current concepts are that the repository will be sealed with crushed tuff or similar material (TSPA 1995) after 100 years of repository pre-closure period. Although some considerations have been given to a no backfill design, the results have not been satisfactory due to high temperatures and humidities predicted by the simulations. The shortcoming in all the simulations and analysis has been that the media around the waste package have been assumed to be relatively stagnant, whether air or crushed tuff. Nye County has conducted simulations based on the concept proposed by Roseboom (1983) and Montazer and Wilson (1984) that the dry and open environment of the repository should be taken advantage of in the design of the repository. Preliminary simulations have been made using simplifying assumptions and the material properties presented in TSPA 1995. The results of these simulations are presented in the following sections.

Ventilation is one of the key features that can be exploited to increase the safety of the Yucca Mountain Site as a potential repository. Ventilation can remove substantial amounts of moisture from the drift walls in a very short period of time. It has been demonstrated in various experiments (Such as Ed Week's observations at UZ-6, and Nye County's observations in the ESF tunnel) that substantial amounts of moisture can be removed from the rocks in the mountain by natural convection due to topographic relief and thermal gradients. In many hillside mines, natural ventilation is the only means of supplying large amounts of air to these mines. Therefore, by considering a naturally ventilated repository (after construction) and taking advantage of the thermal drive of the waste package, the repository may be kept dry during at least the first 1000 years, if not longer. The amount of moisture removed from the rocks during this time will create a thick low-saturation skin around the drifts that will require thousands of years to re-saturate. Ventilation can also remove large amounts of heat generated by the waste canisters.

In case of the TSPA 95's proposed approach, there is very little moisture removal from the system and re-saturation can occur much more rapidly than the ventilated case. In an unventilated case (backfilled repository), the moisture is just forced away from the repository. It has no place to go except for a little atmospheric ventilation along the Solitario Canyon. The moisture is trapped under an umbrella that will eventually return and re-wet the repository.

Of course, there are many other issues that need to be considered in a naturally ventilated repository such as the repository security, seismic stability, etc. such aspects need to be studied carefully.

6.1. SIMULATION SETUP

The purpose of the simplified simulations performed for this section was to evaluate the reasonableness of the parameters used and the conceptual settings of the model.

6.1.1 MESH

The mesh for the simulations is shown in Figure 6-1. It consists of an axi-symetric arrangement of the nodes. The tunnel is in a horizontal direction. No gravity is used in this mesh; therefore, the flow of fluids are due to pressure gradients only. Because of the strong influence of the ventilation flow, the error introduced by ignoring gravitational forces is negligible. However, gravitational effects are expected to enhance ventilation due to buoyancy. More realistic simulations will be performed which will require three-dimensional discretization of the mesh.

The axi-symetric mesh consists of 16 rows of nodes along the tunnel which add up to about 560 meters. Each node represents a cylinder with its axis along the center of the tunnel as shown in Figure 6-1. The mesh has 20 of these concentric cylinders. The first five concentric cylinders represent the tunnel. The rest of the cylinders represent the surrounding rock.

In the forced-ventilation simulation case, the last set of concentric cylinders (at 560 m from the portal) were set to represent the rock which simulates a dead-end tunnel. This special case evaluated an existing condition which was used for comparison with the observed data collected by Nye County since August 1995. The mesh extends to a radius of 300 meters.

6.1.2 INPUT PARAMETERS

The tunnel nodes have atmospheric properties. Table 6-1 summarizes some of the important input parameters. It should be noted that A-TOUGH, unlike other TOUGH family of codes, does not allow liquid flow in the tunnel nodes or between the tunnel nodes and the rock. Only vapor and air flow are allowed in the tunnel nodes and between the tunnel nodes and the rock. The rock properties are set at an equivalent porous media with permeability of $1x10^{-15}$ m^2 and an effective porosity of 35 percent. The initial saturation of 0.95 was assumed for the rock. Initial pressures were set equal to 87470 pascals (12.7 psi) for all the nodes. The pressure in the atmosphere outside the tunnel was kept constant at this value. The initial temperature for all nodes was set at 19 degrees Celsius (66.2 degrees Fahrenheit). The temperature of the atmosphere outside the tunnel was varied for different simulation cases but was kept at an average constant value throughout all simulations. This is not a limitation of the model but a simplification. Future simulations will consider variation of the atmospheric parameters.

6.1.3 CALIBRATION RESULTS

The results of the numerous forced-ventilation simulation for data from April 1996 were used to calibrate the model to ambient conditions. Calibration to ambient conditions does not necessarily imply calibration over the entire range of future repository operations. Substantial variation in relative humidity of the tunnel air was simulated. Eddy diffusivity of 0.01 m^2/s was selected as the best calibration parameter during an average ventilation period. The magnitude of the humidity changes simulated by this model compare well with the observed values.

In order to better conceptualize the eddy diffusivity phenomenon, a schematic drawing of the process is shown in Figure 6-2. Stagnant air has a very low thermal conductivity. Its vapor diffusion is in the order of 2.13 $x10^{-5}$ m^2/s. In flowing air, both vapor and heat are transferred mostly advectively. The mass and heat transfer perpendicular to the direction of flow of air occurs through mixing that results from development of eddies, as shown in Figure 6-2. This transfer is substantially greater than that of a stagnant air and is dependent on the velocity of the air and the state of turbulence. In chemical engineering and atmospheric sciences the transfer coefficient is referred to as eddy diffusivity. The principal of flow of both heat and vapor is the same as the Fick's Law but with a dynamic diffusivity coefficient.

6.2 LONG-TERM VENTILATION SIMULATIONS

The purpose of the simplified simulations performed for this section was to demonstrate the importance of the natural- and forced-ventilation in controlling the thermodynamic processes in a tunnel. Also, the sensitivity of the results to the magnitude of the eddy diffusivity is evaluated.

Table 6-2 presents a summary of the simulations performed for this task. A total of 11 simulation cases were made using the above described mesh setup. The first six simulations were designed to evaluate the sensitivity of the results of the model to variation of the eddy diffusivity and the atmospheric air temperature. These six cases differ only in the value of eddy diffusivity and the temperature of the atmospheric air entering the tunnel. In these six cases forced-ventilation is used similar to the short-term simulation described above.

Simulation cases seven through nine were performed to evaluate the effect of heat as would be applied by the waste package. However, as a demonstration simulation, an equivalent heat that would be provided by 42 waste packages with a spacing of six meters was considered. In these latter three simulations, a ventilation shaft is used instead of forced-ventilation. The shaft node is the only node that has gravitational forces present. The atmospheric pressure and temperature at both the tunnel portal and the top of the shaft are kept at the same constant value. Therefore, the driving forces for the air movement in the tunnel and along the shaft are the buoyancy caused by the temperature of the waste package, the host rock temperature, and the pressure caused by the weight of the column of air in the shaft (opposing buoyancy). These conditions simulate atmospheric conditions that promote air suction in the wells.

The average temperature of 15 degrees is used, which is conservatively high compared to the average annual temperature at Yucca Mountain. Lower atmospheric air temperature would result in a larger air flow and cooler temperature in the waste area. The atmospheric air was assumed to have an average relative humidity of 10 percent.

Simulation cases 10 and 11 are different from cases 7 through 9 only in the pressure at the top of the shaft that promotes outflow in the shaft (helping the buoyancy). Only two cases of 0.01 and 0.001 eddy diffusivity are used in this case. Thermal load in the tunnel is increased in these two cases by increasing the number of nodes (or grid blocks) with thermal load to 10 instead of six.

6.3. RESULTS OF SIMULATIONS WITH FORCED VENTILATION (CASES 1 TO 6)

The results of these simulations show that simulated pressure in the host rock drops by about 25 pascals (approximately 0.004 psi) within the first 25 m radius in about 11 days. Such changes have already been observed in NRG-4 as presented earlier. After 100 years, the pressure in the entire 300-m radial distance is affected by about 225 pa (0.0331 psi). This is not unreasonable, considering the observations and simulations presented for the ESF tunnel-ONC #1 interactions. The simulated temperature in the entire first 25 m radius of the model drops by at least one degree Celsius. Comparison of the April 1995 with August 1996 temperature data in NRG-4 indicates that probes 4 and 5 which are at the tunnel level have dropped by about one degree Celsius, whereas probes above and below show only about 0.1 to 0.2 degrees decline in temperature.

In summary, comparison of these six cases indicates that in the long-term, higher outside temperature and larger eddy diffusivity result in an increase in both heat and mass transfer between the host rock and the tunnel air, i.e., a cooler and dryer host rock. The direction of the flow could be different depending on the relative magnitude of the temperature of the two media.

6.4 RESULTS OF SIMULATIONS WITH NATURAL VENTILATION (CASES 7, 8, 10, AND 11)

Figure 6-3 conceptually shows the condition that these simulations represent. A naturally ventilated repository would have a more complex set of shafts and tunnels that would be designed to optimize the flow of air Figure 6-4 shows the heat load used for this set of simulations.

The results of these simulations indicate that the pressure distribution is similar between the three cases. An increase in pressure at the end of the tunnel near the shaft occurs due to the column of air in the shaft. Because the pressure at the top of the shaft is set at the same pressure as the atmosphere at the tunnel portal.

The simulated temperature values in early times for Cases 8 and 9 with smaller eddy diffusivity values are higher and approach those of the TSPA 95 cases. In both Cases 7 and 8, the temperature of the repository approaches that of the atmospheric temperature of 15 °C after 10,000 years. Significant differences are noted in the first 10 years. In Case 7 the eddy diffusivity of 0.01 (m^2/s) results in a much faster cooling effect than in the other two cases. The hot spot (temperatures in the rock nodes adjacent to tunnel reaches about 20 °C in Case 7 and 22.5 °C in Case 8. The flow rate through the shaft in all these cases is about 1130 m^3/min (40,000 cfm). In the worst case, the temperature of the air near the canister reaches 130 °C and drops to 45 °C after 100 years. However, these simulations predict that the temperature of the air in the tunnel near the rock remains within 15 to 20 °C. In these three cases, radiation heat flux is not considered. In Cases 10 and 11, radiative heat flux is included in the simulations.

In all cases, absolute values of the capillary pressure increase with time. More importantly, the gradients of the capillary pressure are such that the flow of water is towards the tunnel. These gradients are strongest for Case 7 with eddy diffusivity of 0.01 m^2/s and decline as the smaller eddy diffusivity is used for simulations.

Saturation values follow the capillary pressure trends, as expected. Saturation values decline to about 60 percent after 10,000 years in case 7 and to about 70 percent for Case 8. In Case 7, the rock nodes near the tunnel become dry after 1000 years.

Figure 6-5 is a plot of the thermal load for the Cases 10 and 11. As noted earlier, in these two cases, the pressure outside the tunnel is set to correspond to natural atmospheric pressure. That is the pressure at the top of the shaft is smaller than the pressure at the tunnel portal. The pressure difference was calculated by considering the elevation difference of the two points and the density of the air at 15 °C temperature. In these cases eddy diffusivities of 0.01 and 0.001 were used.

Simulated pressure distribution is about the same for both cases. In these cases, a lower pressure at the end of the tunnel (bottom of the shaft) is noticed. This is due to lower density of air in the shaft that is carrying a warmer air to the surface. Pressure distribution after 10,000 years represents a steady state condition that is equilibrated between the outside pressure and the pressure in the tunnels. At this time, the pressure at the bottom of the shaft is influenced by the temperature distribution in the tuff cylinder.

The temperature distribution for Case 10 is shown in Figure 6-6 for various times. A temperature gradient is still present after 10,000 years when the temperature in the tuff cylinder has begun to equilibrate with the atmospheric temperature of 15 °C. The hot spot in the tunnel near the waste package reaches a maximum of 33 °C. The rock temperature near the tunnel continues to drop below 10 °C until after about 2 years when it rises back to approach 15 °C (see figure 6-7). The reason for continued drop of the rock temperature is the air current that is caused by the presence of the heat source (waste canisters). As the heat source weakens, the air current in the tunnel also declines in rate. As a result, there is less evaporative cooling and the rock temperature climbs to equilibrate with the atmospheric temperature. This pattern can also be observed in the saturation curve in Figures 6-8 and 6-9. Capillary pressure gradients remain directed towards the tunnel at all times (Figure 6-10).

Results of Case 11 show that temperature rises to a higher level. The air in the vicinity of the tunnel reaches a maximum temperature value of 75 °C and declines slowly to about 62 °C in the first 20 years. From then, it declines to a temperature of about 16 °C. The temperature in the rock nodes in the vicinity of the tunnel drop from 19 °C (initial condition) to about 6 °C and then rises to approach an equilibrium temperature of 15 °C. Saturation of the rock in the vicinity of the tunnel drops to a dry state at 2000 years and remains dry for the remainder of the 10,000-year simulation.

In summary, the data collected from the ESF tunnel indicate that there is substantial temperature and moisture loss from the rock surface as a result of ventilation air. Simulation of the existing conditions suggest that an eddy diffusivity value of between 0.001 and 0.01 m^2/s is an appropriate value for flow rates between 1132 and 2830 m^3/min (40,000 and 100,000 cfm). Long-term simulations and calibration with the data from NRG-4 provided thermal conductivity and air permeability values that were needed for simulation of the heated conditions. Strong air currents may be produced by natural ventilation. Application of the natural ventilation aided by the heat source may provide a cool and dry host rock with a moisture gradient that will be toward the emplacement tunnels during the first 10,000 years.

It is realized that these simulations are very simplistic and many other factors need to be considered. No infiltration was used in these simulations. The amount of bulk infiltration is negligible compared to the amount of moisture that is removed by the natural ventilation. However, pulse infiltration at fault zones and areas near Ptn may result in more water inflow into the tunnel than can be handled by the natural infiltration. Engineering of an open repository will be complicated and need special study.

The presentation of the results of these simulations is intended to generate interest in this potential alternative waste emplacement. The results should not be used as any design criteria or for any decision making about the waste disposal.

7.0 EVALUATION OF THE USE OF WATER IN THE TUNNEL

Recently, Nye County's Nuclear Waste Repository Project team visited the Exploratory Studies Facility (ESF) tunnel. One of the observations made by the team was related to the water usage in the tunnel. Nye County has observed on several occasions standing water throughout the entire length of the tunnel boring machine (TBM) and its attachments. Also it was noted that water spraying with a high pressure hose is routinely being used by the miners to wash the walk ways and other seemingly unnecessary areas. Furthermore, recent evaluation of the report on chlorine 36 has revealed that majority of the samples were contaminated with the J-13 water (tagged with lithium bromide) which is the main source of the ESF tunnel water. It is noteworthy that these samples have been taken at least 10 cm into the rock and from the walls of the tunnel which are not subjected to standing water and are only sprayed for cleaning purposes. Nye County has recently performed preliminary mass balance calculations to evaluate the water usage in the tunnel. These calculations augment previous Nye County work on the impact of ventilation on water removal from the ESF.

In order to demonstrate the significance of the wet surfaces in the tunnel, a simple conceptual numerical model of the situation was setup. The conceptual model was 5 meters wide by 25 meters deep. A vertical fracture zone of about 0.5 meter thickness was placed in the middle of the model. The properties of this fracture zone are equivalent to a broken Topopah Springs Welded Unit. The surrounding rock has the properties of the matrix of this unit. The floor of the tunnel was kept wet (at a 95% saturation) for the entire duration of simulation. Evaporation equivalent to that induced by the ventilation was imposed at the tunnel floor. The rock matrix was initially set at 65% saturation and that of the fracture zone was set at 20% saturation (to simulate a drained fracture). The wetting (saturation) front in the fracture travels a distance of 10 m (30 ft) in about 0.003 days (4 minutes). After this time, the wetting front travels at a relatively slower rate. However, after 8 days it reaches the lower boundary of this model which is at 20 meters (66 feet) below the floor of the tunnel.

Although this model is very simplified, it demonstrates the potential for propagation of even a slight wetness in a fractured zone.

8.0 SUMMARY AND CONCLUSIONS

Nye County Nuclear Waste Repository Project Office's (NWRPO) Independent Scientific Investigation Program (ISIP) is concerned with several key scientific issues that may impact the repository design and performance. The ISIP presently includes borehole and tunnel instrumentation, monitoring, data analysis, and numerical modeling activities to address some of these concerns.

Nye County has installed and is currently monitoring pressure and temperature instruments in boreholes UE-25 ONC#1 and USW NRG-4 to evaluate the long-term pneumatic conditions at strategic depths in the subsurface both in response to fluctuations in atmospheric conditions and in response to other possible disturbances resulting from site characterization activities such as ESF tunnel construction. Nye County has also installed instruments to measure temperature, pressure, and humidity within the ESF tunnel to characterize the air being used to ventilate the tunnel which could potentially impact the performance of the repository. Finally, Nye County is conducting numerical modeling simulations to evaluate factors (including tunnel ventilation) which affect both short-term and long-term pneumatic and moisture conditions in the repository host rock .

A summary of activities undertaken by ISIP during the past year are as follows:

- Evaluation of critical data and information as it became available from the DOE's YMP Site Characterization Office.
- Observed water usage in the tunnel and its potential impact on the repository horizon and the scientific investigation results. Completed an analysis and a recommendation report and forwarded it to YMP Site Characterization Office.
- Prepared detailed review of procedures and methods used for in-situ air permeability tests and evaluated the results of some of these tests.

- Completed several letter reports to DOE on the interpretation of the results of the ^{36}Cl and other environmental and geological isotope studies. These communications have resulted in DOE giving more focused attention to the need for more detailed studies in the ESF tunnel, limiting the use of construction water, and enhanced interpretation of the results of the isotope sampling.

- Evaluated the saturated zone pumping tests that were performed in the C-Well complex during the past year.

- Monitored responses to these pumping tests in the ONC#1 saturated-zone instrumentation.

- Collected gas samples in the vadose zone in ONC#1 and analyzed the samples for fluorocarbons, tritium, and carbon isotopes.

- Estimated the apparent ages of the gas samples from ONC#1 and compared with the results of samples obtained from other boreholes at Yucca Mountain Site.

As a result of the evaluation of the ESF tunnel climatological data collected, Nye County concluded that substantial moisture was being removed from the rocks penetrated by the tunnel ventilation. In response to issues raised by Nye County, DOE assigned a task force to conduct observations in the ESF and perform numerical simulations for interpretation of the results in parallel with Nye County's effort. Nye County provided data, preliminary analytical and simulation results, and input for developing the proposal to this task force. Nye County data indicated that in addition to moisture, substantial amount of heat is being removed by the ventilation. Nye County performed additional simulations using A-TOUGH, a computer code designed to simulate coupled-open air with geologic formations and discovered that there is a tremendous potential for natural ventilation at the site due to its climate and its physiographic setting. Simplified simulations using A-TOUGH were performed to evaluate the potential of a naturally ventilated repository. One conclusion is that it is possible to design a repository that is naturally ventilated with peak rock temperatures of less than 30 degrees Celsius over a 10,000-year period. These simulations also showed that the capillary pressure distribution would promote a strong gradient for water flow towards the emplacement tunnels during the entire 10,000 years. Nye County, believes that long-term waste containment implications of a naturally-ventilated repository warrants additional analysis.

Nye County is planning to perform several investigations in the near future to understand some of the issues that were outlined above, by installing new wells in both the saturated and unsaturated zones, testing and sampling these wells, and performing data analysis and modeling. These issues are related to the steep gradients in the saturated zone north and west of the site, the potential for dilution in the saturated zone as unsaturated zone moisture enters the saturated zone, the atmospheric and pneumatic boundaries in the Solitario Canyon that might impact the repository performance, and the large-scale transport properties of the fractured formations in both saturated and unsaturated zones.

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Table 6-1 Material Properties Used For Simulation of Ventilation Effects

Material Name	Density (Kg/m3)	Porosity	Permeability m2	Saturated Heat Conductivity (W/m C)	Specific Heat (J/kg C	Compressibility (1/Pa)	Expansivity (1/C)	Tortuosity Factor	m	Slr	1/Po (1/Pa)	Pmax (Pa)	Sls
ROCK1	2650	0.342	10^{-15}	2.4	1255	0	0	0.66	0.4438	0.06	5.67×10^{-7}	10^{7}	1.001
ATMOS	-	0.99	5×10^{-6}	0.021	1000	10^{-5}	0	0	-	-	-	-	-

Table 6-2 - Summary of simulation setup for evaluation of natural ventilation effects

CASE	Eddy Diffusivity (m2/s)	Atmosphere Temp. (C)	Initial Heat Load (KW)	Total Run Time (Years)	Initial Rock Temp. (C)
1	0.01	15	0	100	19
2	0.01	28	0	100	19
3	0.001	15	0	100	19
4	0.001	28	0	100	19
5	0.0001	15	0	100	19
6	0.0001	28	0	100	19
7	0.01	15	360	10000	19
8	0.001	15	360	10000	19
9	0.0001	15	360	10000	19
10	0.01	15	445	10000	19
11	0.001	15	445	10000	19

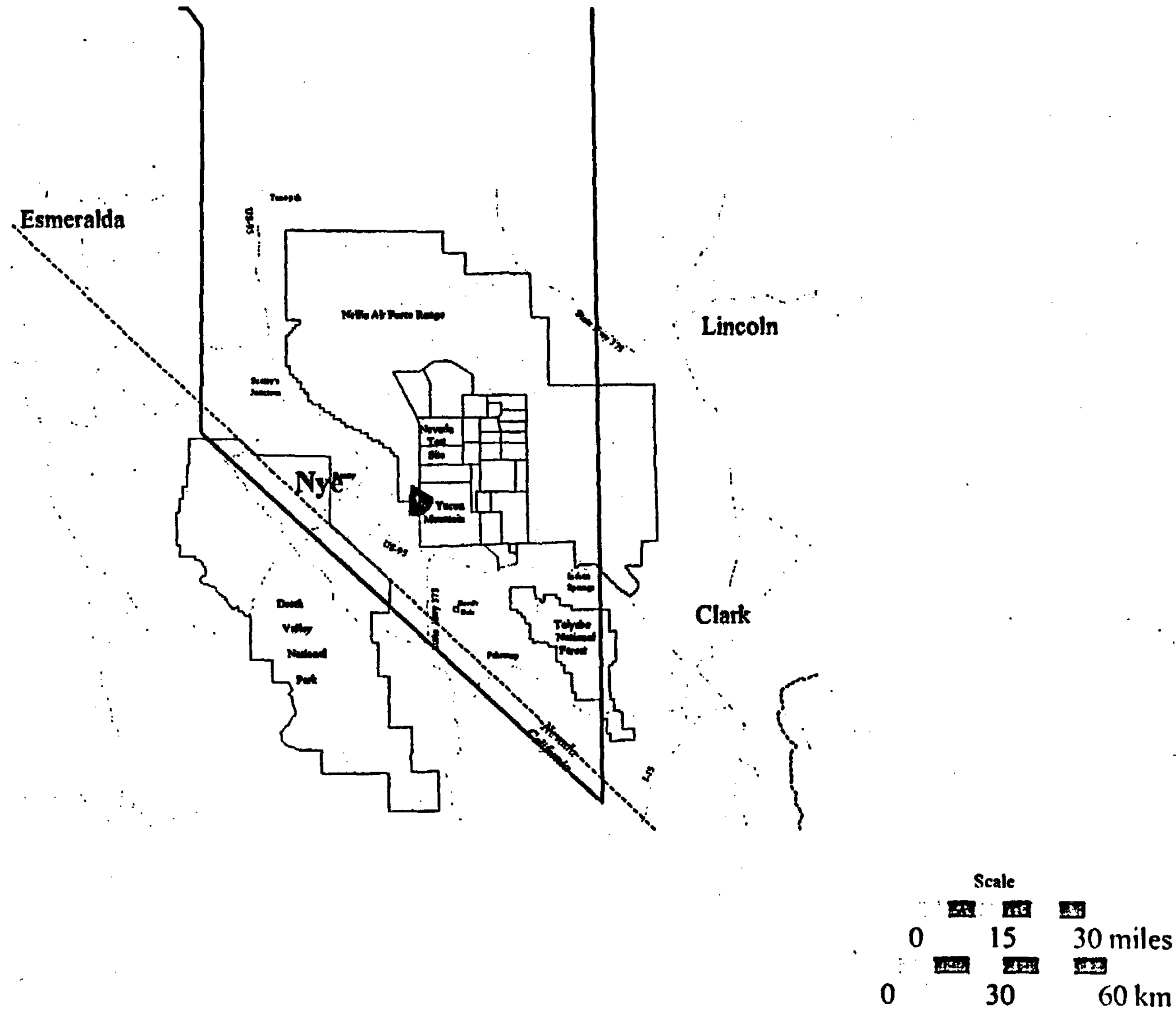

Figure 1 -1 Location of Yucca Mountain Site in Nye County, Nevada.

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Newport Beach, CA

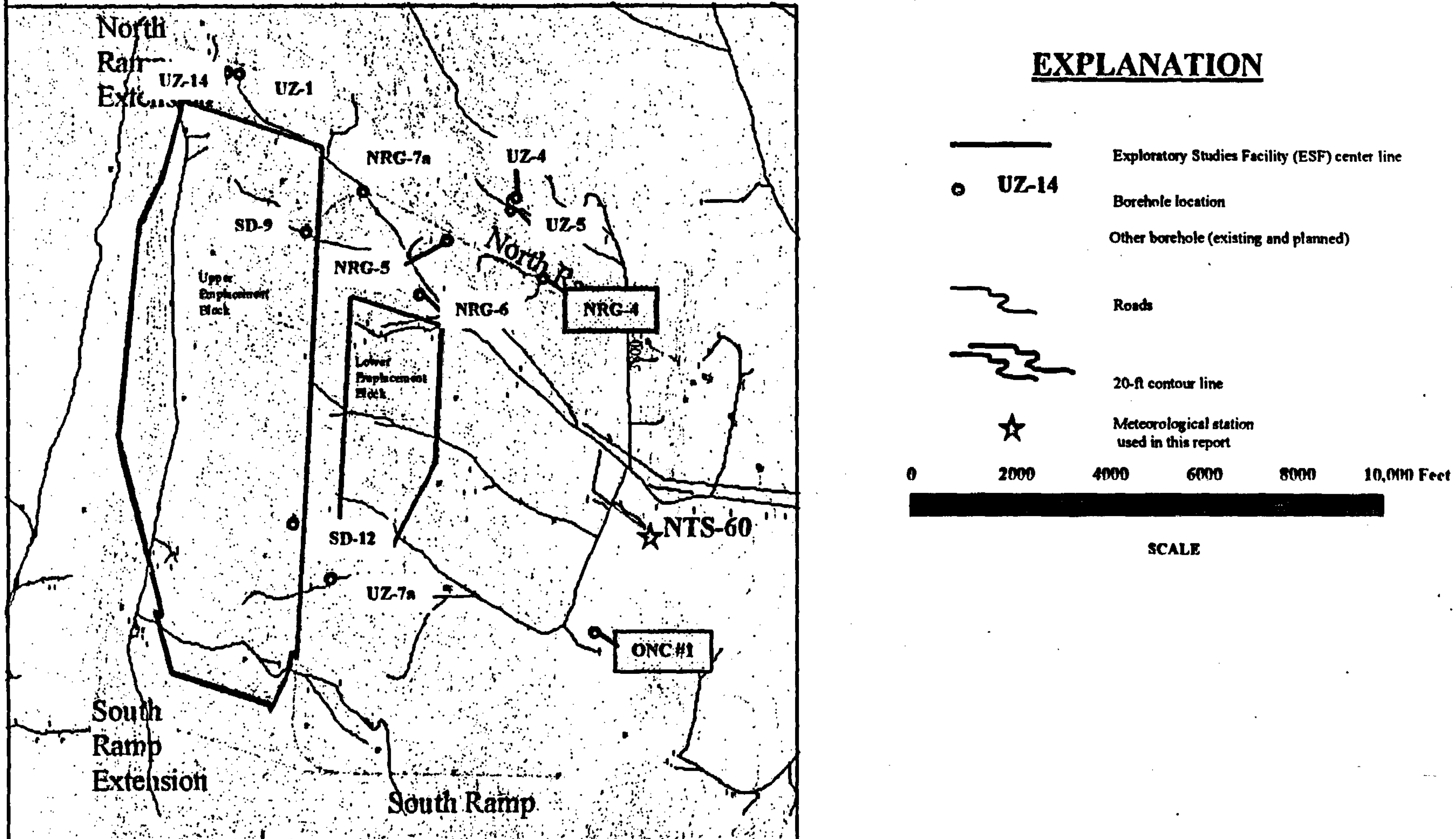

Figure 1-2 - Topography, location of selected boreholes, and ESF centerline at Yucca Mountain Site.

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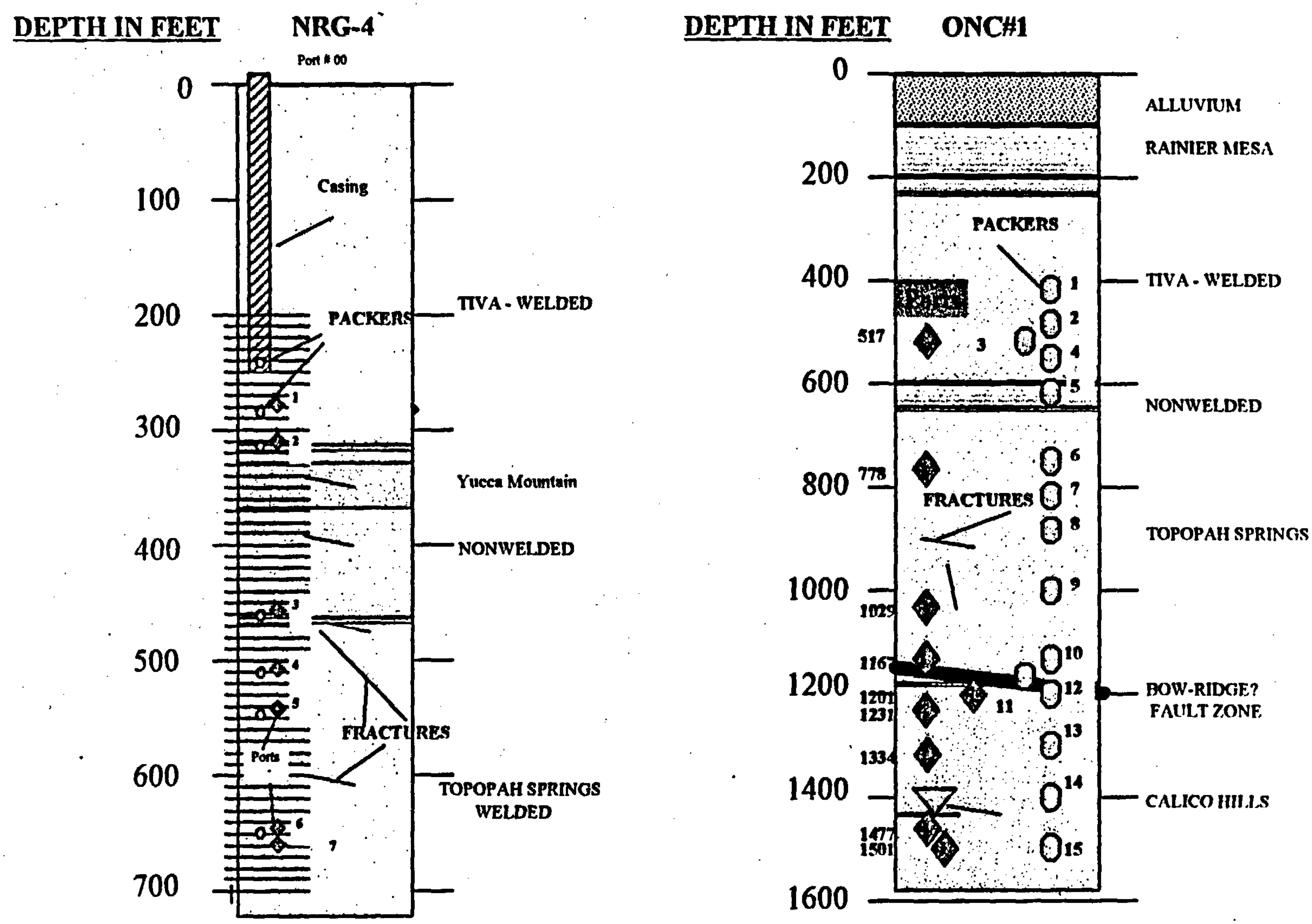

Figure 2-1 Schematic profile of instrumentation setup in UE-25 ONC# 1 and USW NRG-4

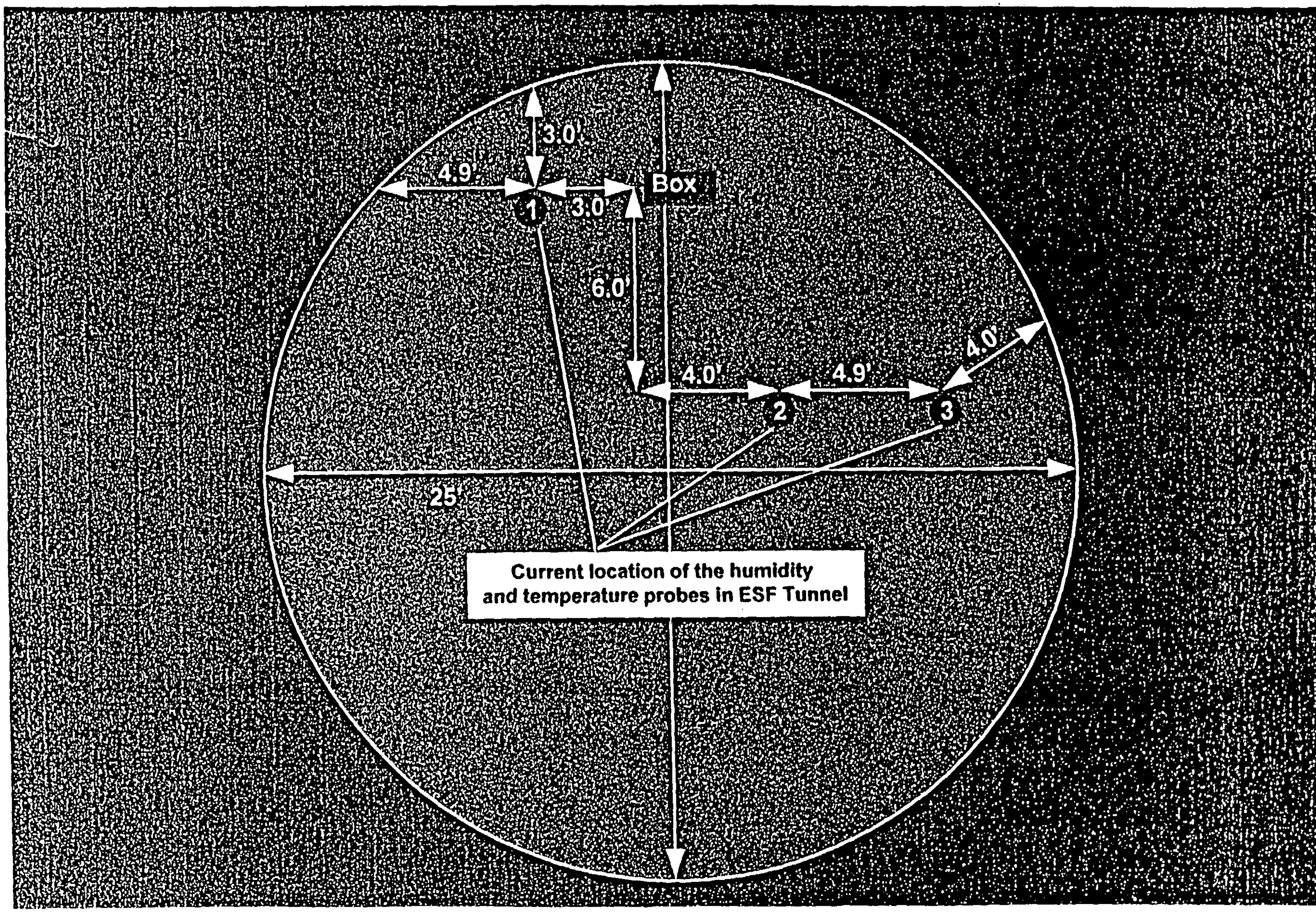

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Figure 2-2

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Figure 3-1 SURFACE ATTACHMENTS

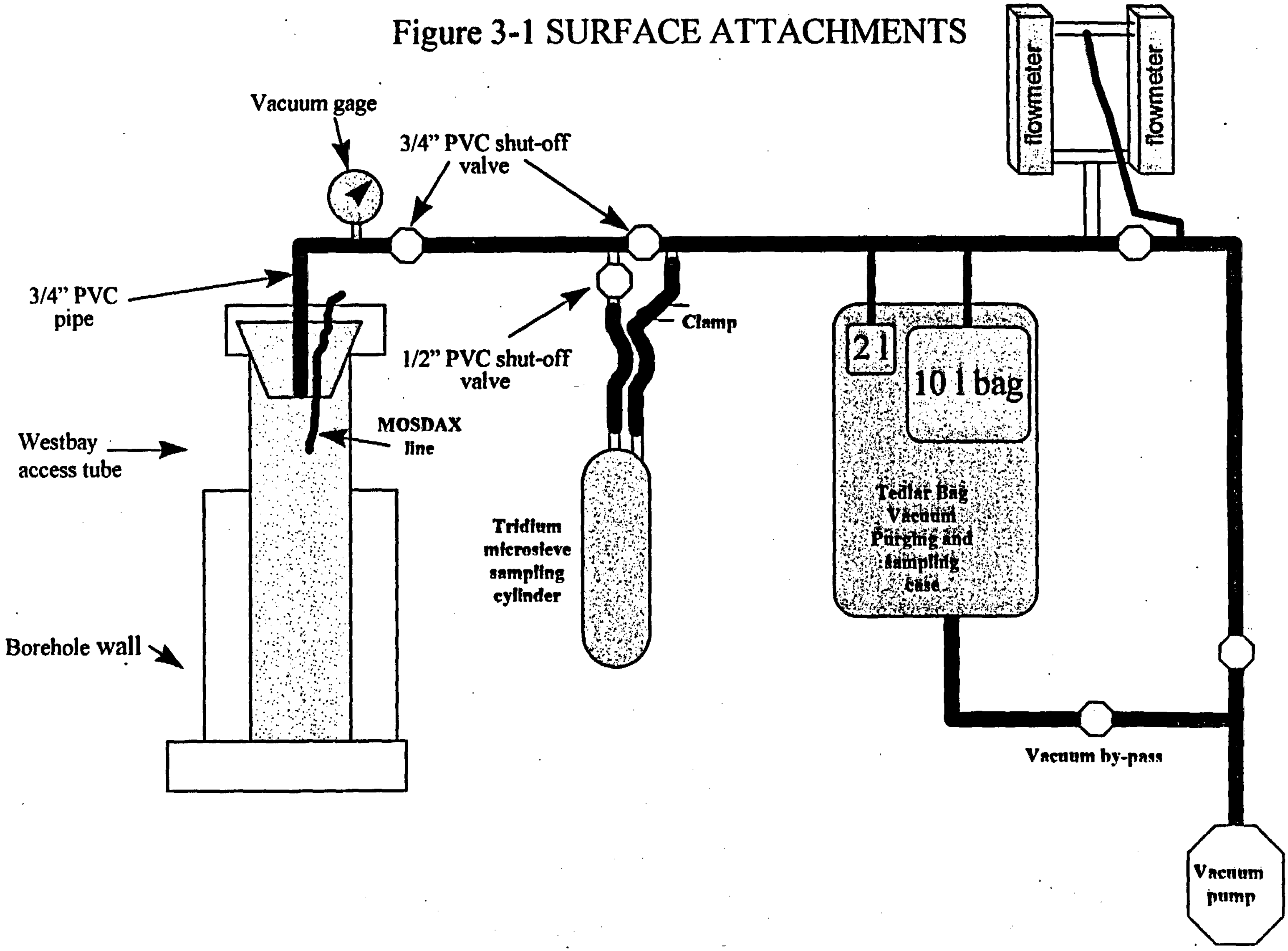
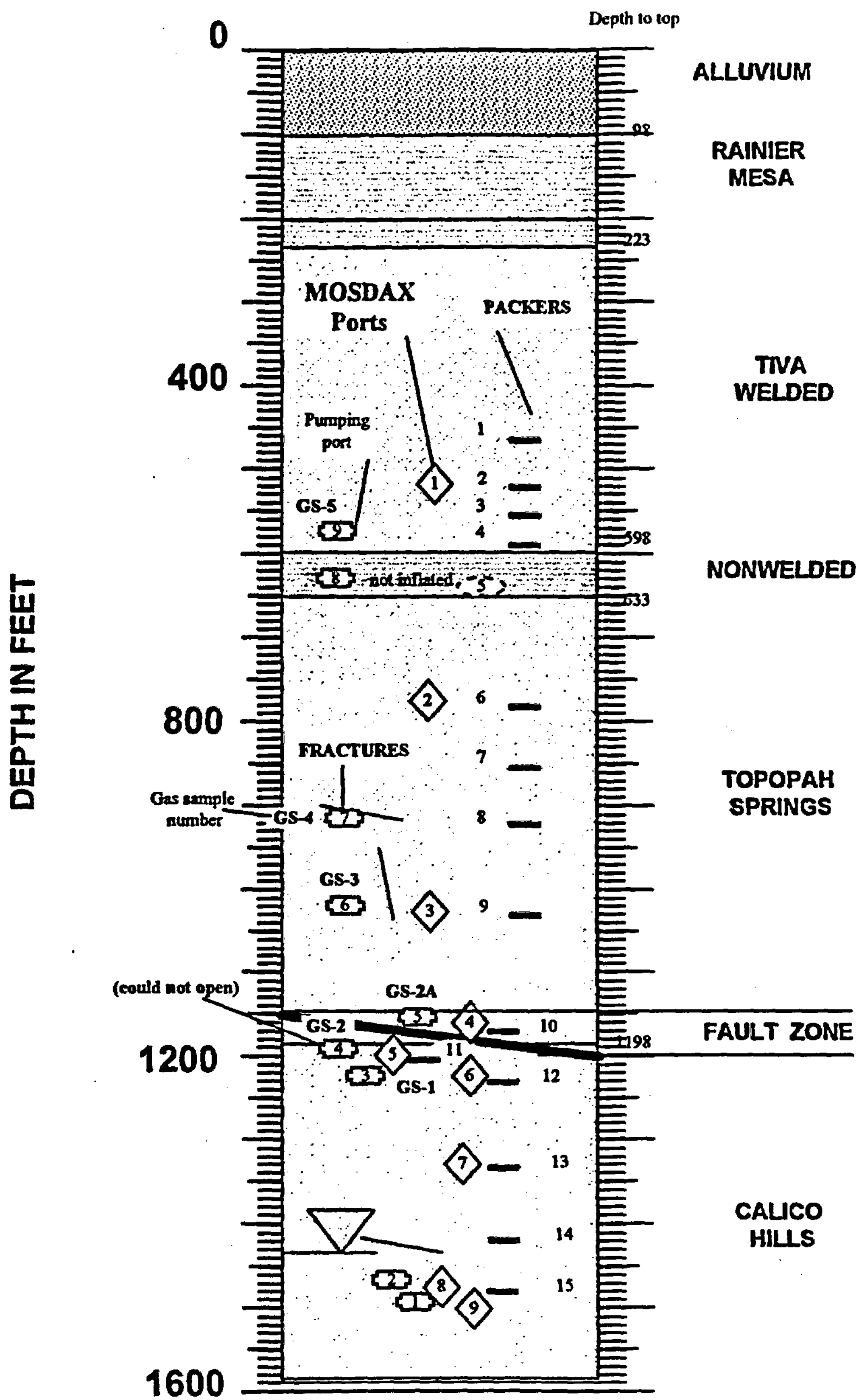


Figure 3-2 - ONC-#1 STRATIGRAPHY & INSTRUMENTATION PROFILE



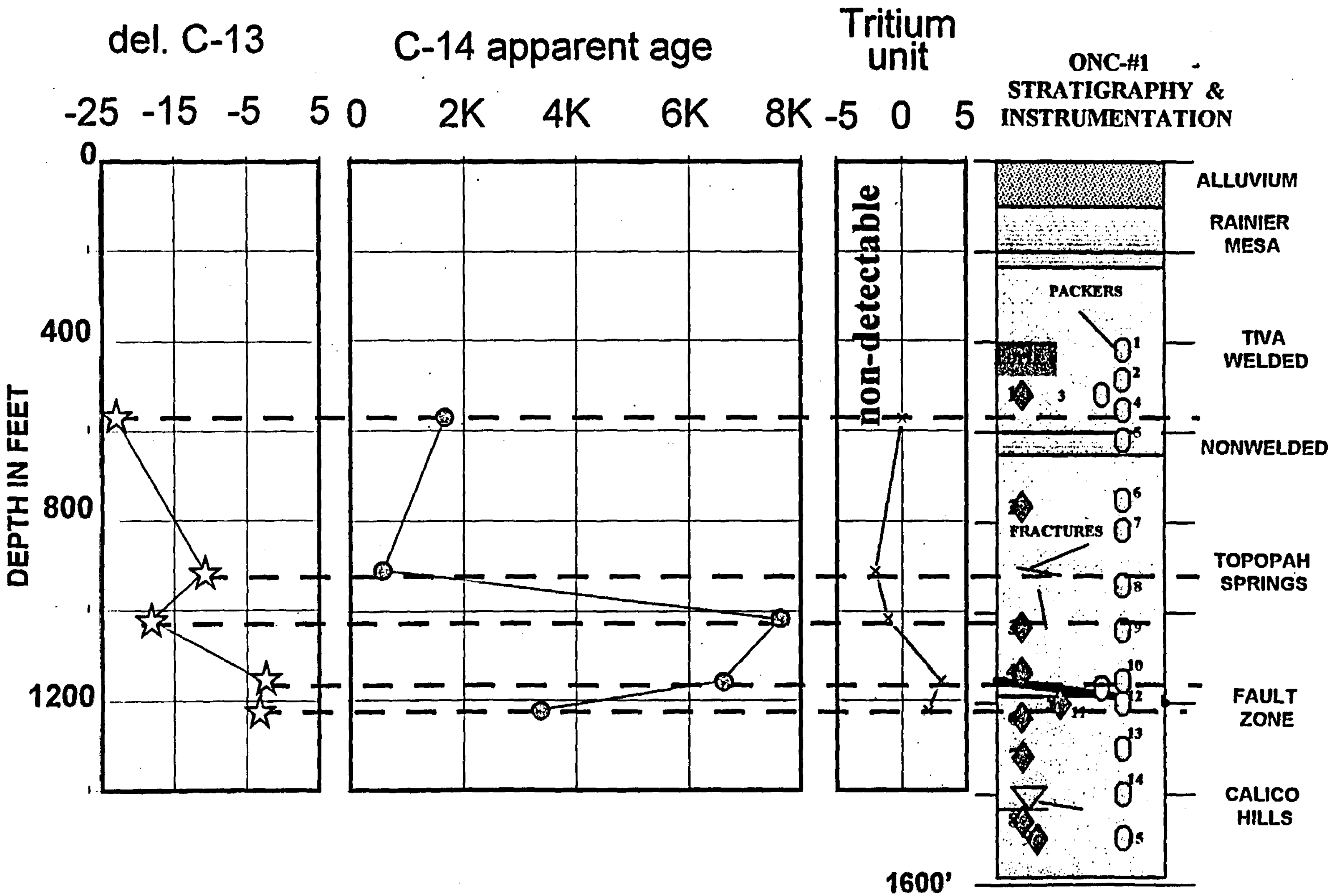
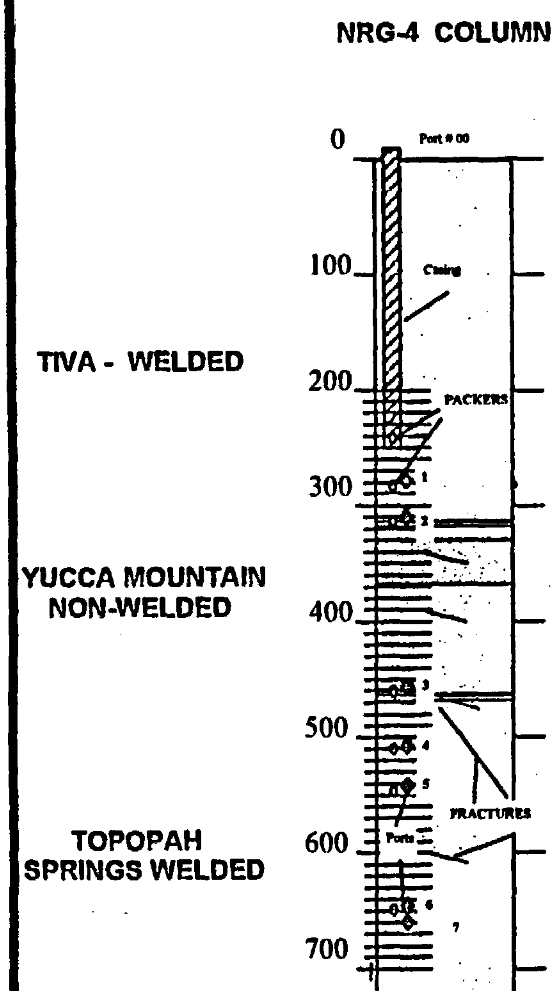


Figure 3-3 - Preliminary results of chemical analysis.

Figure 5-1 ONE-DIMENSIONAL GRID AND THE RESULTS OF PERMEABILITY CALCULATIONS FOR USW NRG-4



MODELED COLUMN

Thickness		Rock Type	Depth to bottom of layer		Permeability		Equivalent Porosity
m	feet	atmos	feet	m	m2	Darcy	cm/sec
30.48	100	Tiva1	100.00	328.08	1.00E-10	1.01E+02	9.80E-02
30.48	100	Tiva2	200.00	656.17	1.00E-10	1.01E+02	9.80E-02
26	85.3	Tiva3	285.30	936.03	1.00E-10	1.01E+02	9.80E-02
9.14	29.99	Tiva4	315.29	1034.41	1.00E-10	1.01E+02	9.80E-02
45.83	150.4	Ptn	465.65	1527.72	3.50E-12	3.55E+00	3.43E-03
14.76	48.43	Topo1	514.07	1686.60	5.00E-13	5.07E-01	4.90E-04
9.14	29.99	Topo2	544.06	1784.98	5.00E-10	5.07E+02	4.90E-01
33.26	109.1	Topo3	653.18	2142.99	2.30E-08	2.33E+04	2.25E+01
20.2	66.27	Topo4	719.46	2360.42	2.30E-08	2.33E+04	2.25E+01
608	1995	Topo5	2714.21	8904.88	2.30E-08	2.33E+04	2.25E+01

Pressure Fluctuation With Time in ONC#1 During January 1996

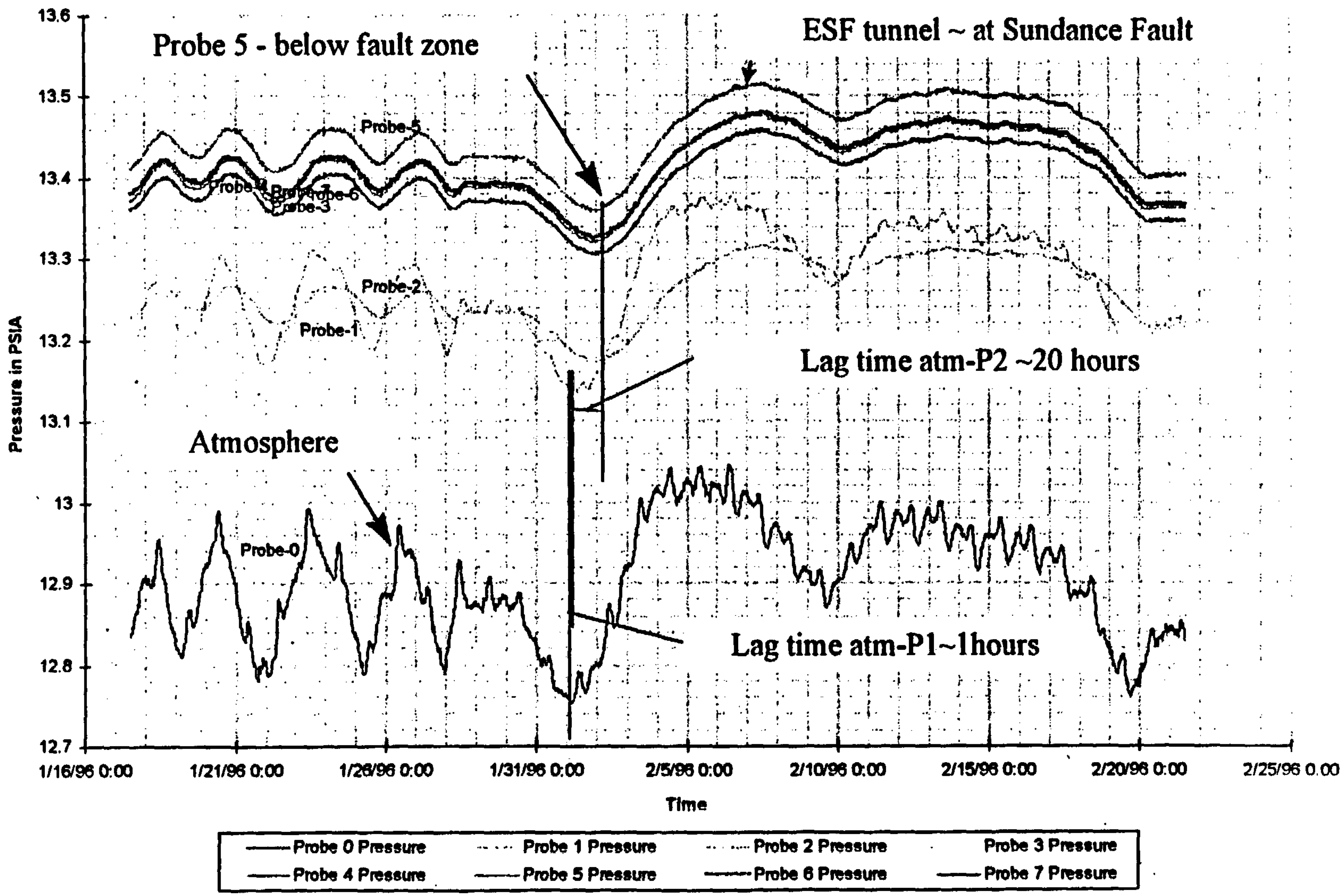


Figure 5-2

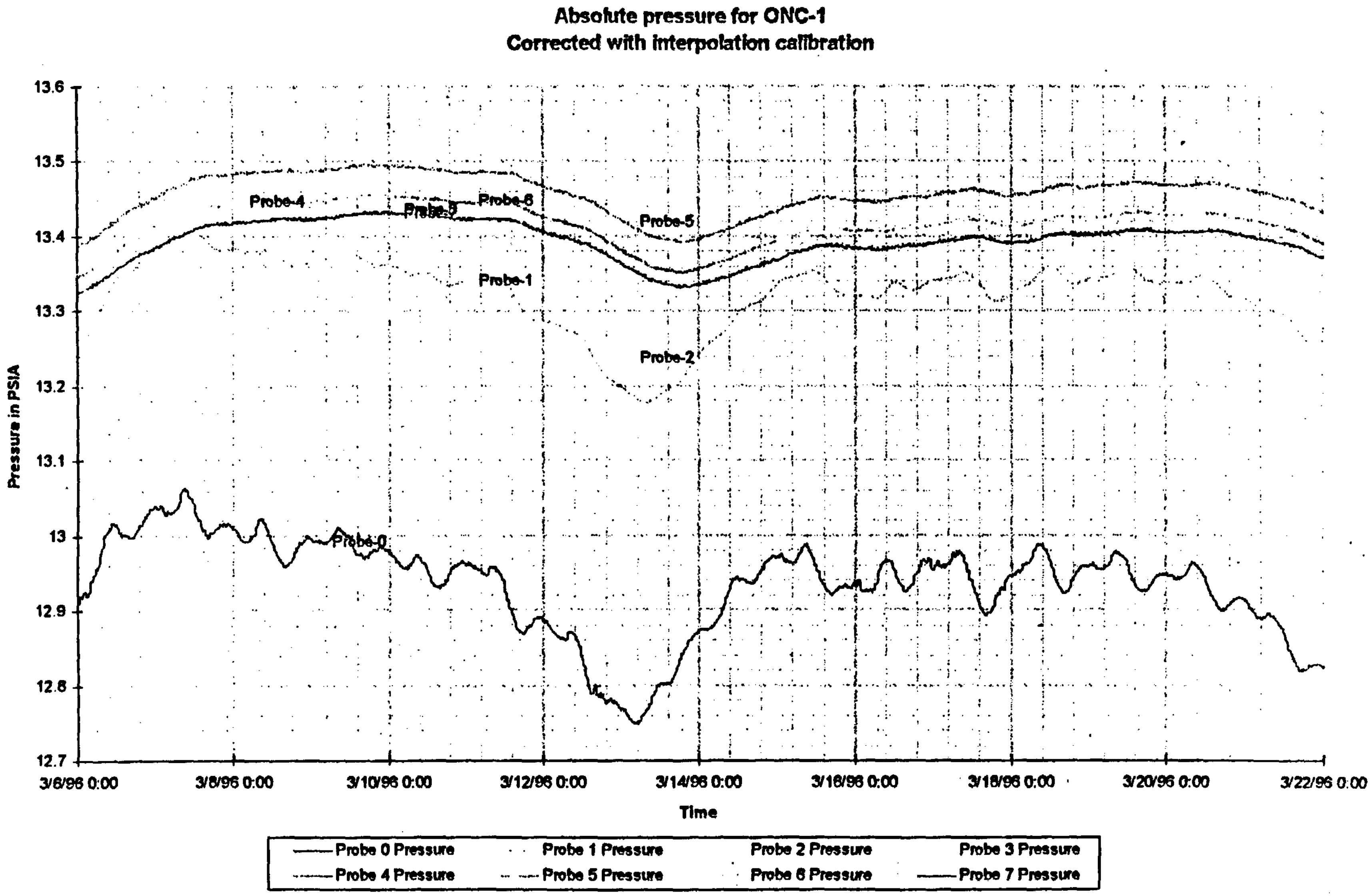


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Figure 5-3

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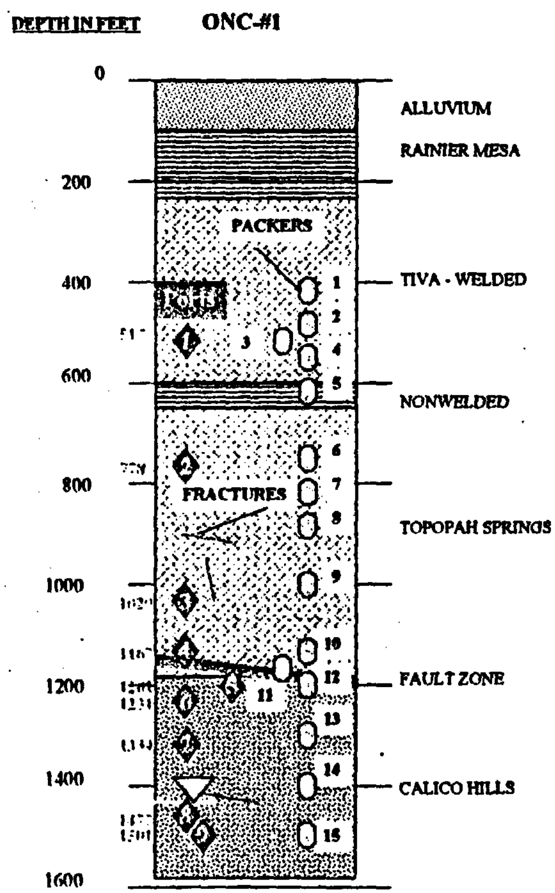
MODELED COLUMN FOR NYE COUNTY BOREHOLE ONC#1



Thickness in m	Rock Type	Depth feet tb	Depth in m tb	PERMEABILITY (m2)	PERMEABILITY (darcy)	Equivalent Conductivity cm/sec	Equivalent Porosity
2	atmos						
60.96	tiva1	200.00	60.96	5.00E-11	5.07E+01	4.90E-02	3.42E-01
60.96	tiva2	400.00	121.92	5.00E-11	5.07E+01	4.90E-02	1.00E-03
30.48	tiva3	500.00	152.40	5.00E-11	5.07E+01	4.90E-02	3.42E-02
30.48	tiva4	600.00	182.88	5.00E-13	5.07E-01	4.90E-04	3.42E-03
101.92	topo1	934.38	284.80	8.00E-10	8.11E+02	7.84E-01	3.00E-02
20	top11			8.00E-10	8.11E+02	7.84E-01	3.00E-02
30.48	topo2	1034.38	315.28	5.00E-10	5.07E+02	4.90E-01	3.00E-02
49.98	topo3	1198.36	365.26	1.00E-10	1.01E+02	9.80E-02	3.00E-02
Fault	[illegible]	1206.38	367.76	5.00E-09	5.07E+3	4.9E+00	1.00E-03
	[illegible]	[illegible]	367.76	[illegible]	5.07E+03	[illegible]	1.00E-03
10	cal01	1239.37	377.76	5.00E-09	5.07E+03	4.90E+00	4.92E-01
49.98	cal02	1403.35	427.74	5.00E-09	5.07E+03	4.90E+00	4.92E-01
25	pro01	1485.37	452.74	2.31E-08	2.35E+04	2.27E+01	4.92E-01
39.1	pro02	1613.65	491.84	2.31E-18	? Saturated	2.27E-09	4.92E-01
60.96	pro03	1813.65	552.80	2.31E-18	? Saturated	2.27E-09	4.92E-01
Sundance Fault in 3-D connection				8.00E-11	8.11E+01	7.84E-02	1.00E-05

Prepared for:
Nye County Waste Repository Project Office

Figure 5-4

Prepared by:
Multimedia Environmental Technology, Inc.
Newport Beach, CA

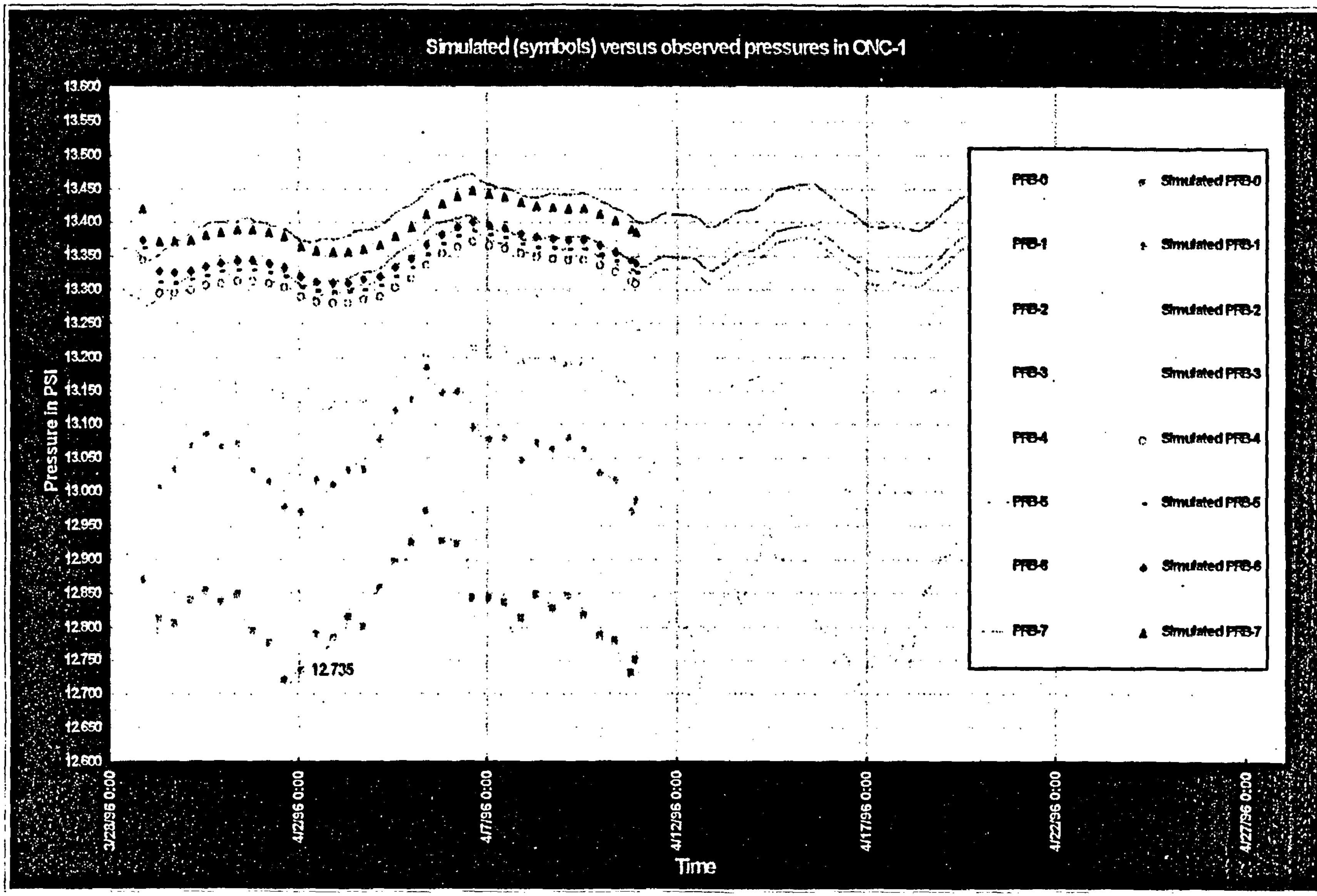


Figure 5- 5 Comparison of the simulated and observed barometric pressure responses in ONC #1 borehole using one-dimensional vertical column of nodes in April 1996

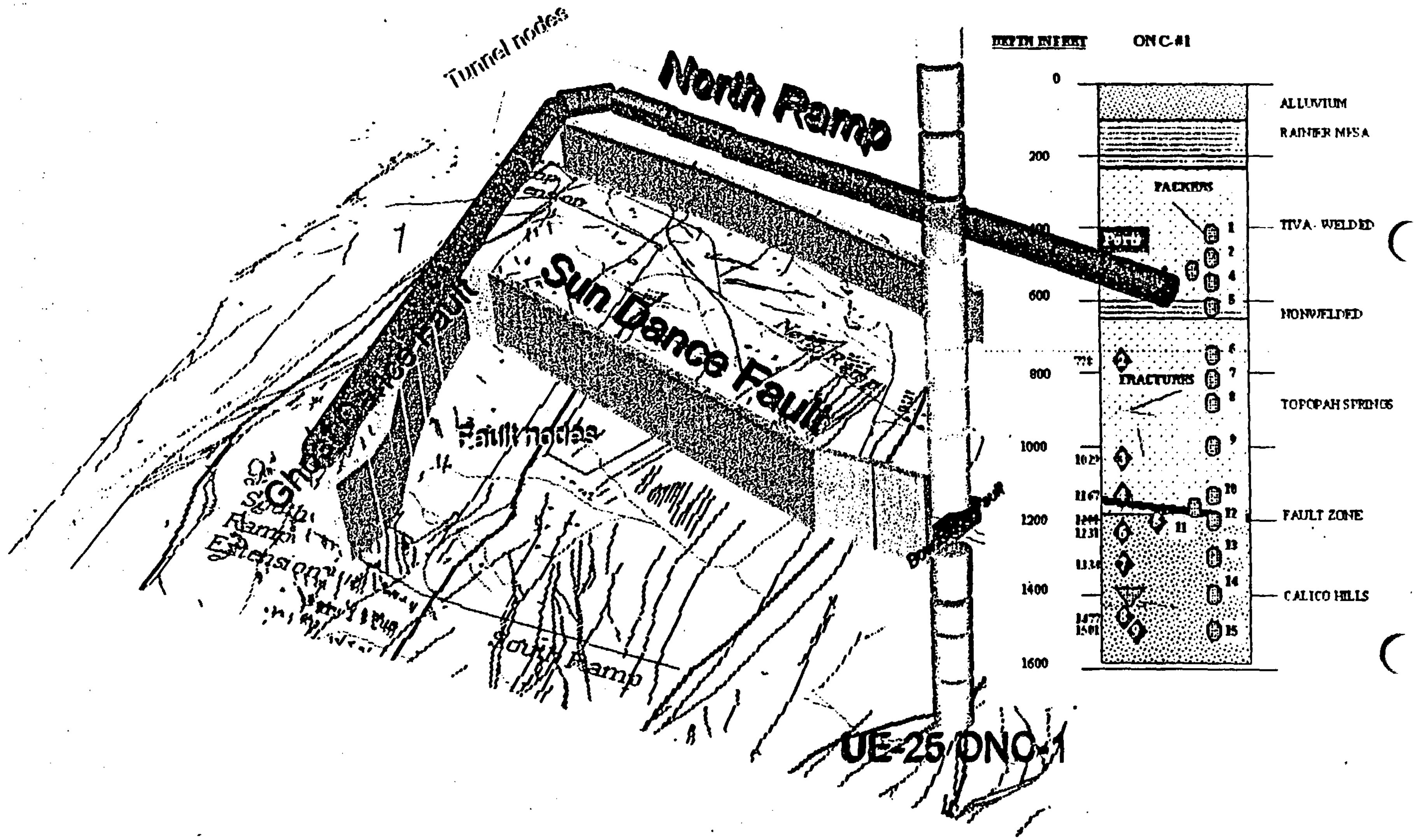


Figure 5-6 Detail of UE-25 ONC#1

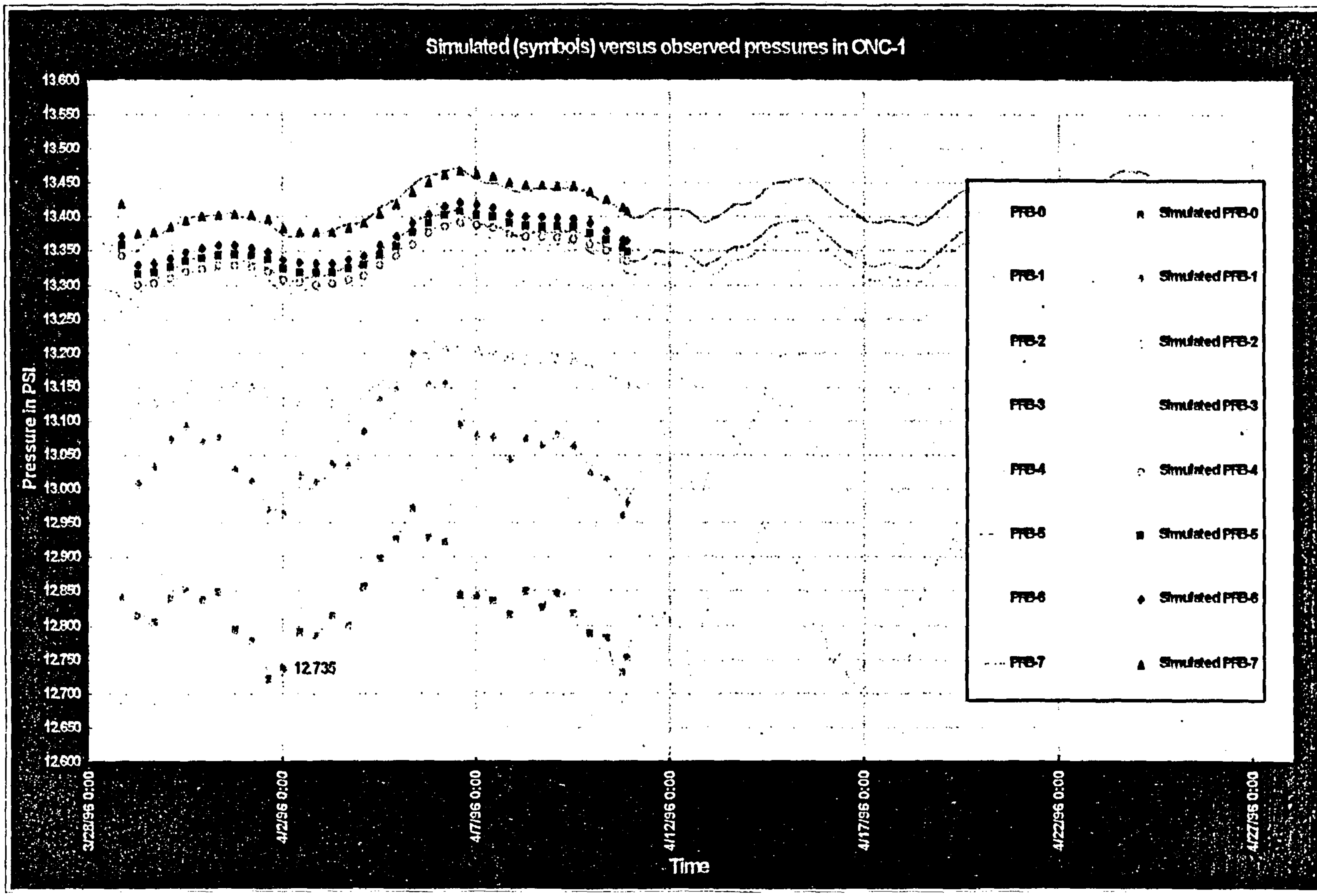


Figure 5-7 Comparison of the simulated and observed barometric pressure responses in ONC #1 borehole using tunnel and a one-dimensional mesh for April 1996.

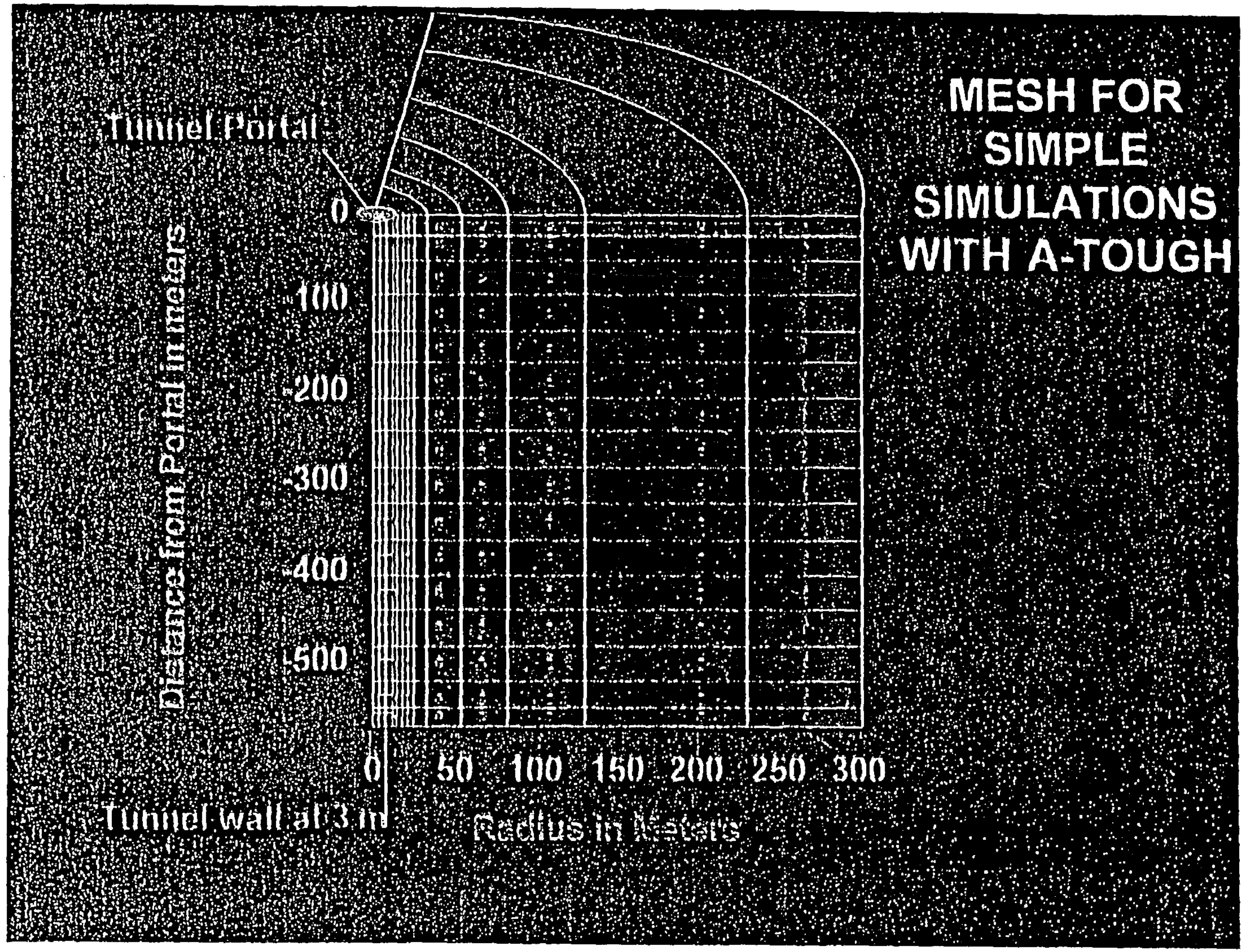


Figure 6-1 - Plan view of the axi-symetric mesh used for simulations of tunnel ventilation.

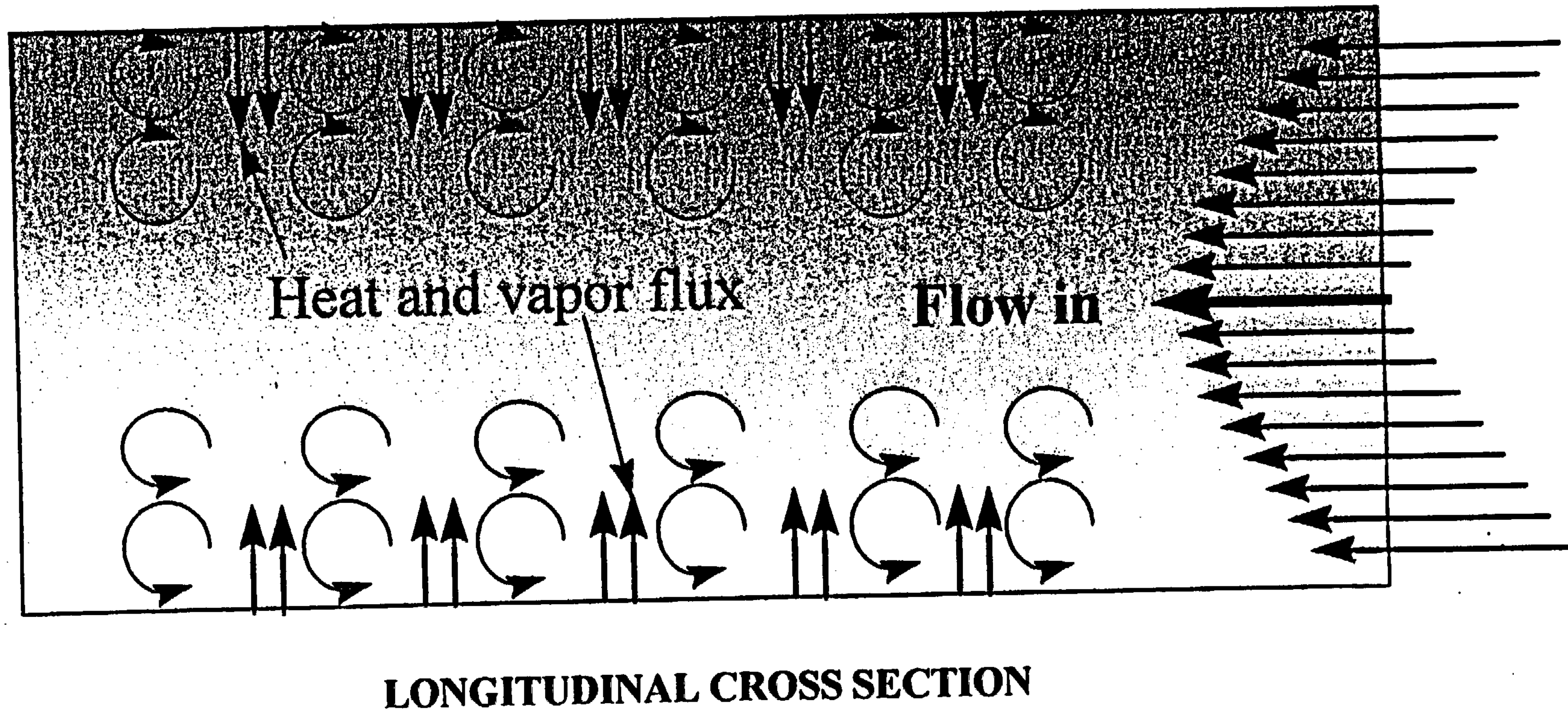


Figure 6-2 Schematic diagram of flow through a tunnel (eddy diffusivity concept)

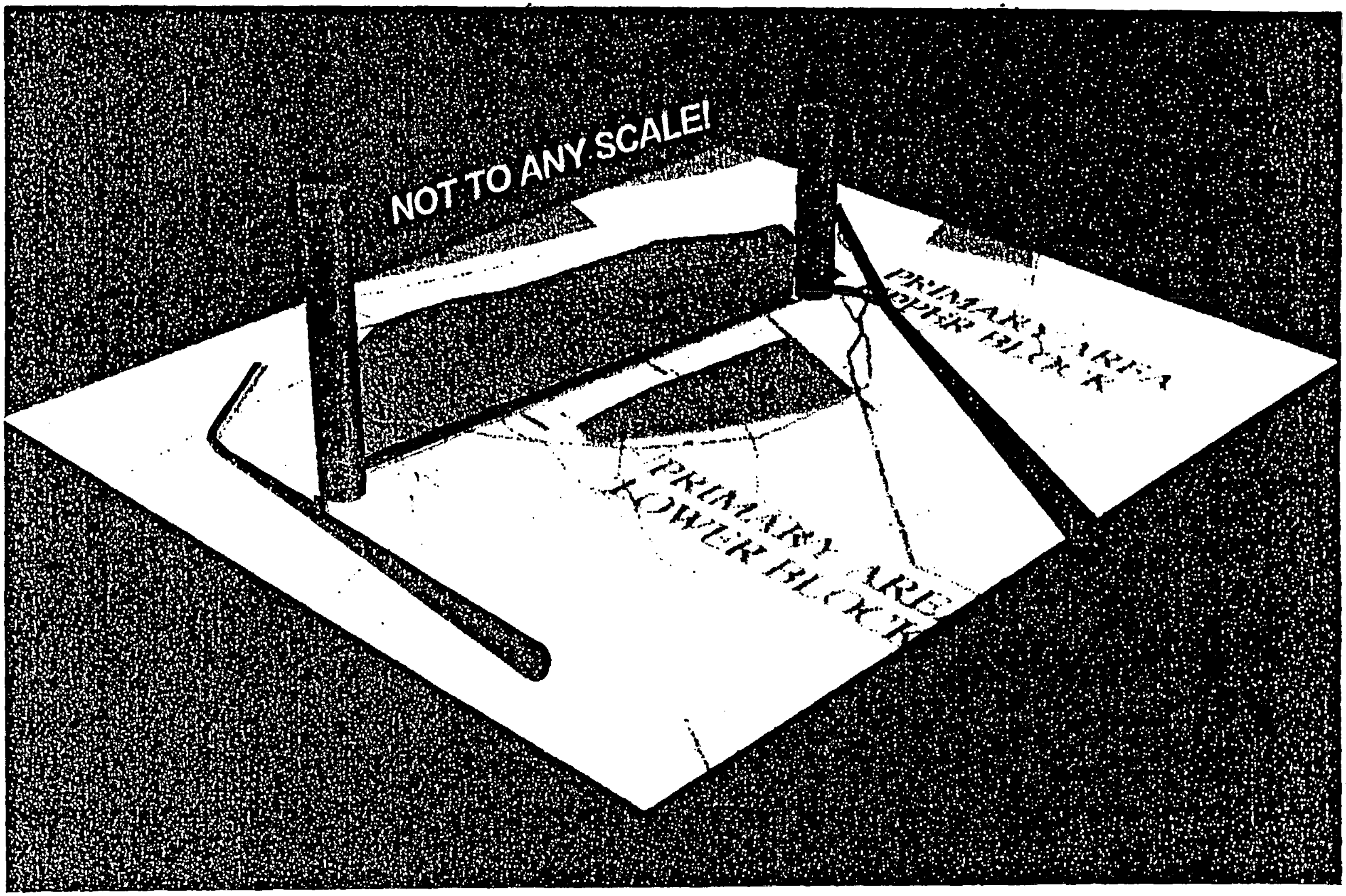


Figure 6-3 - Conceptual model of ventilation shafts relative to the ESF tunnel.

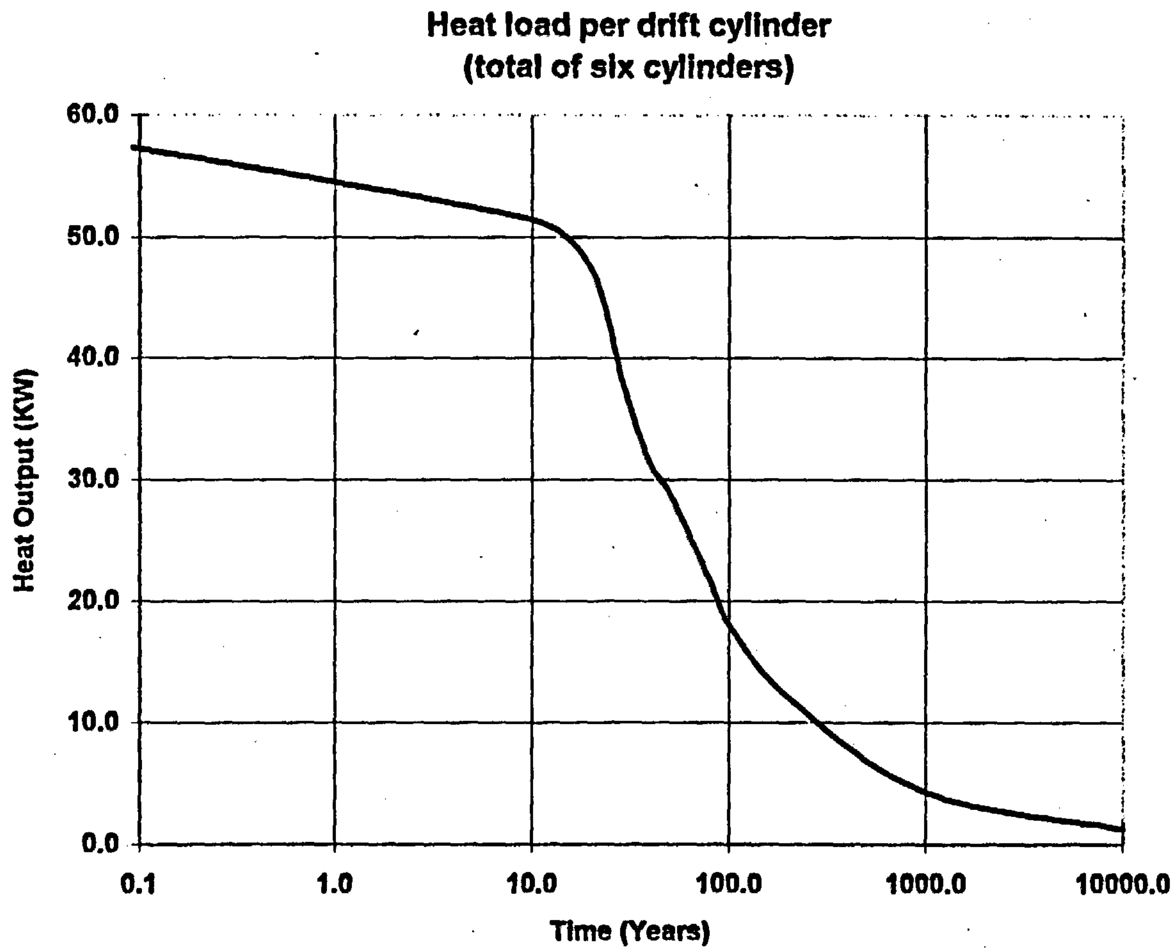
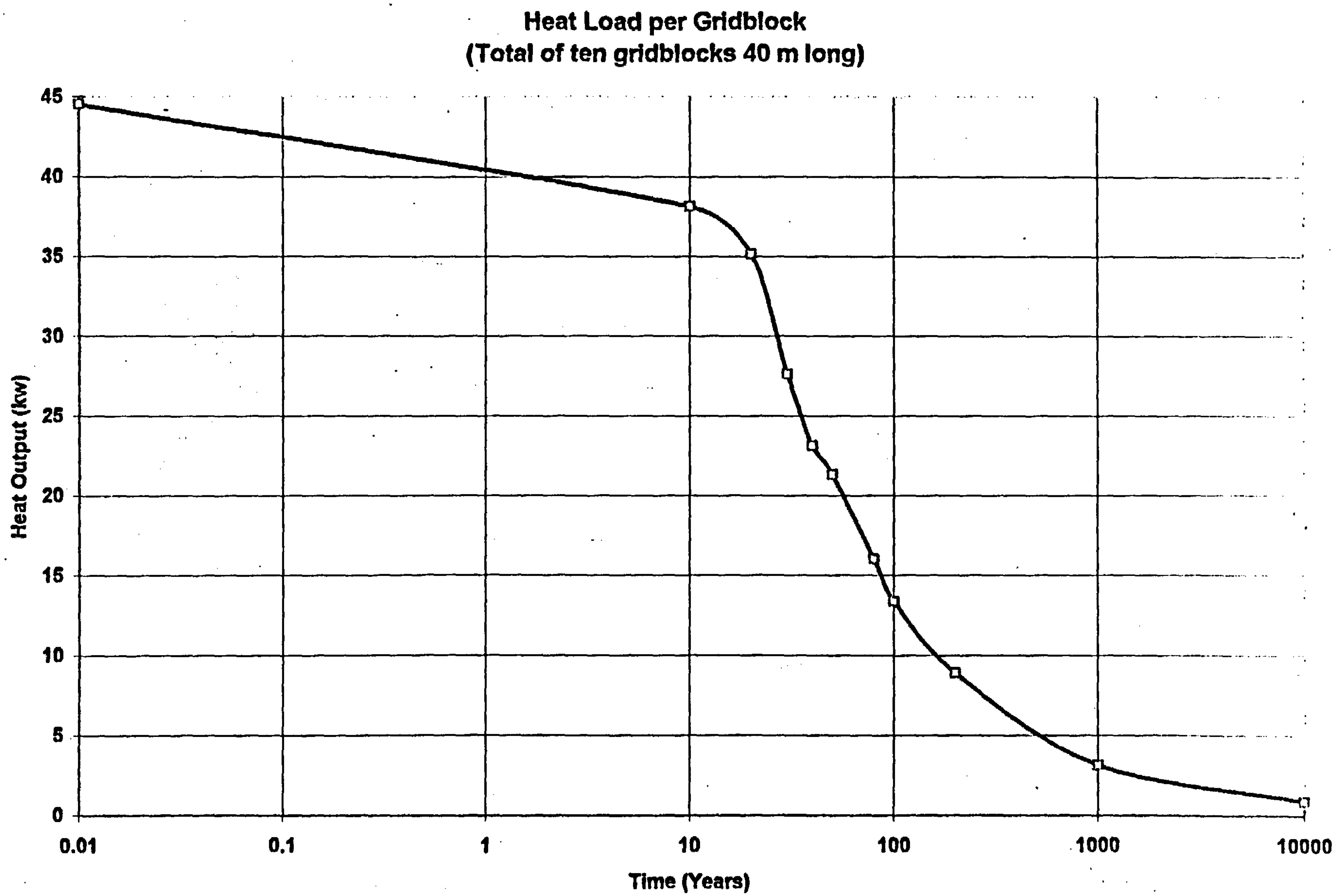

Heat load per drift cylinder
(total of six cylinders)
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Heat Output (KW)
0.1
1.0
10.0
100.0
1000.0
10000.0
Time (Years)

Figure 6-4



Heat Load per Gridblock
(Total of ten gridblocks 40 m long)
45
40
35
30
25
20
15
10
5
0
Heat Output (kw)
0.01
0.1
1
10
100
1000
10000
Time (Years)

Figure 6-5

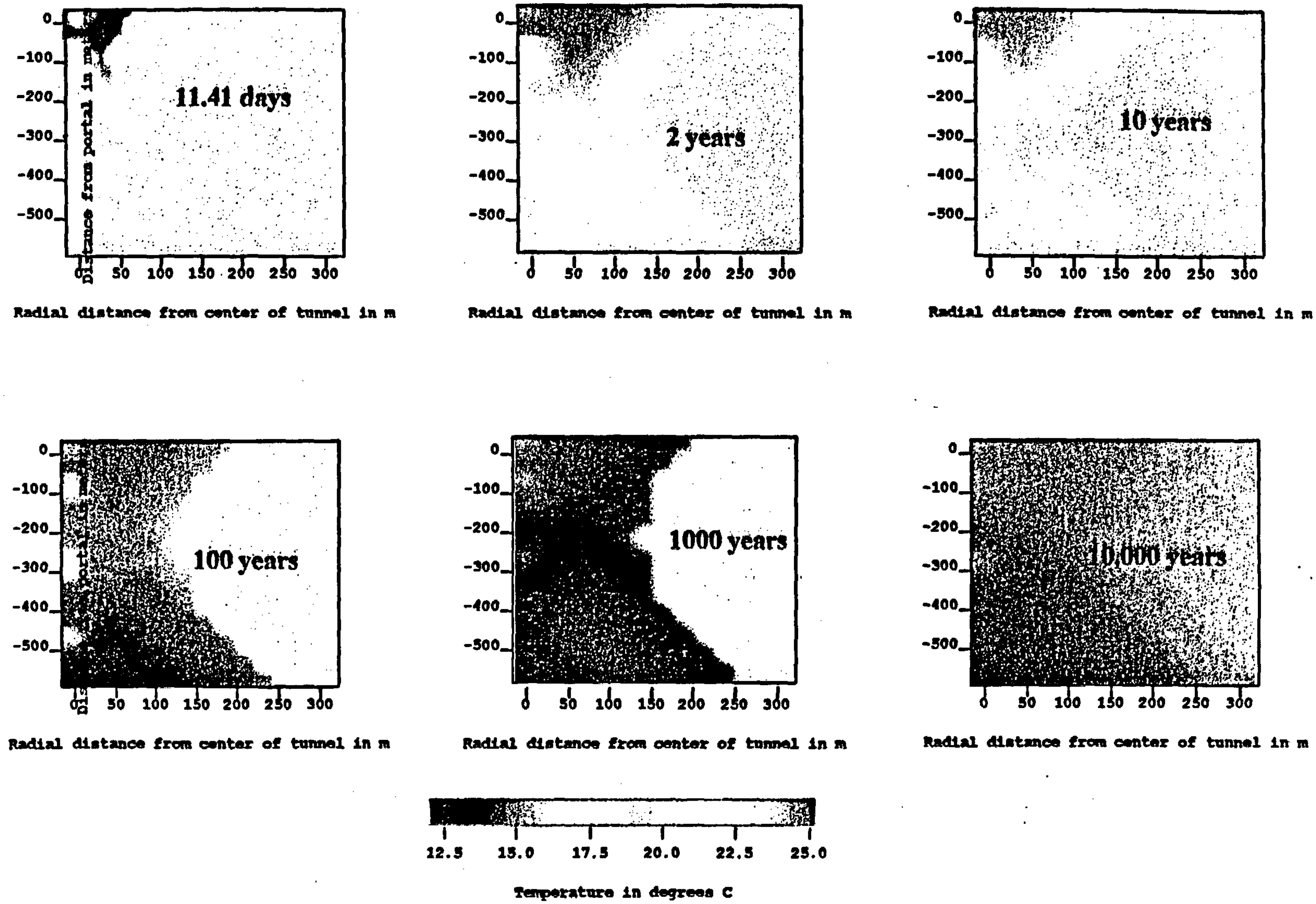


Figure 6-6 - Simulated temperature around the tunnel for various times. Case 10, with decaying heat load. Eddy diffusivity = 0.01, atmosphere temperature = 15 °C.

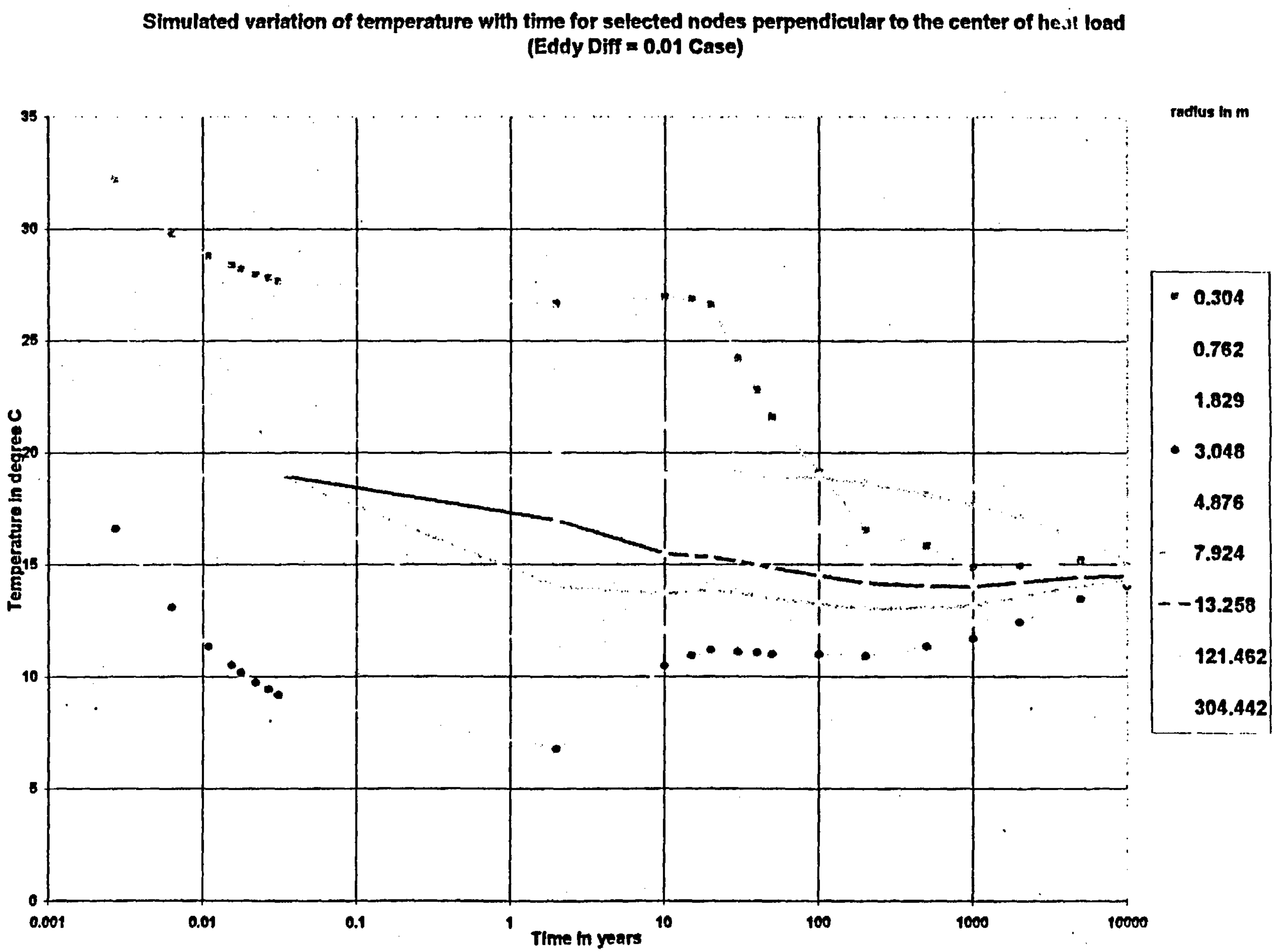


Figure 6-7 Case 10

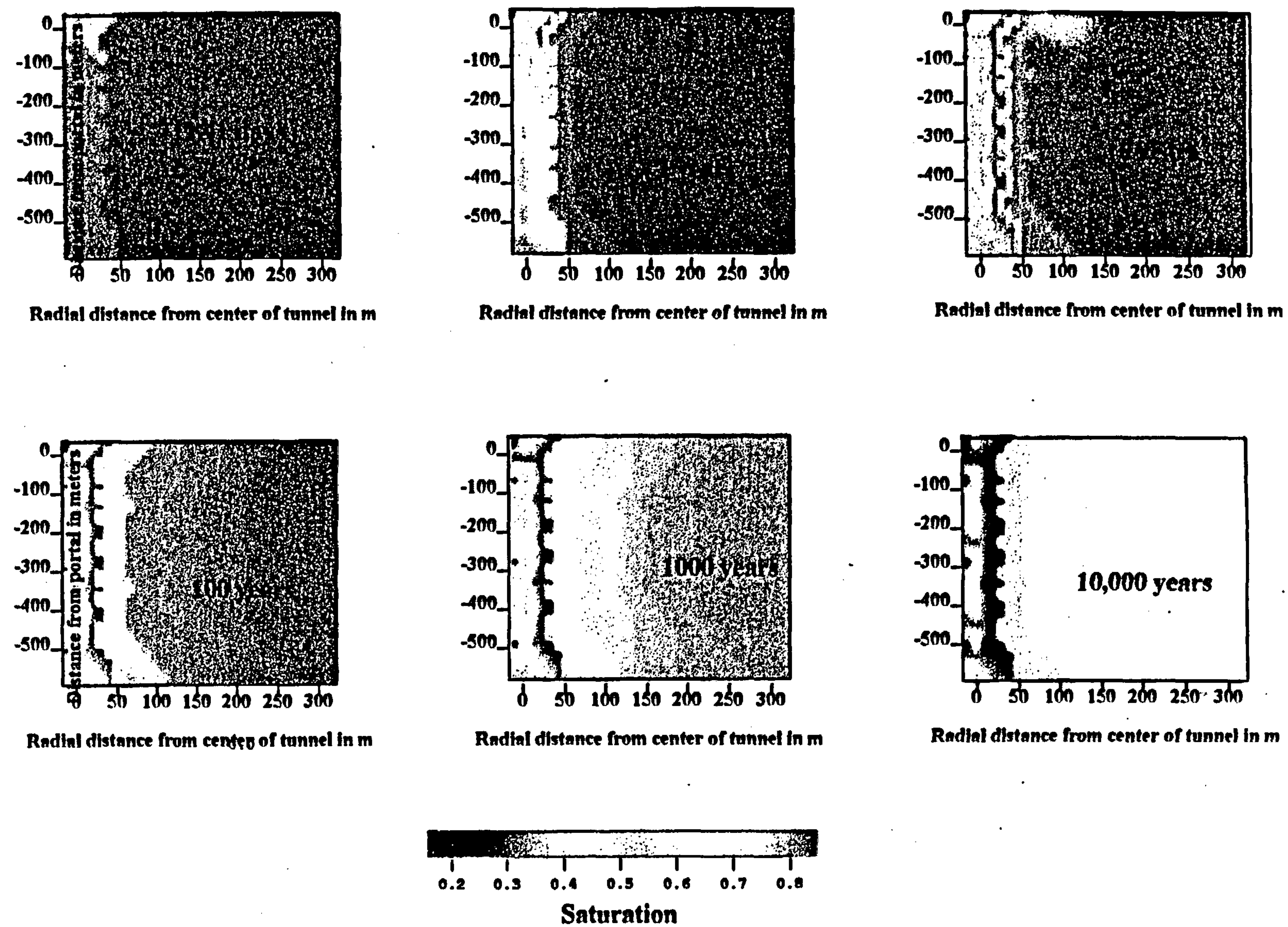


Figure 6-8 - Simulated saturation around the tunnel for various times. Case 10, with decaying heat load. Eddy diffusivity = 0.01, atmosphere temperature = 15 °C.

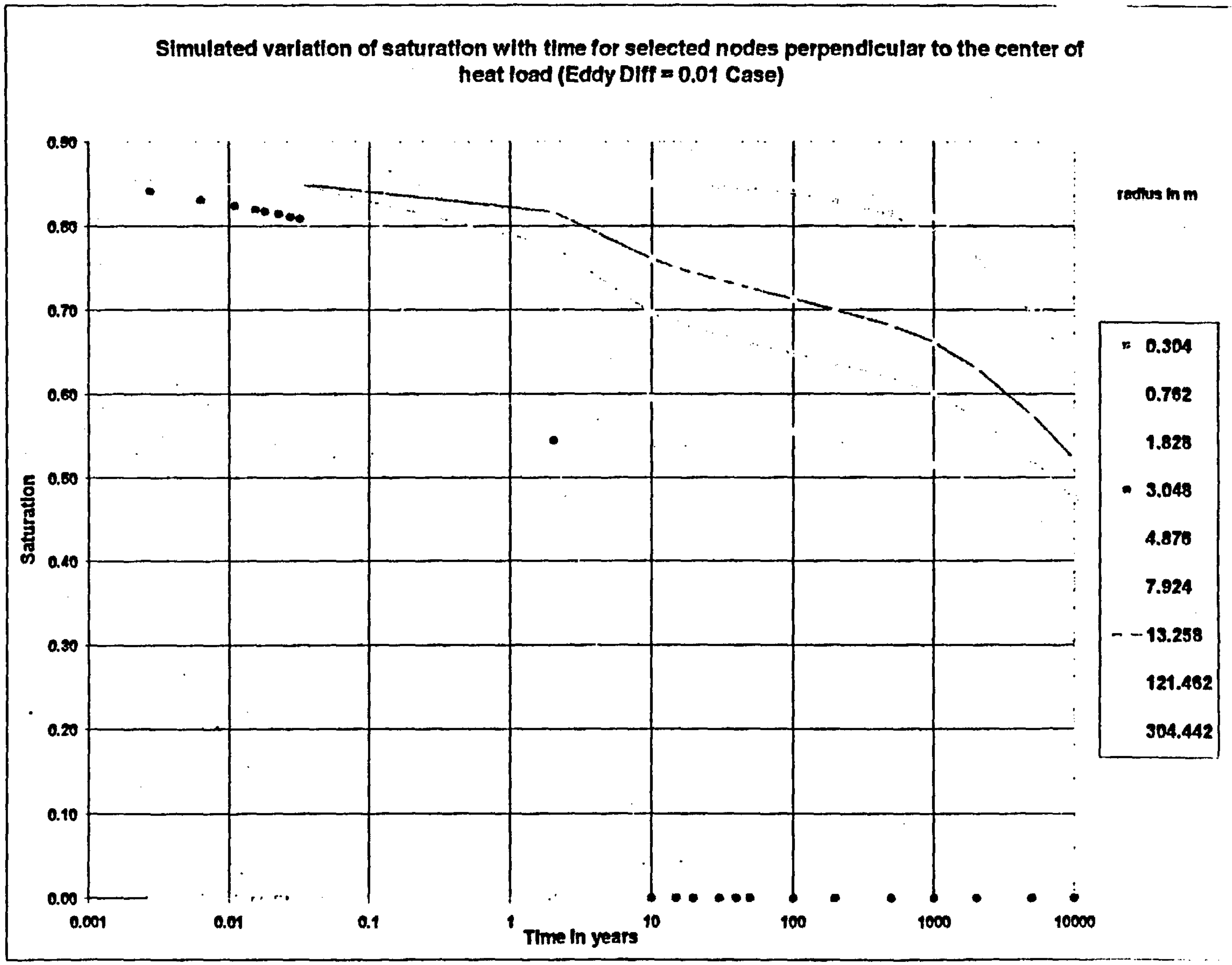


Figure 6-9 Case 10

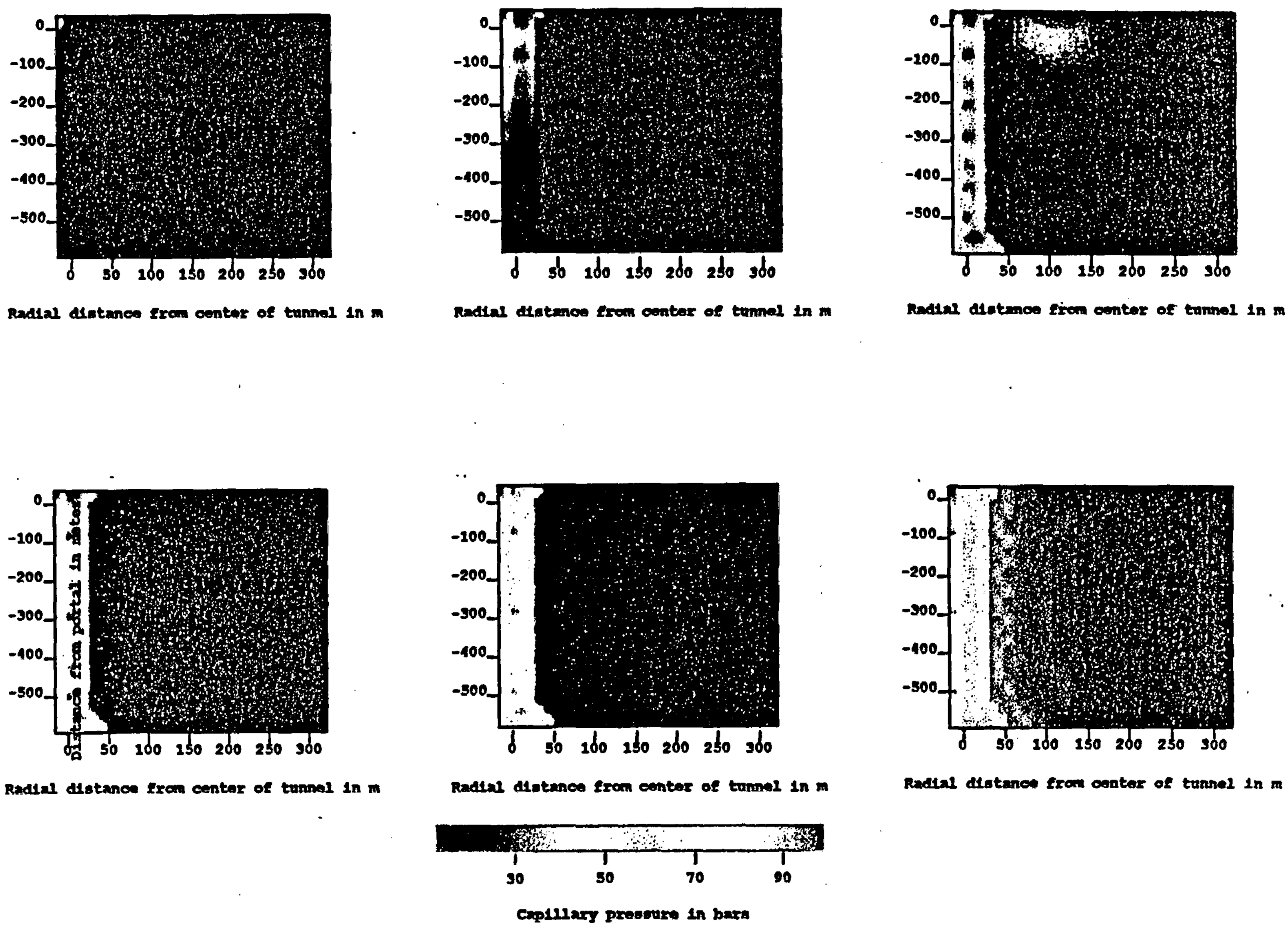


Figure 6-10 - Simulated capillary pressure around the tunnel for various times. Case 10, with decaying heat load. Eddy diffusivity = 0.01, atmosphere temperature = 15 °C. Note: scale changes among graphs.