NYE COUNTY TECHNICAL PROGRAM

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On Site Representative

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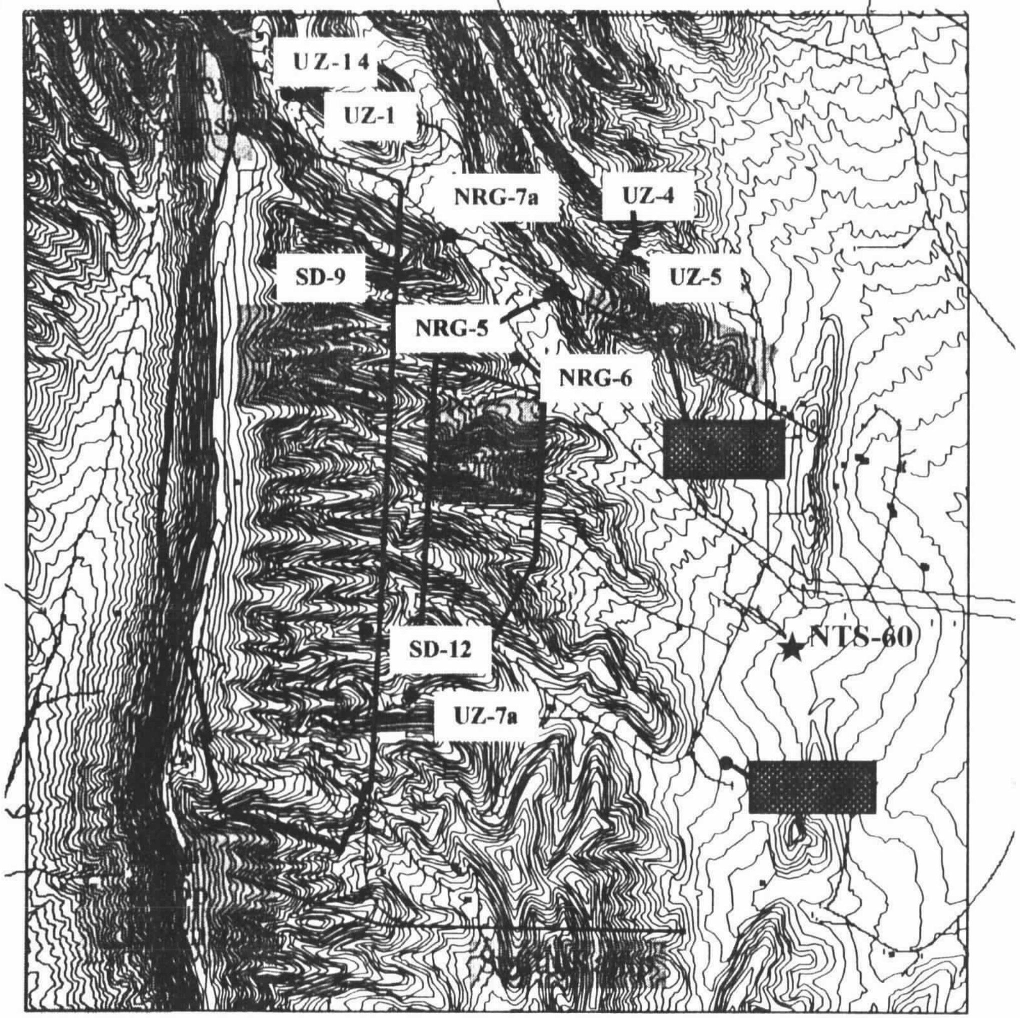
January 29, 1997

SIMULATIONS AND OBSERVATIONS AT YUCCA MOUNTAIN
NYE COUNTY
SCIENTIFIC OVERSIGHT PROGRAM , YUCCA MOUNTAIN, NEVADA



EXPLANATION

Exploratory Studies Facility

UZ-14 Borehole location

Other borehole s

Roads

20-ft contour line

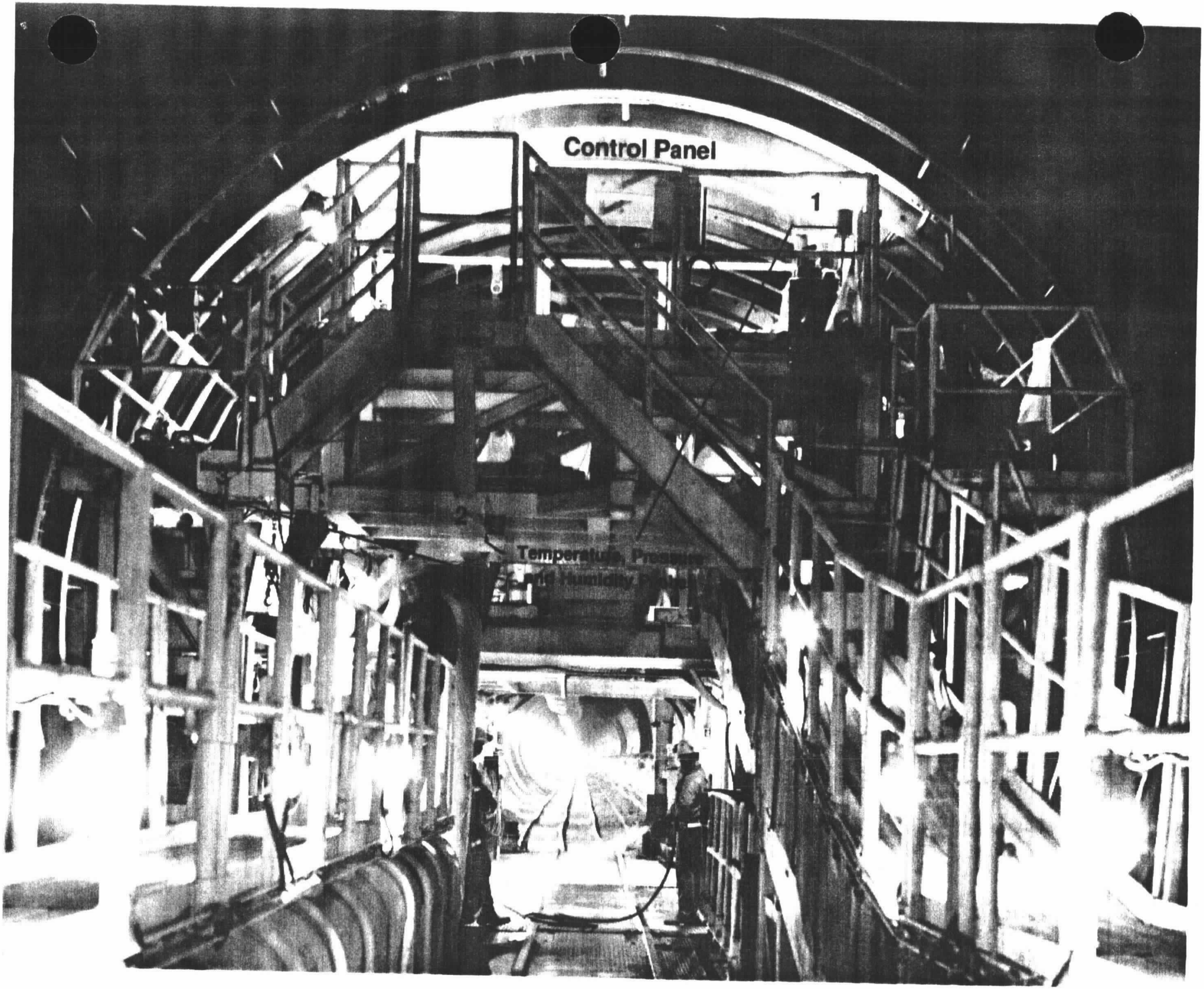
★ Meteorological station

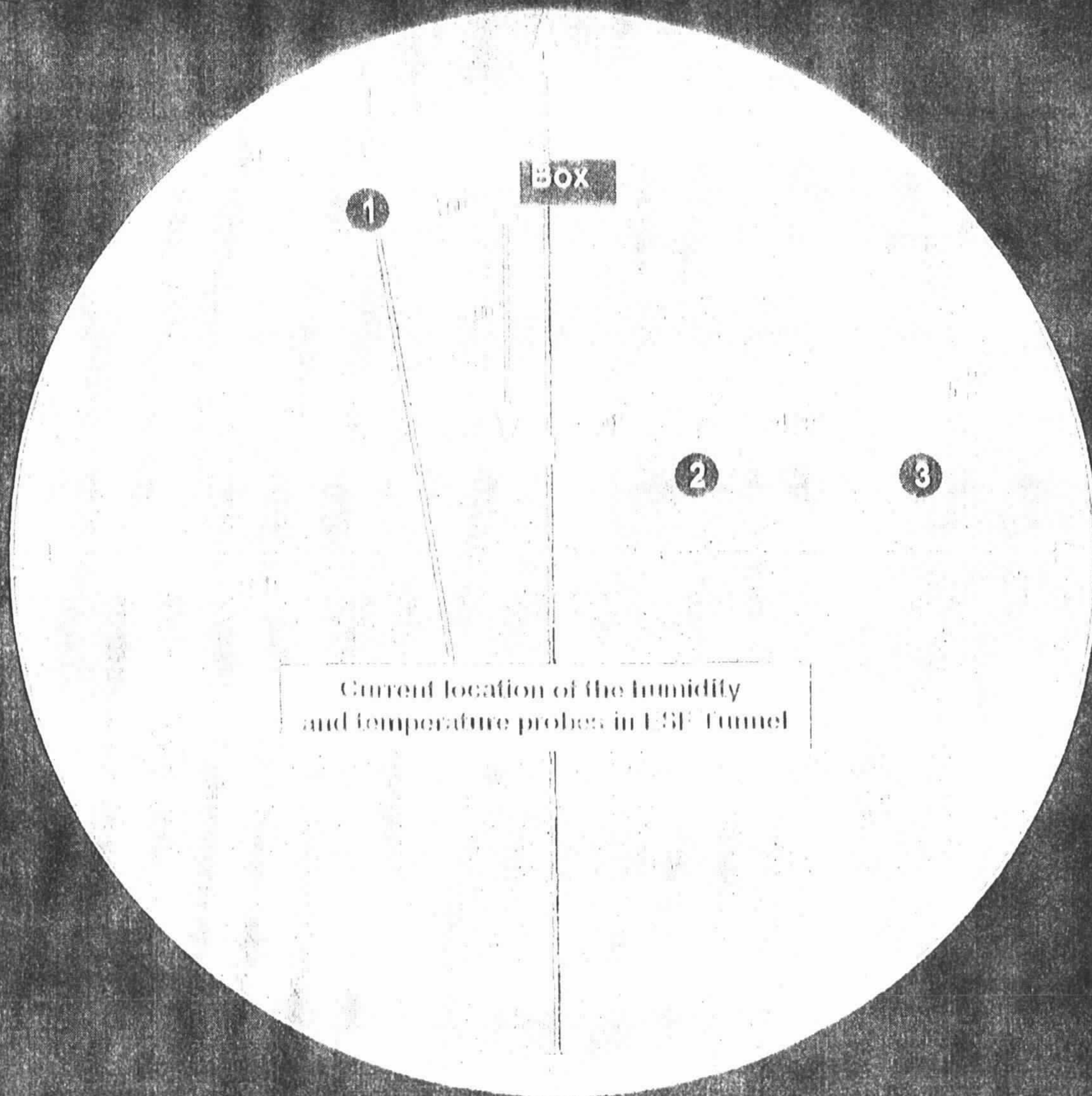
0 2000 4000 6000 8000 10,000

SCALE Feet

ESF INSTRUMENTATION

- TO EVALUATE THE POTENTIAL FOR MOISTURE REMOVAL BY VENTILATION
- TO EVALUATE IF ESF VENTILATION CAN BE USED TO ESTIMATE LARGE-SCALE ROCK PROPERTIES
- TO EVALUATE POTENTIAL ALTERNATIVE REPOSITORY DESIGNS
- TO OBTAIN REAL-TIME DATA FOR SIMULATIONS NEEDED FOR ABOVE OBJECTIVES

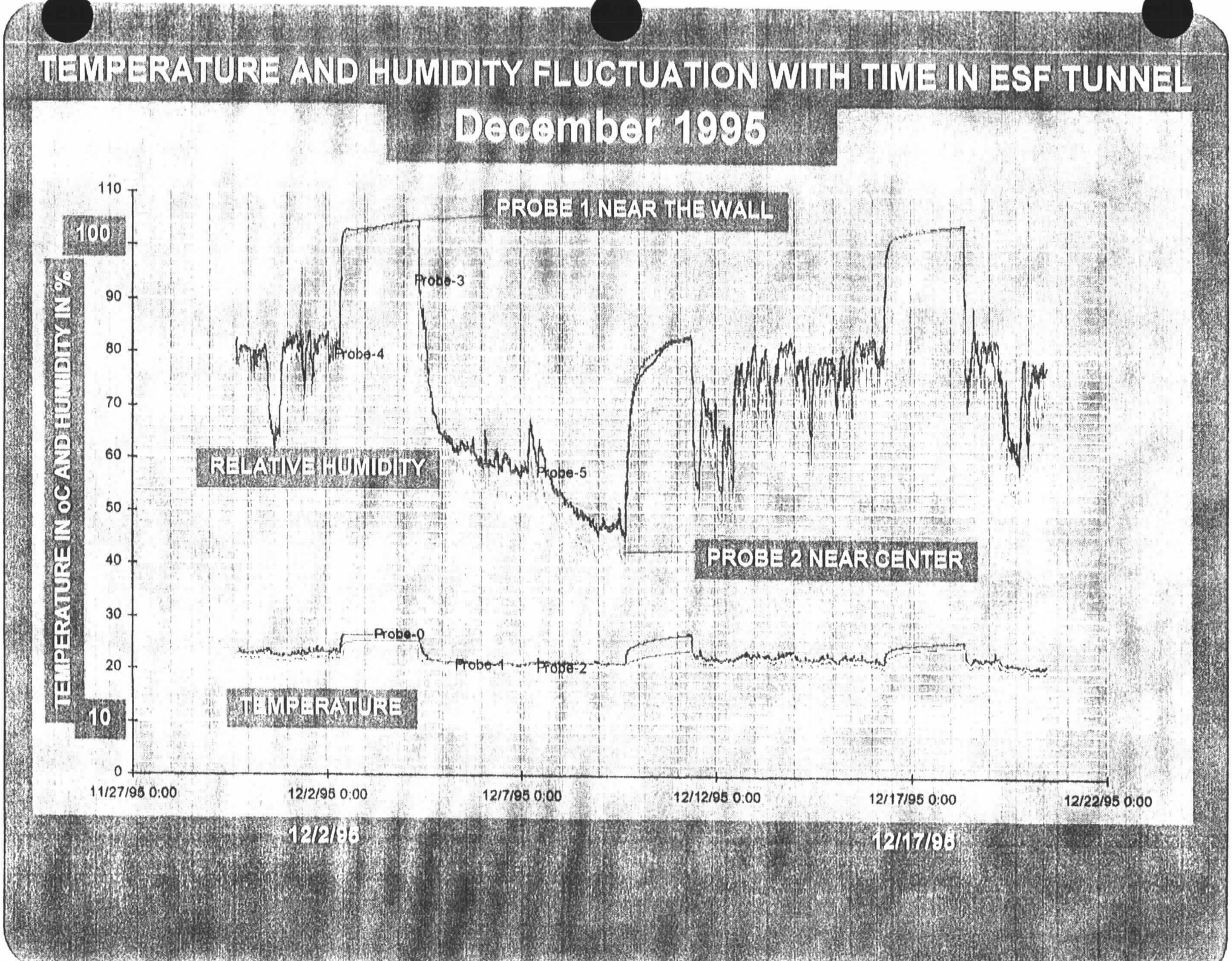

Control Panel
1
2
Temperature, Pressure
and Humidity Panel



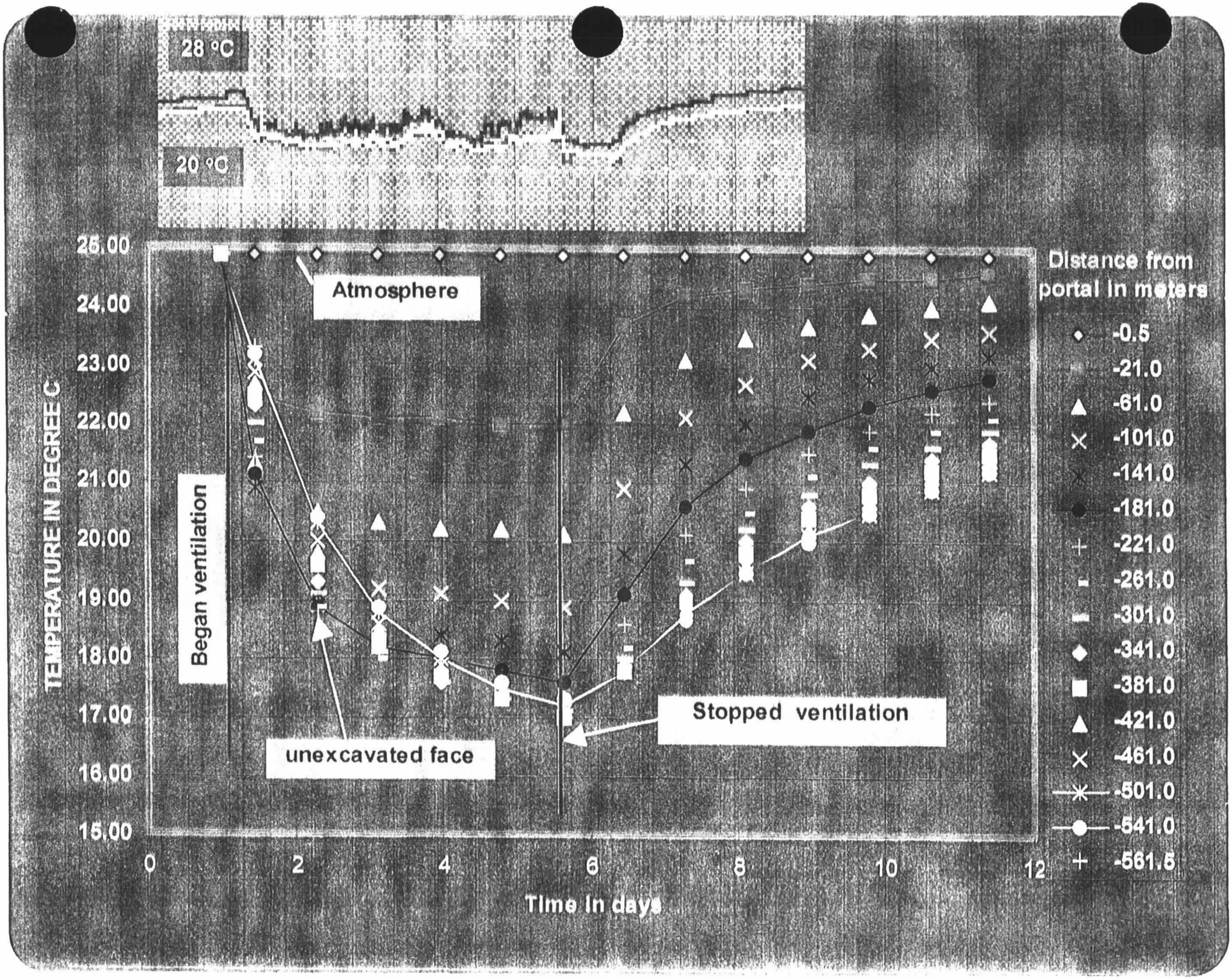
April, 96

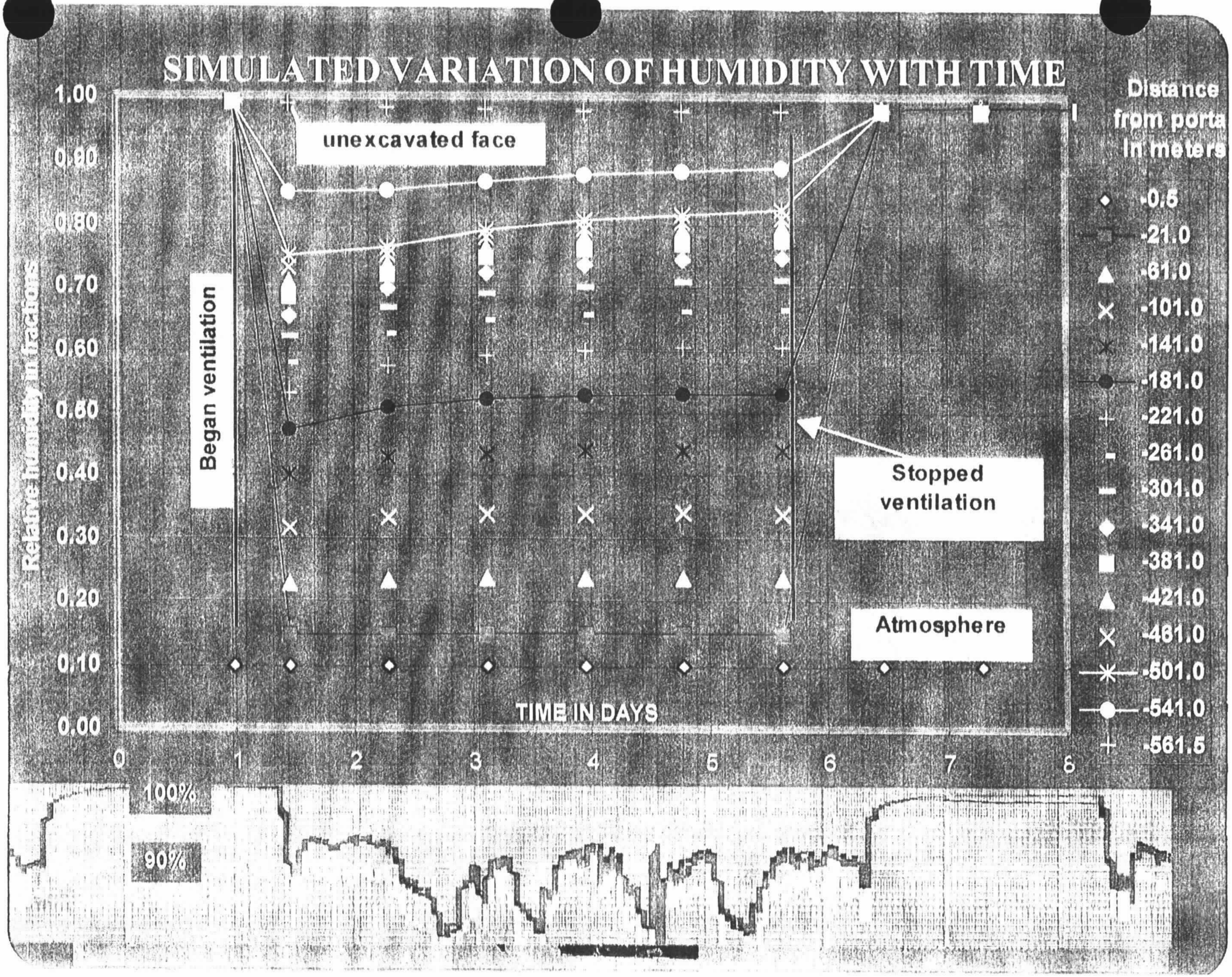
NYE COUNTY

Prepared by:

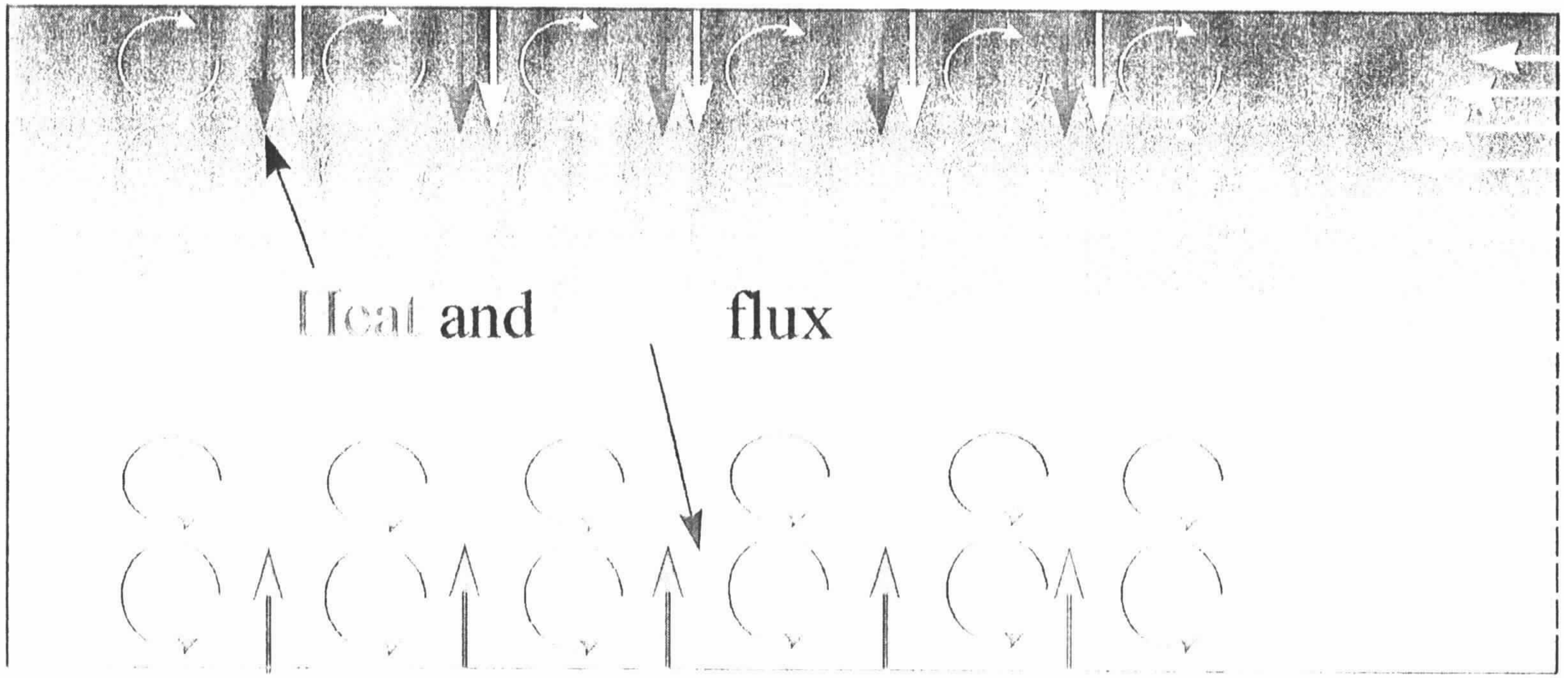


TEMPERATURE AND HUMIDITY FLUCTUATION WITH TIME IN ESF TUNNEL
December 1995
PROBE 1 NEAR THE WALL
PROBE 2 NEAR CENTER
RELATIVE HUMIDITY
TEMPERATURE
TEMPERATURE IN oC AND HUMIDITY IN %
Probe-0
Probe-1
Probe-2
Probe-3
Probe-4
Probe-5
0
10
20
30
40
50
60
70
80
90
100
110
11/27/95 0:00
12/2/95 0:00
12/7/95 0:00
12/12/95 0:00
12/17/95 0:00
12/22/95 0:00
12/2/95
12/17/95


28 °C
20 °C
25.00
24.00
23.00
22.00
21.00
20.00
19.00
18.00
17.00
16.00
15.00
TEMPERATURE IN DEGREE C
0
2
4
6
8
10
12
Time in days
Atmosphere
Began ventilation
unexcavated face
Stopped ventilation
Distance from portal in meters
-0.5
-21.0
-61.0
-101.0
-141.0
-181.0
-221.0
-261.0
-301.0
-341.0
-381.0
-421.0
-461.0
-501.0
-541.0
-561.5

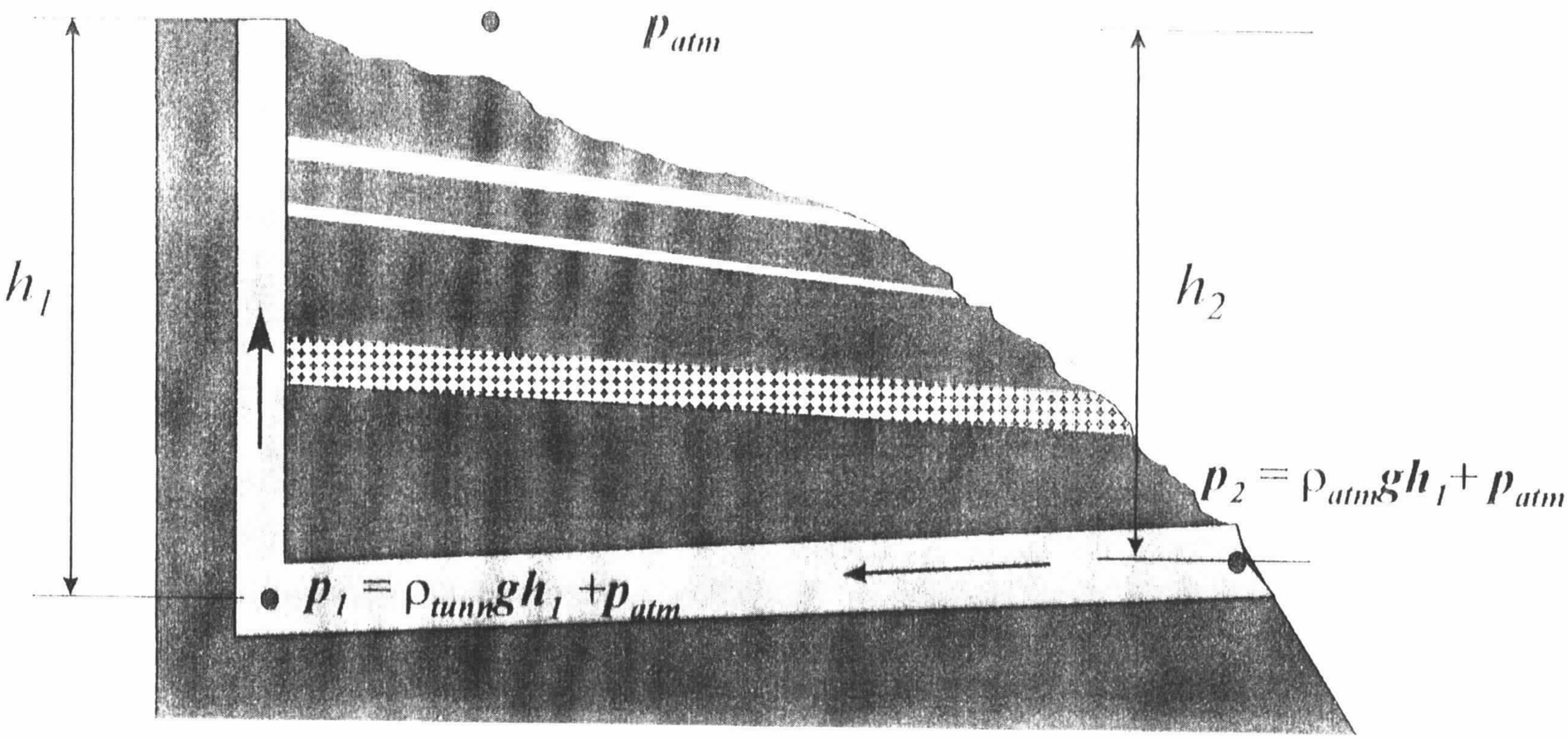


SIMULATED VARIATION OF HUMIDITY WITH TIME
Relative humidity in fractions
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
unexcavated face
Began ventilation
Stopped ventilation
Atmosphere
TIME IN DAYS
0
1
2
3
4
5
6
7
8
Distance from porta in meters
-0.5
-21.0
-61.0
-101.0
-141.0
-181.0
-221.0
-261.0
-301.0
-341.0
-381.0
-421.0
-461.0
-501.0
-541.0
-561.5
100%
90%

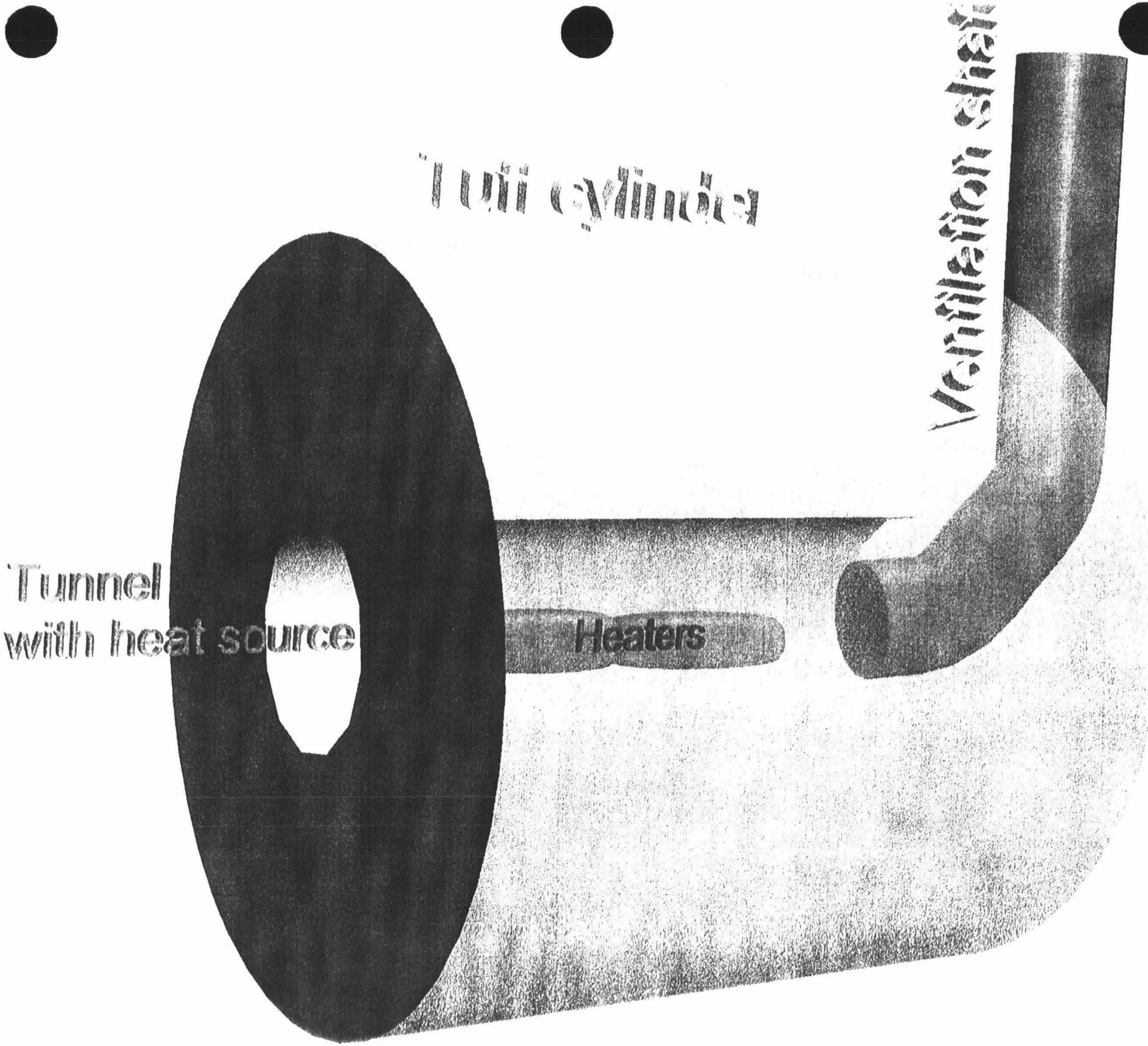


LONGITUDINAL CROSS SECTION

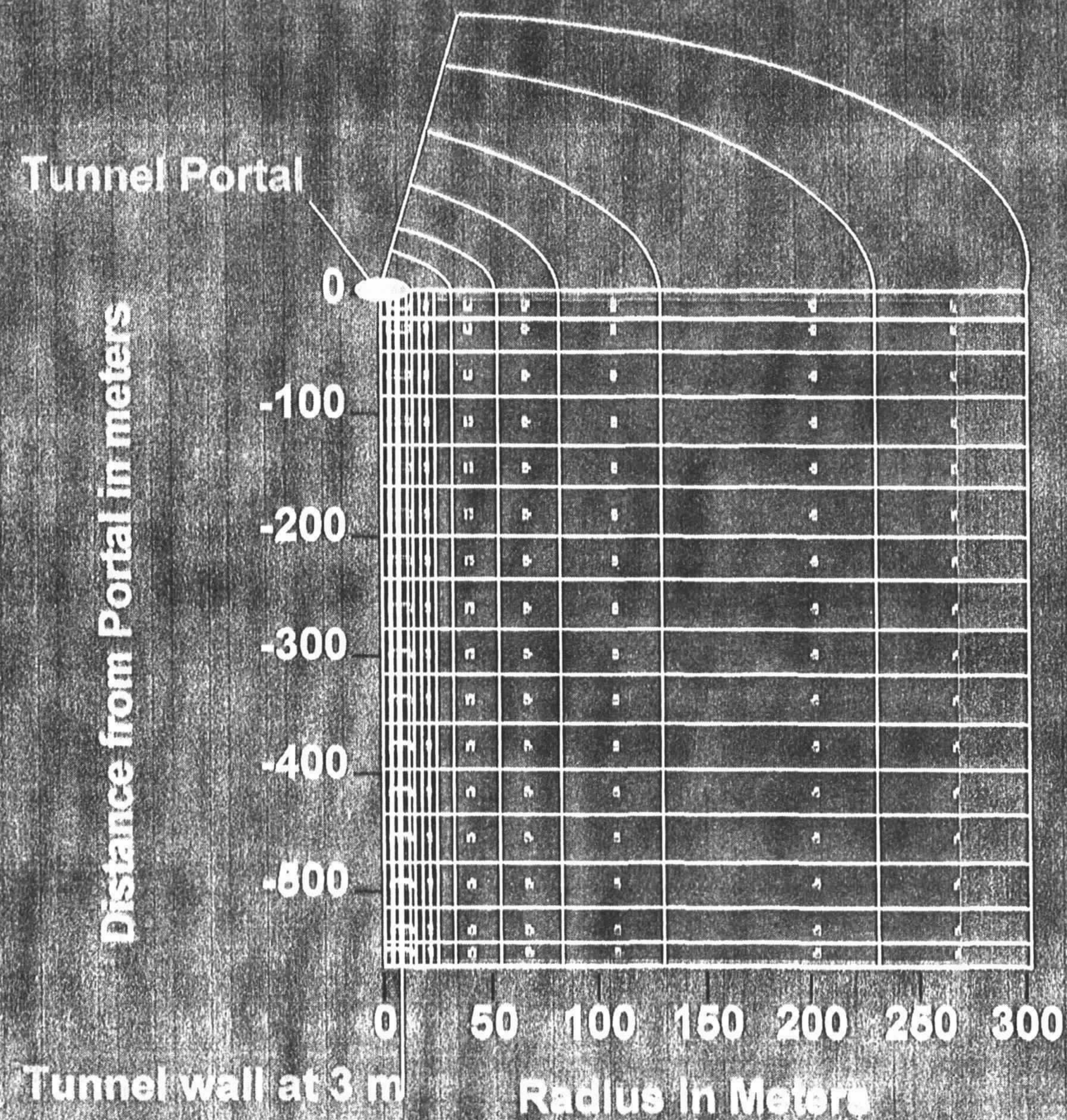
Figure 6-32 - Schematic diagram of flow through a tunnel (eddy diffusivity concept).



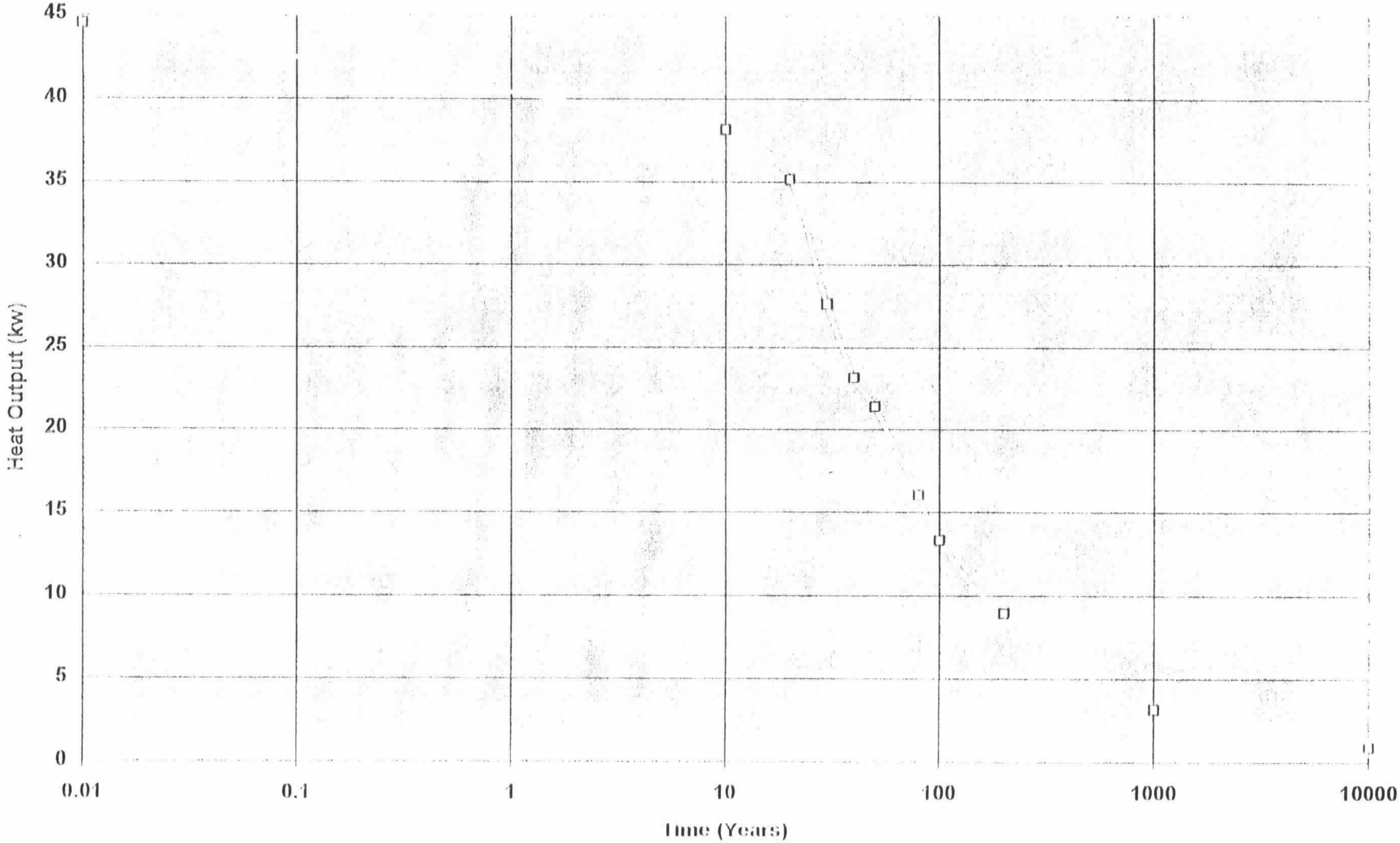
CONCEPTUALIZATION OF NATURAL VENTILATION


Tuff cylinde
Ventilation shaf
Tunnel
with heat source
Heaters

MESH FOR SIMPLE SIMULATIONS WITH A-TOUGH



Heat Load per Gridblock
(Total of ten gridblocks 40 m long)



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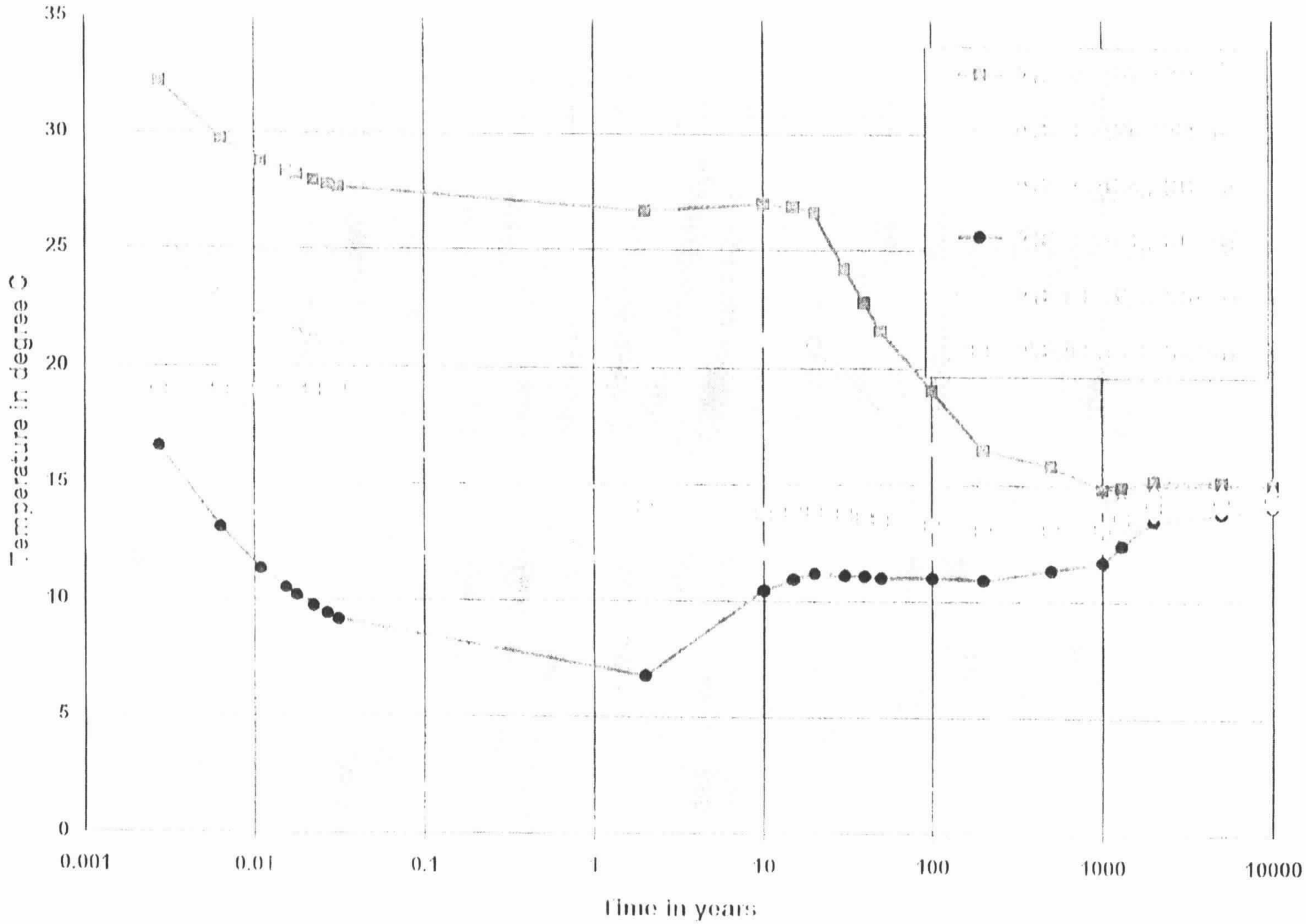
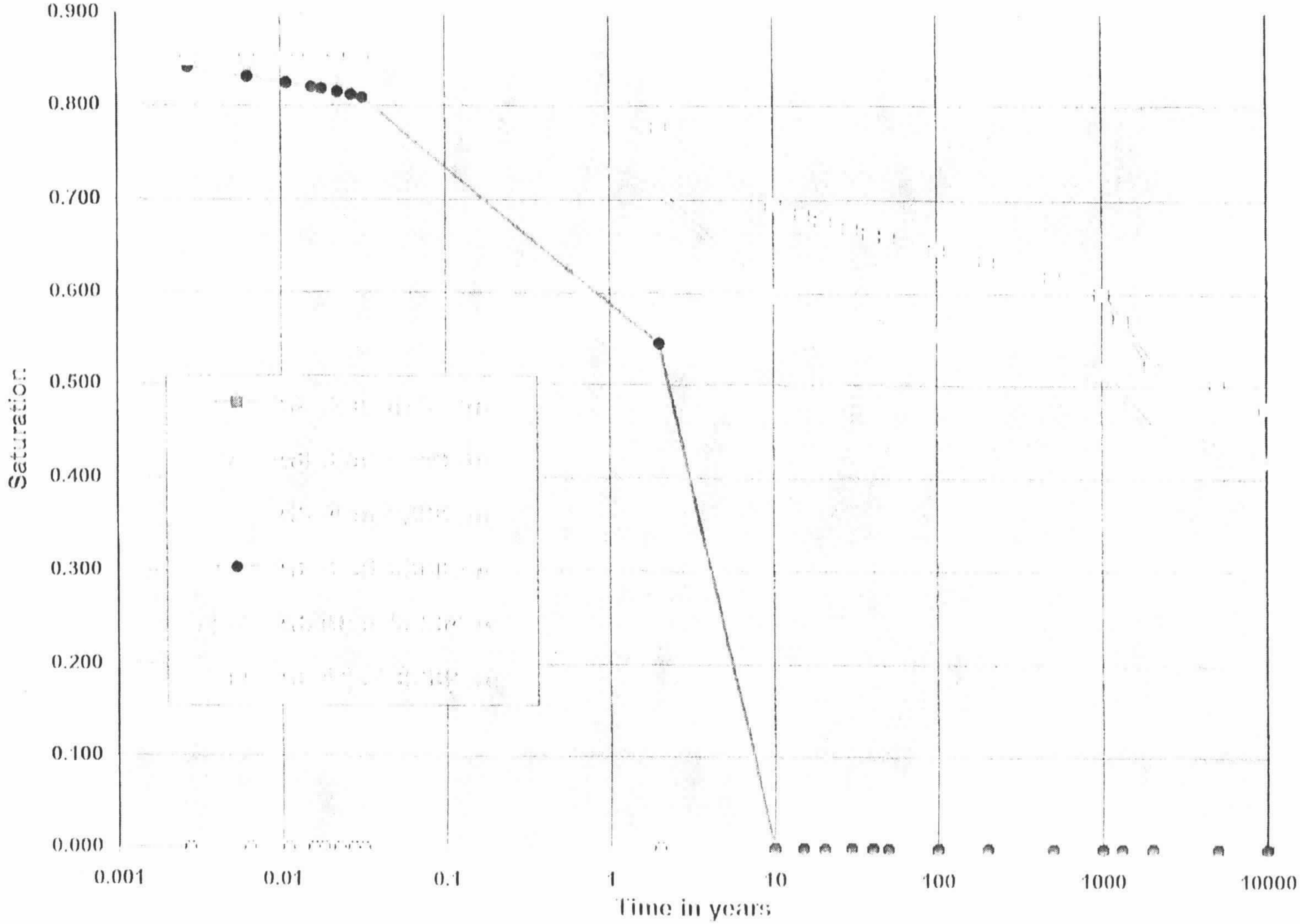
Nye County Nuclear Waste Repository Project Office

Simulated varation of temperature with time for selected nodes perpendicular to the center of heat load (Eddy Diff = 0.01 Case)



Simulated varation of saturation with time for selected nodes perpendicular to the center of heat load (Eddy Diff = 0.01 Case)



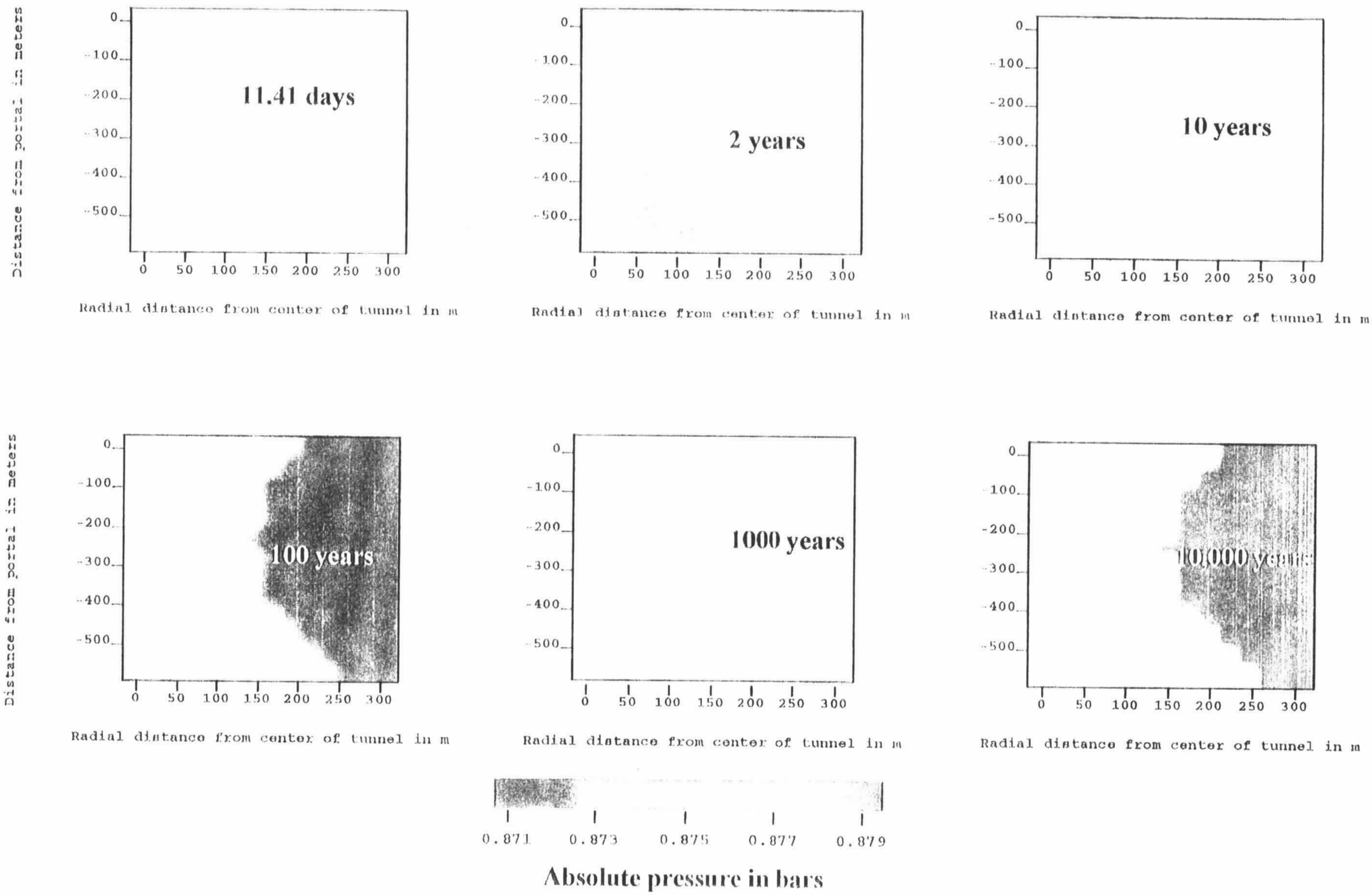


Figure 6-20 - Simulated pressure around the tunnel for various times. Case 7, with decaying heat load. Eddy diffusivity = 0.01, atmosphere temperature = 15 °C.

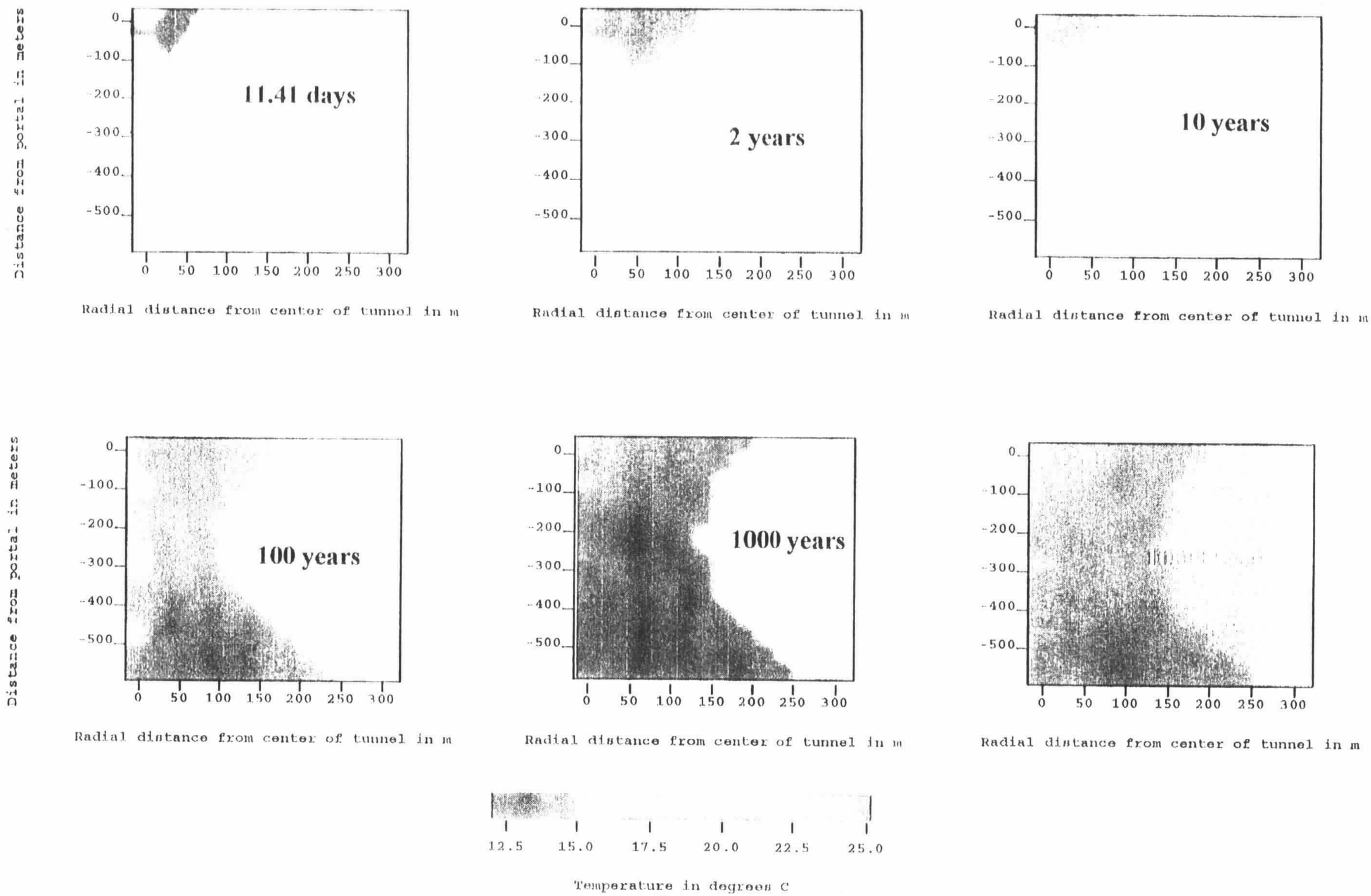


Figure 6-21 - Simulated temperature around the tunnel for various times. Case 7, with decaying heat load. Eddy diffusivity = 0.01, atmosphere temperature = 15 °C.

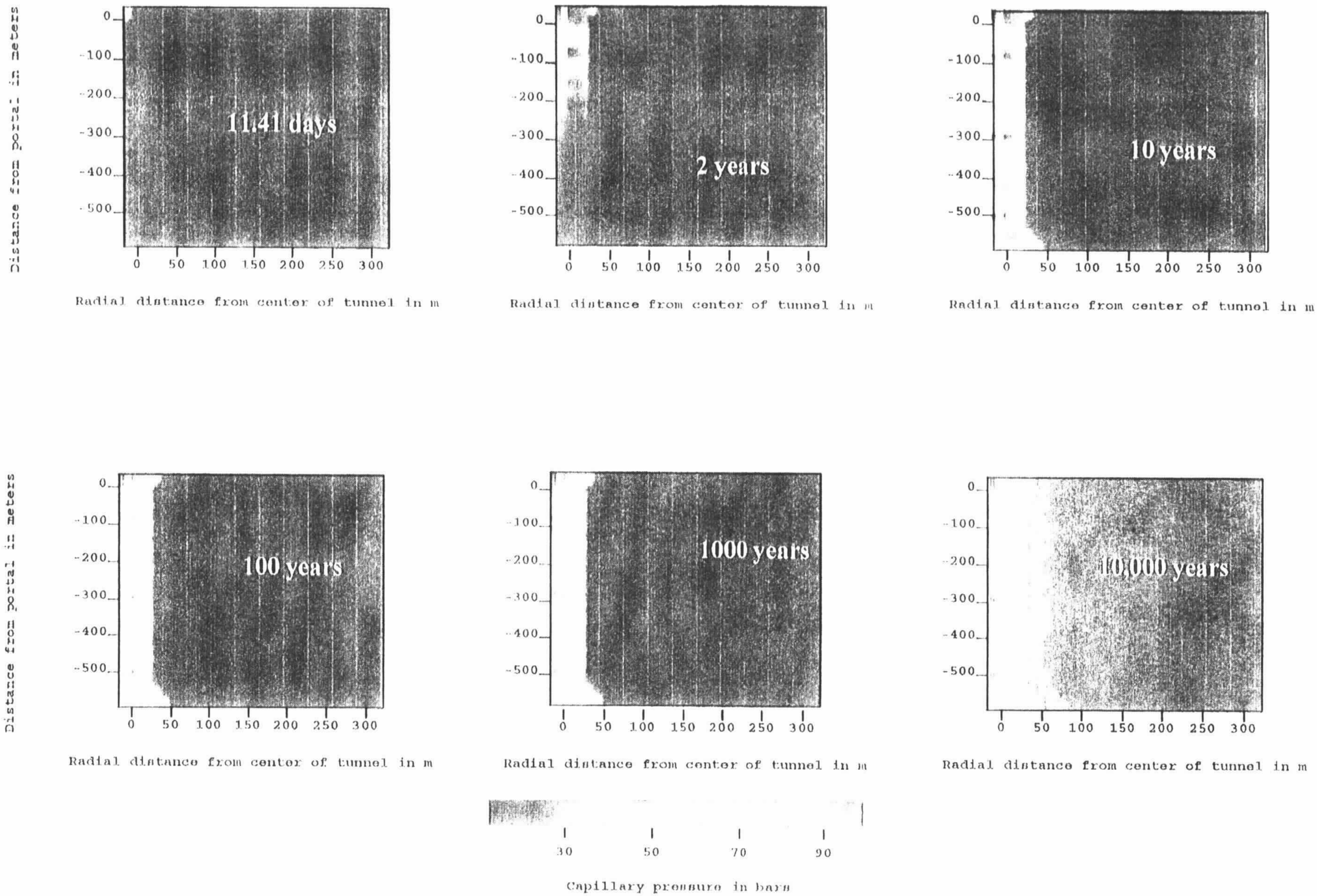


Figure 6-22 - Simulated capillary pressure around the tunnel for various times. Case 7, with decaying heat load. Eddy diffusivity = 0.01, atmosphere temperature = 15 °C. Note: scale changes among graphs.

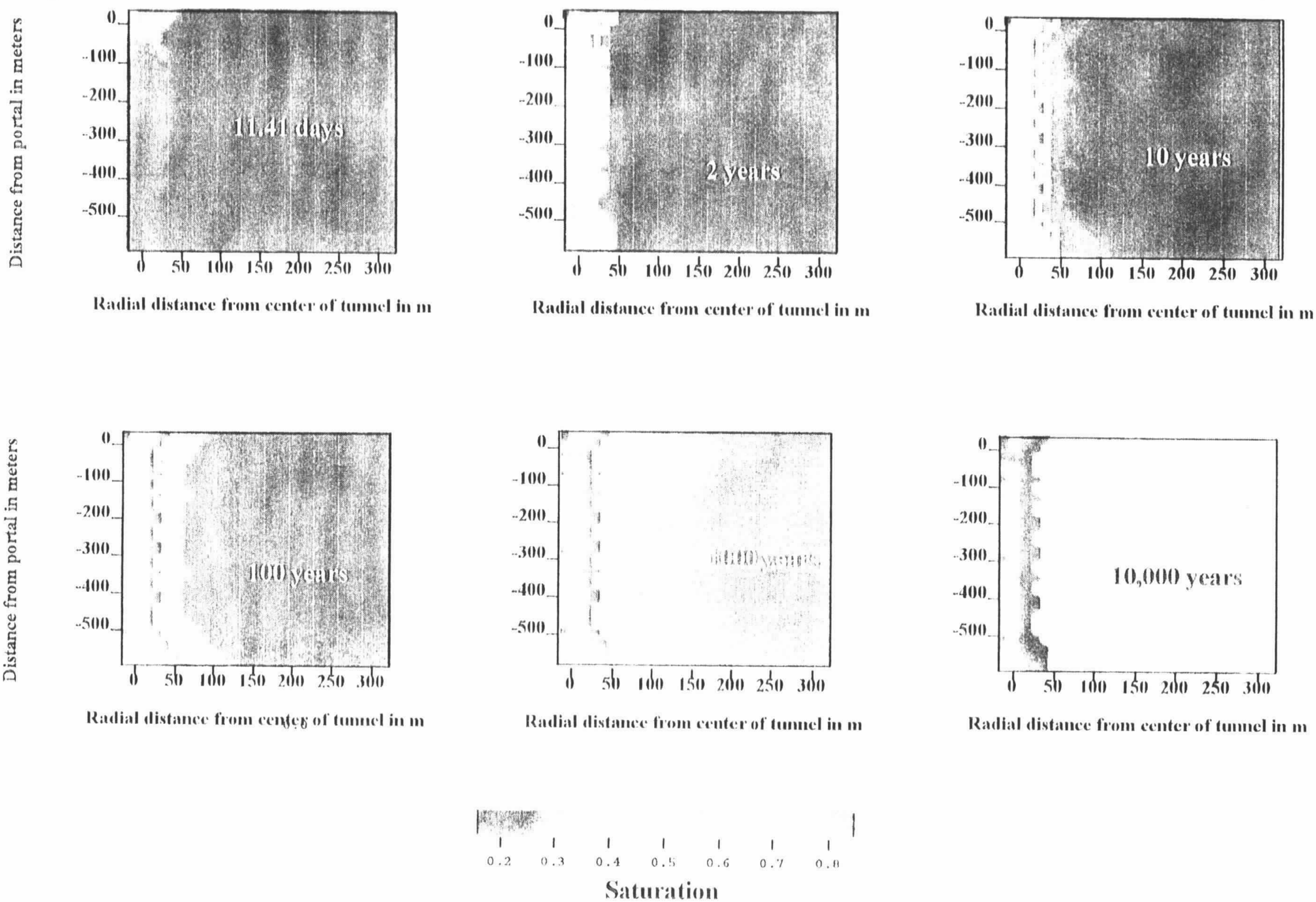
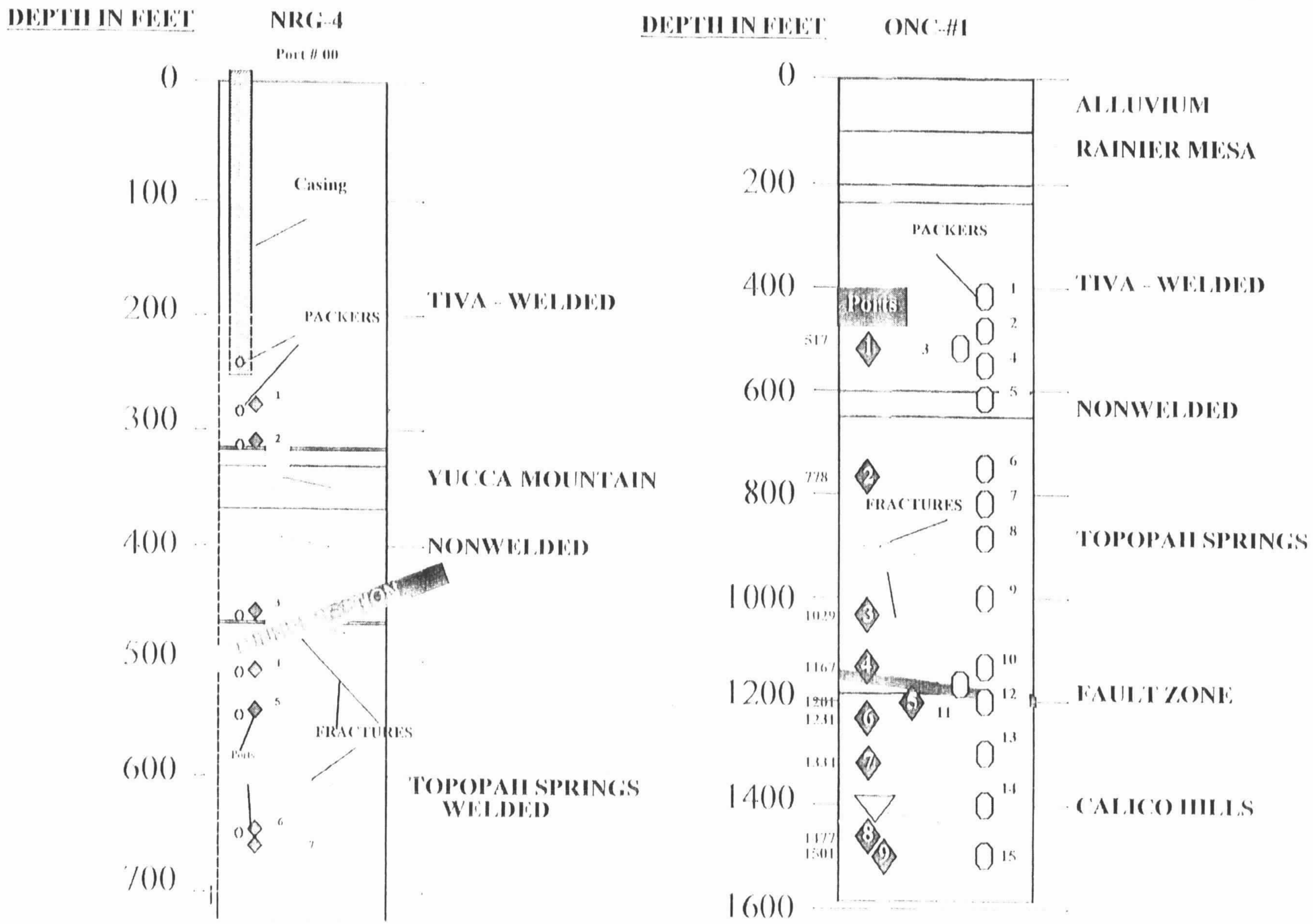
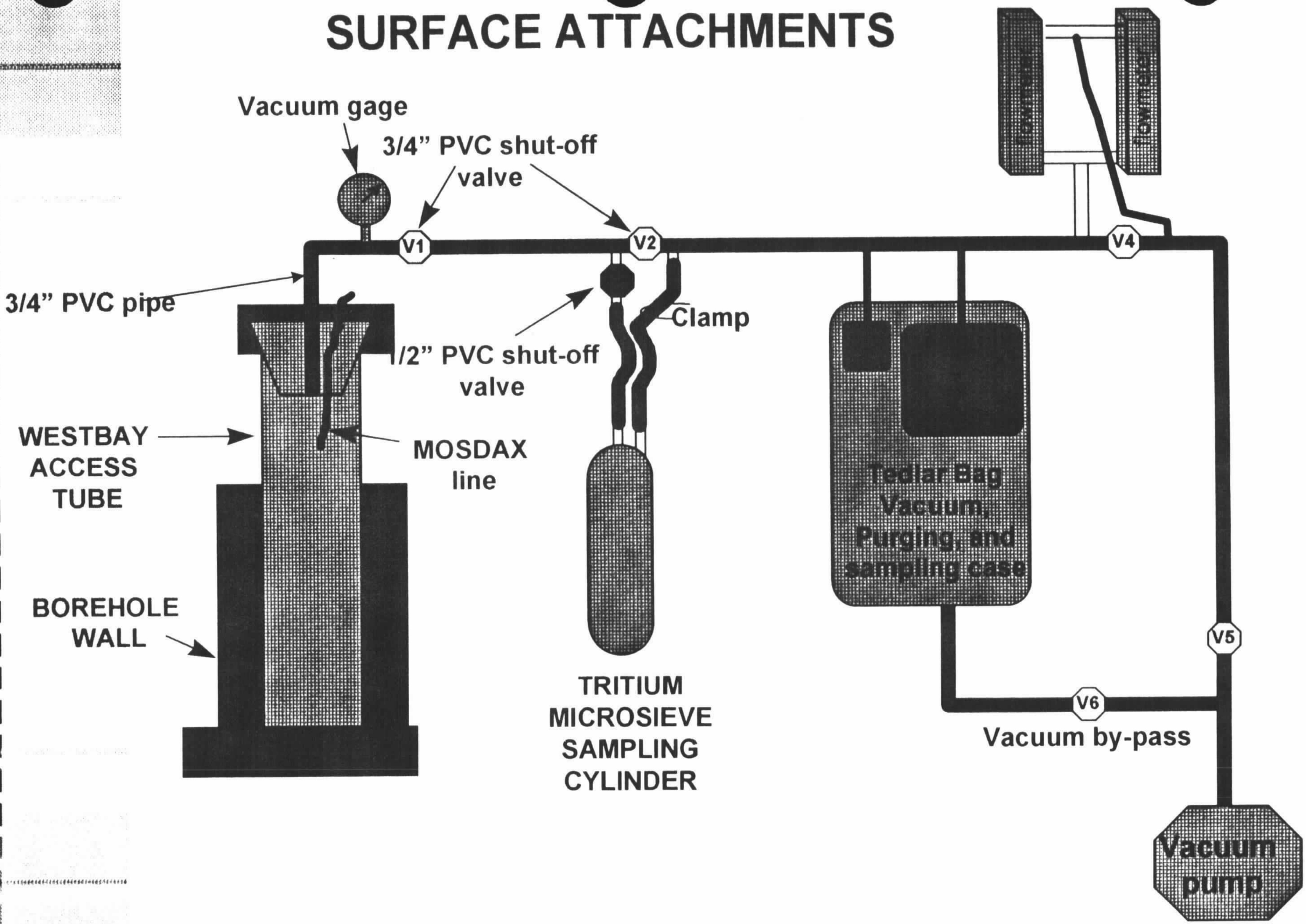


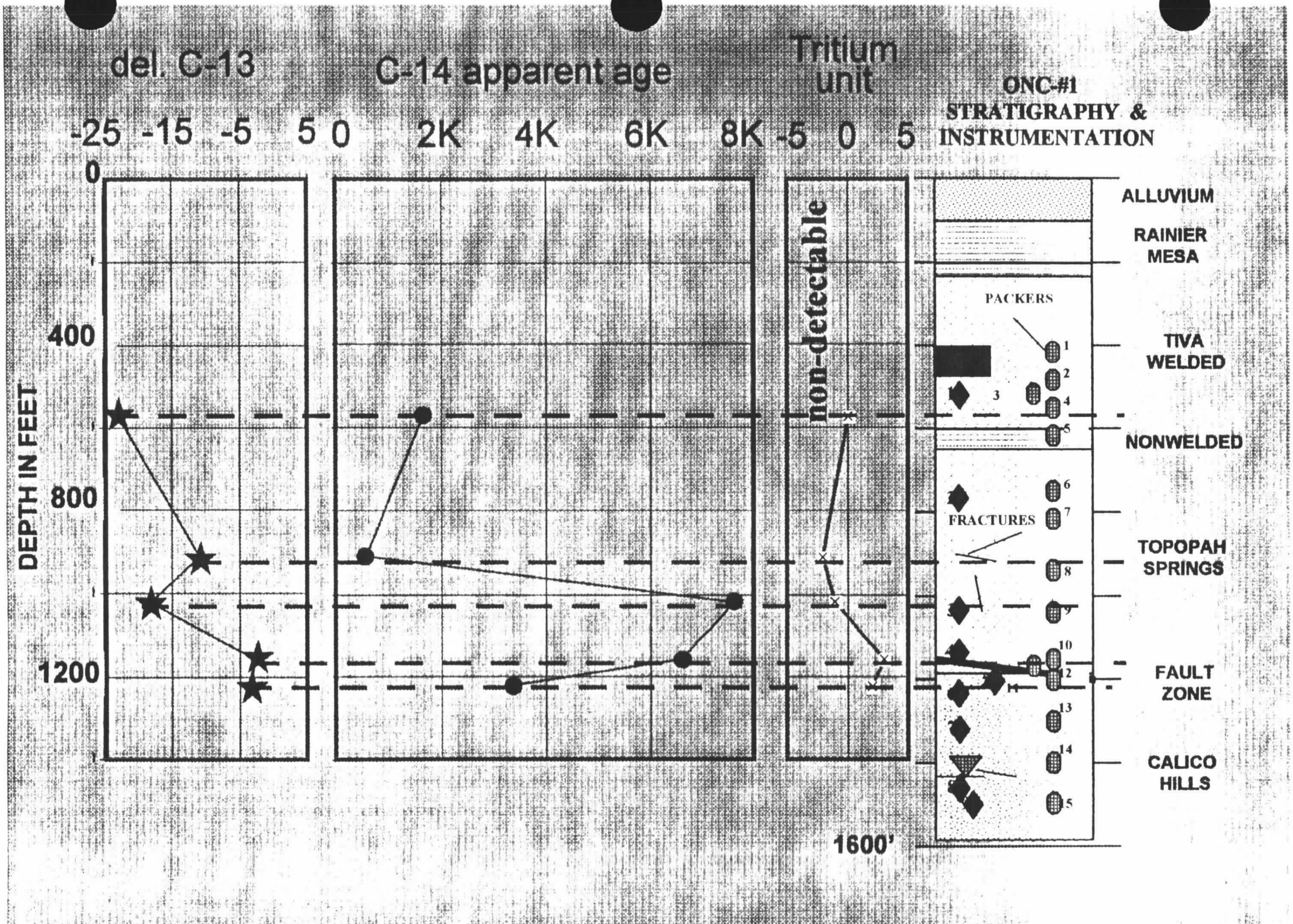
Figure 6.23 Simulated saturation around the tunnel for various times. Case 7, with decaying heat load. Eddy diffusivity = 0.01, atmosphere temperature = 15 °C.

SCHEMATIC PROFILE OF INSTRUMENTATION SETUP IN UE-25 ONC# 1 AND USW NRG-4



SURFACE ATTACHMENTS





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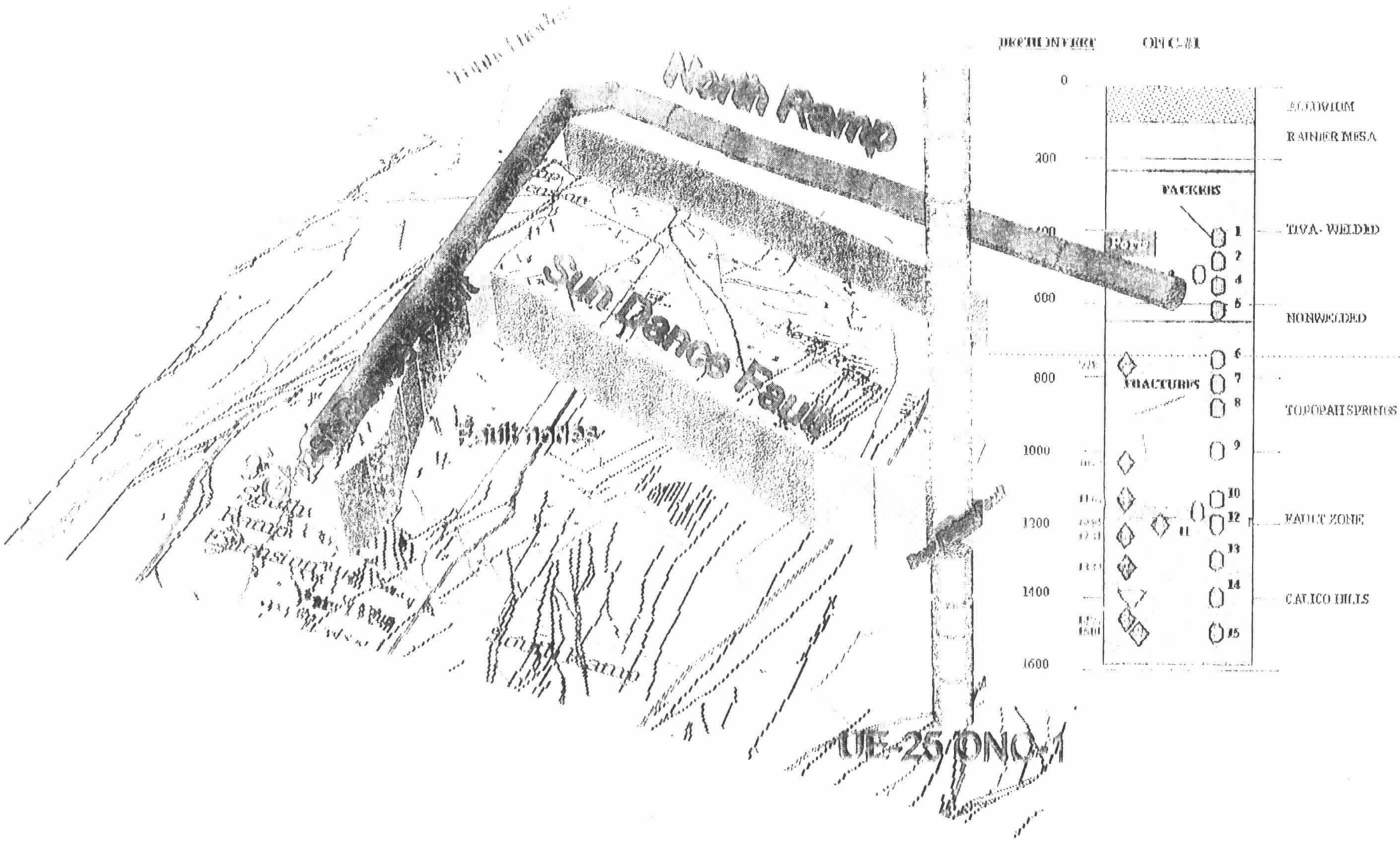
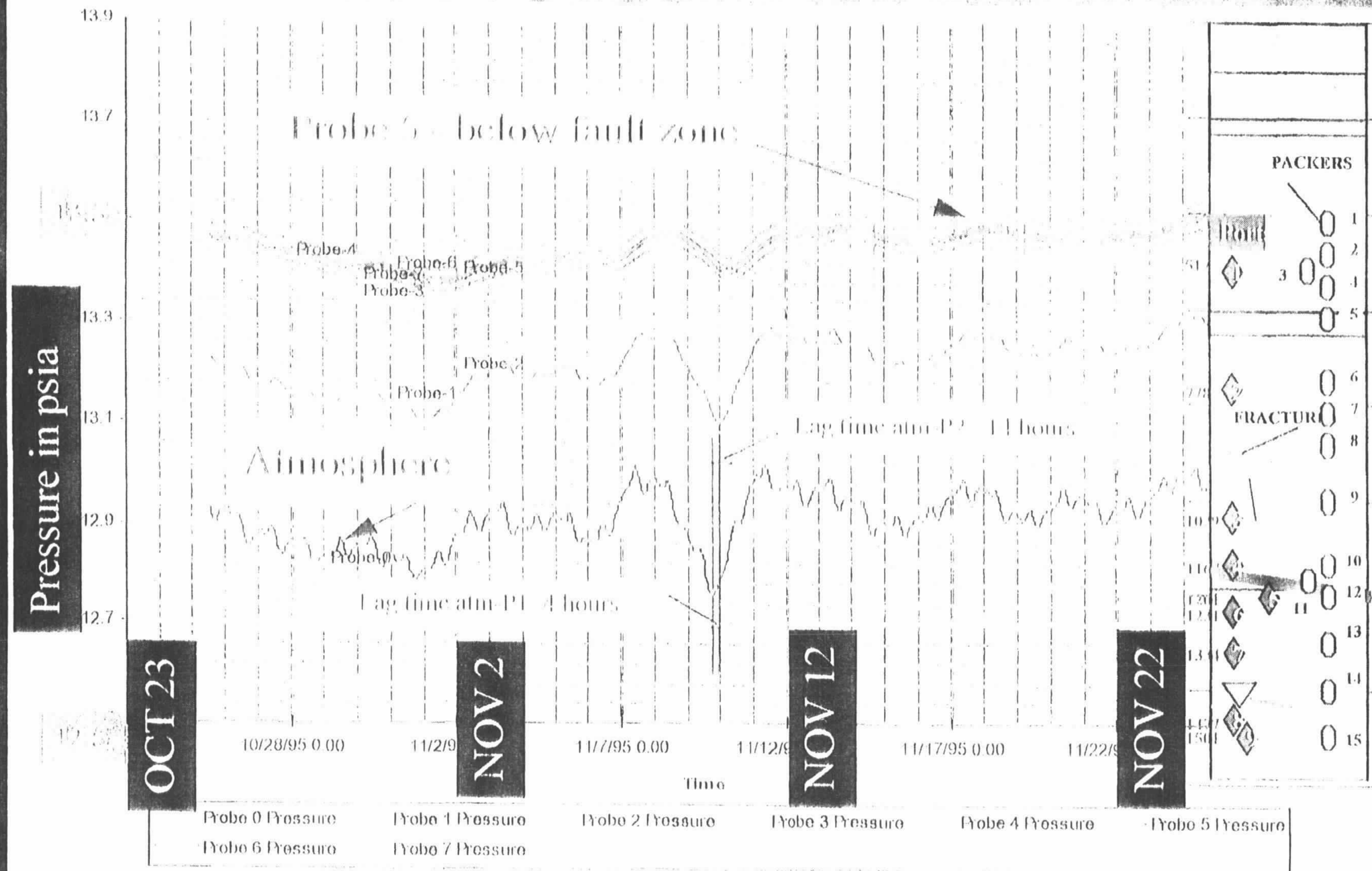
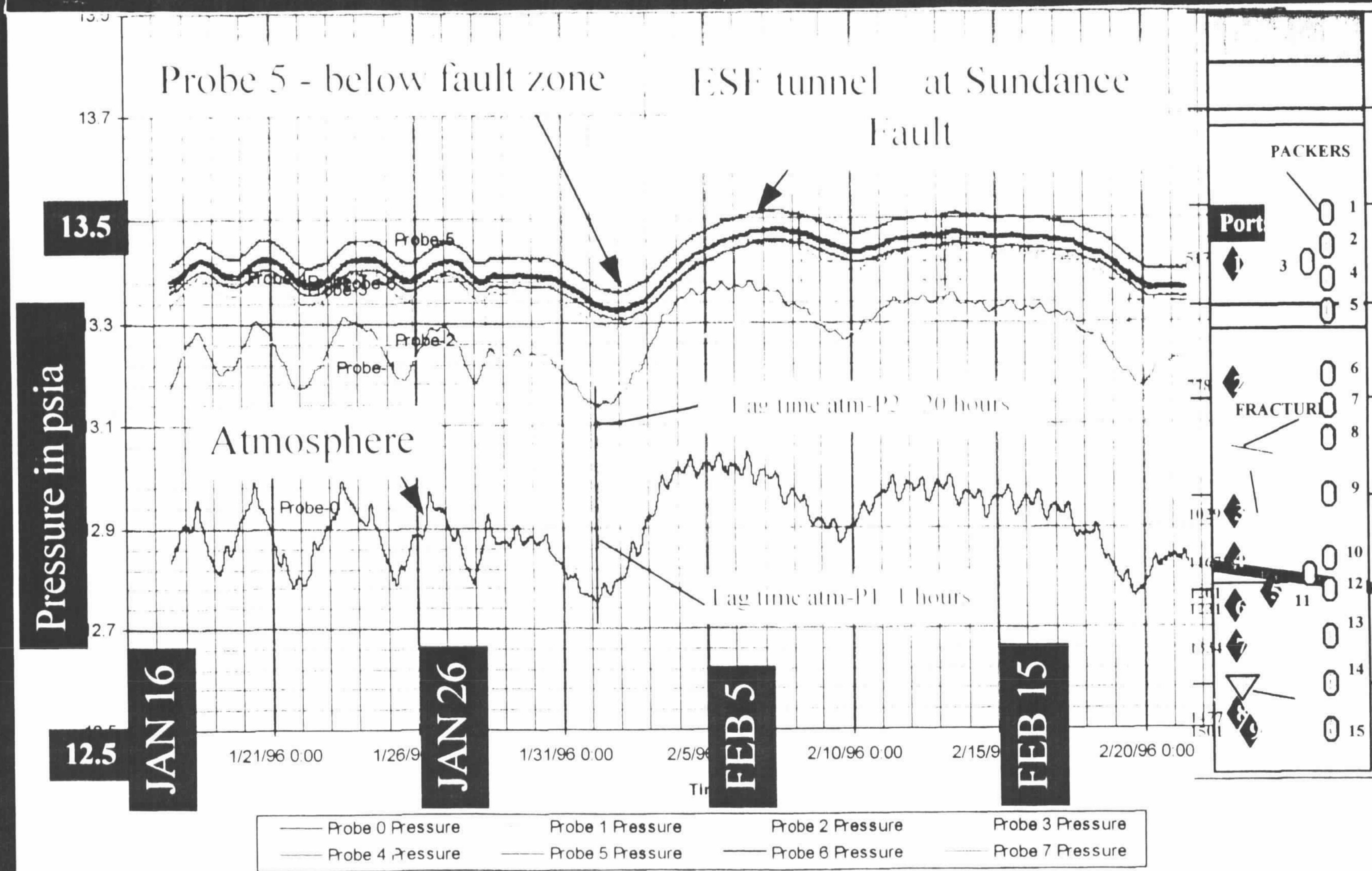
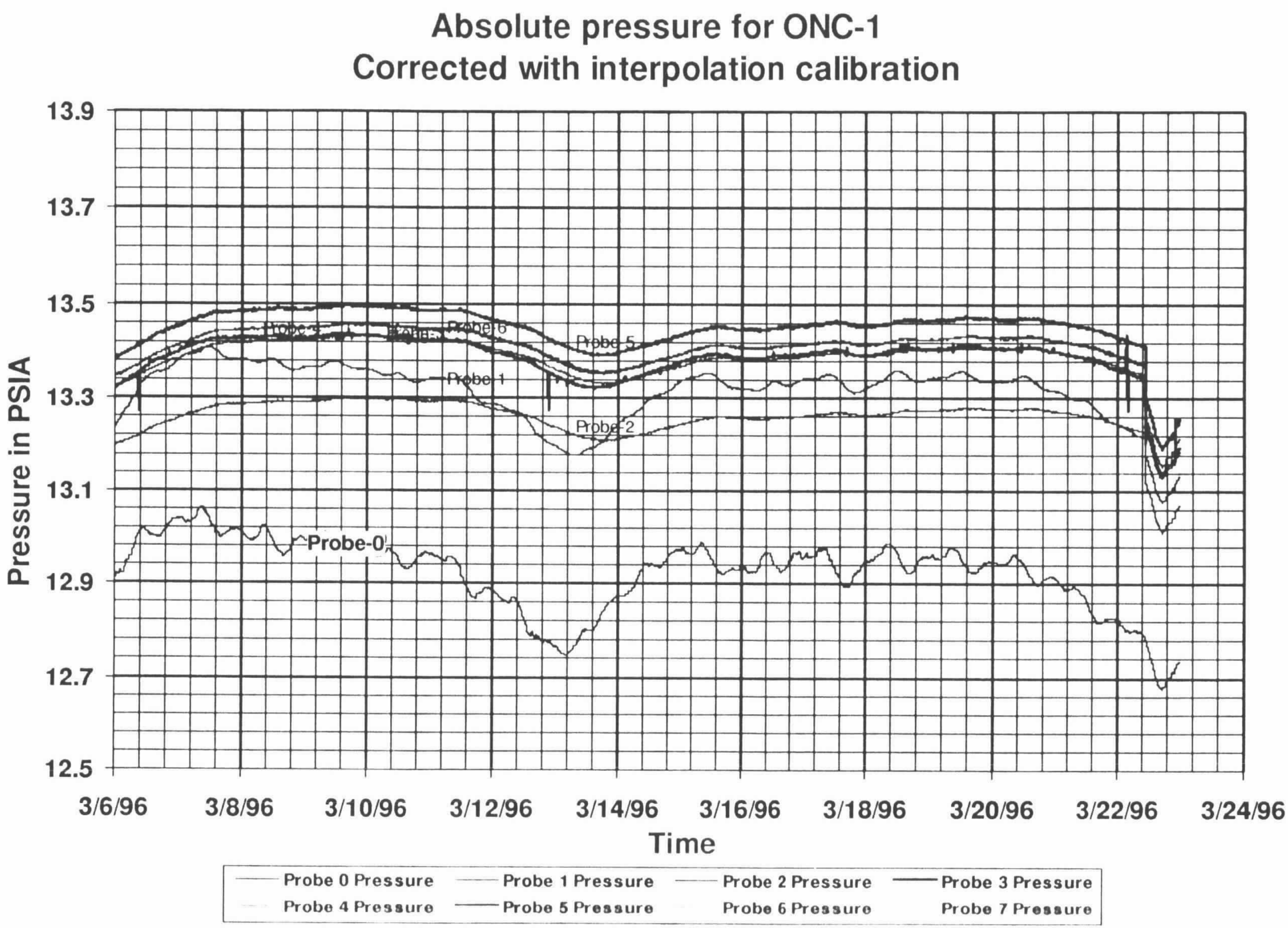

North Ramp
Sun Dance Fault
UE-25 ONC-1
DEPTH IN FEET
ONC-#1
0
200
600
800
1000
1300
1400
1600
ALLUVIUM
RAINIER MESA
PACKERS
TIVA - WELDED
NONWELDED
FRACTURES
TOPOPAH SPRINGS
FAULT ZONE
CALICO HILLS
1
2
4
5
6
7
8
9
10
11
12
13
14
15

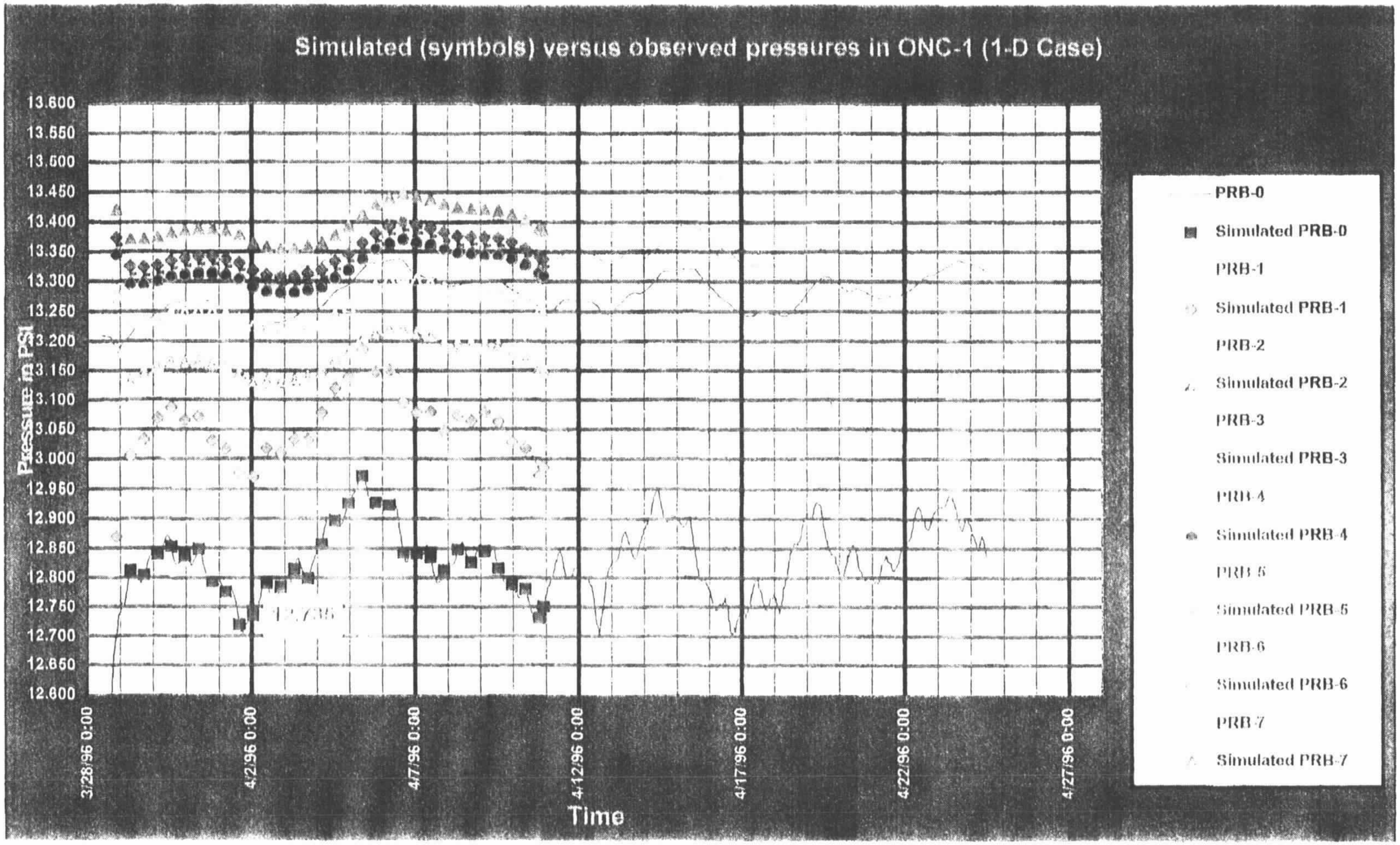
PRESSURE FLUCTUATION WITH TIME IN ONC #1 DURING NOVEMBER 1995



PRESSURE FLUCTUATION WITH TIME IN ONC #1 DURING JANUARY 1996

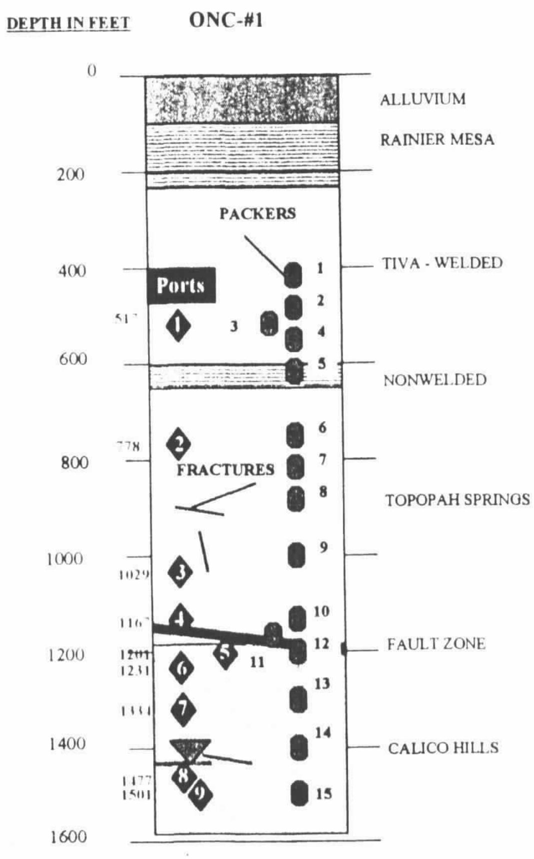



Absolute pressure for ONC-1
Corrected with interpolation calibration
Pressure in PSIA
13.9
13.7
13.5
13.3
13.1
12.9
12.7
12.5
3/6/96
3/8/96
3/10/96
3/12/96
3/14/96
3/16/96
3/18/96
3/20/96
3/22/96
3/24/96
Time
Probe 6
Probe 5
Probe 1
Probe 2
Probe-0
Probe 0 Pressure
Probe 1 Pressure
Probe 2 Pressure
Probe 3 Pressure
Probe 4 Pressure
Probe 5 Pressure
Probe 6 Pressure
Probe 7 Pressure



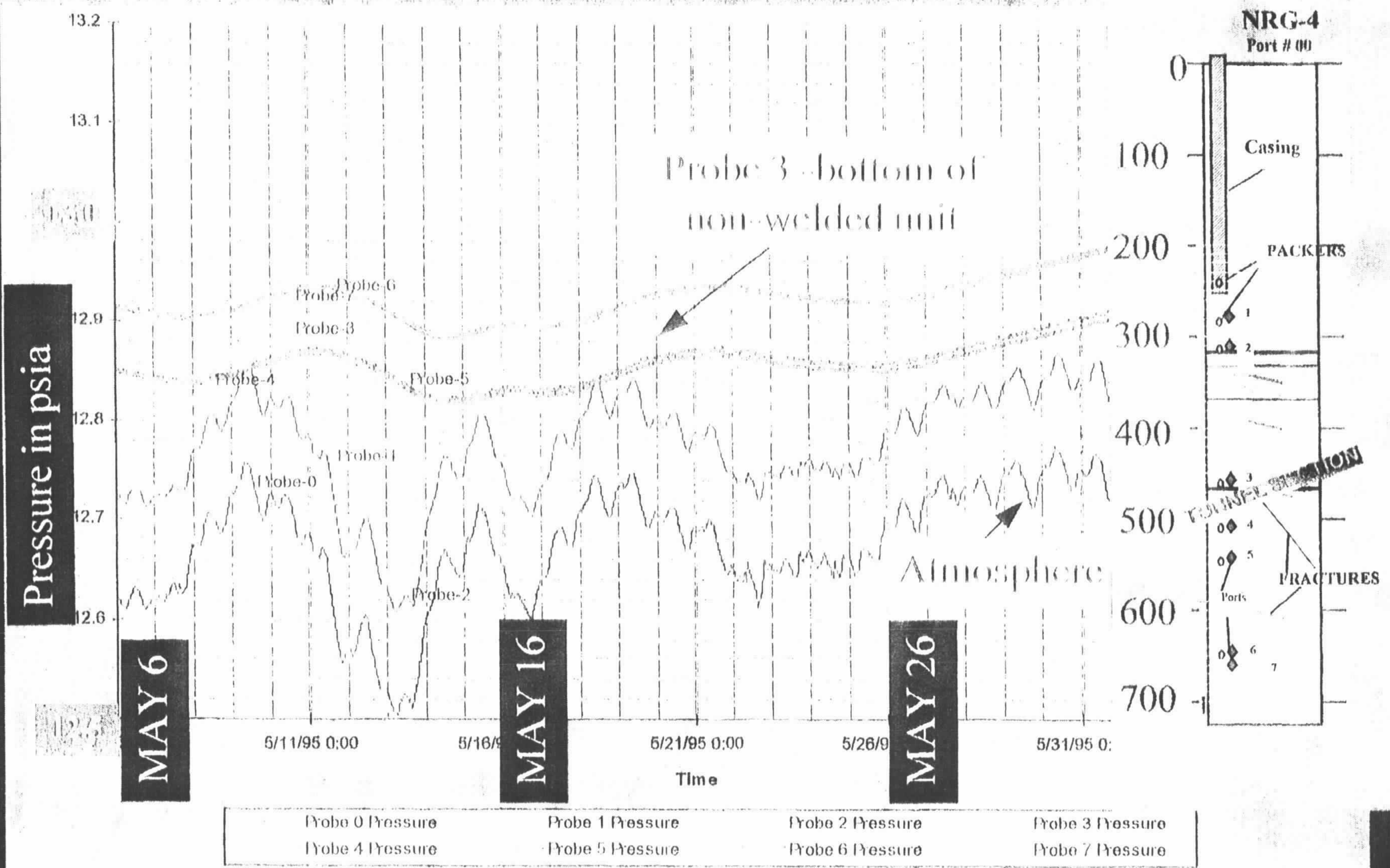
Simulated (symbols) versus observed pressures in ONC-1 (1-D Case)
Pressure in PSI
13.600
13.550
13.500
13.450
13.400
13.350
13.300
13.250
13.200
13.150
13.100
13.050
13.000
12.950
12.900
12.850
12.800
12.750
12.700
12.650
12.600
3/28/96 0:00
4/2/96 0:00
4/7/96 0:00
4/12/96 0:00
4/17/96 0:00
4/22/96 0:00
4/27/96 0:00
Time
PRB-0
Simulated PRB-0
PRB-1
Simulated PRB-1
PRB-2
Simulated PRB-2
PRB-3
Simulated PRB-3
PRB-4
Simulated PRB-4
PRB-5
Simulated PRB-5
PRB-6
Simulated PRB-6
PRB-7
Simulated PRB-7

MODELED COLUMN FOR NYE COUNTY BOREHOLE ONC#1

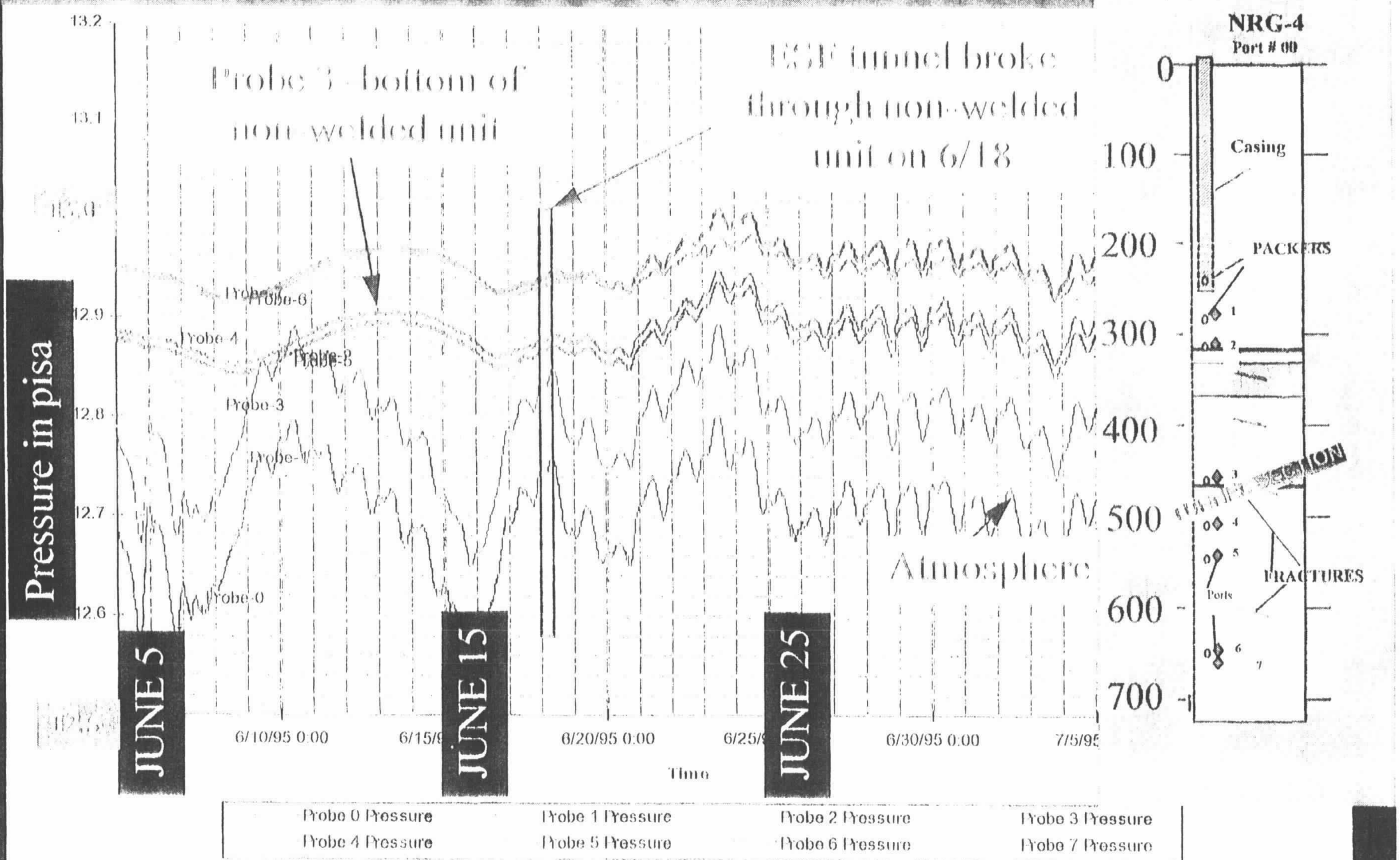


Thickness in m	Rock Type	Depth feet tb	Depth in m tb	PERMEABILITY (m2)	PERMEABILITY (darcy)	Equivalent Conductivity cm/sec	Equivalent Porosity
2							
60.96	tiva1	200.00	60.96	5.00E-11	5.07E+01	4.90E-02	3.42E-01
60.96	tiva2	400.00	121.92	5.00E-11	5.07E+01	4.90E-02	1.00E-03
30.48	tiva3	500.00	152.40	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		934.38	284.80	8.00E-10	8.11E+02	7.84E-01	3.00E-02
20				8.00E-10	8.11E+02	7.84E-01	3.00E-02
30.48		1034.38	315.28	5.00E-10	5.07E+02	4.90E-01	3.00E-02
49.98		1198.36	365.26	1.00E-10	1.01E+02	9.80E-02	3.00E-02
Falut		1206.36	367.76	5.00E-09	5.07E+3	4.9E+00	1.00E-03
	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

PRESSURE FLUCTUATION WITH TIME IN NRG-4 DURING MAY 1995

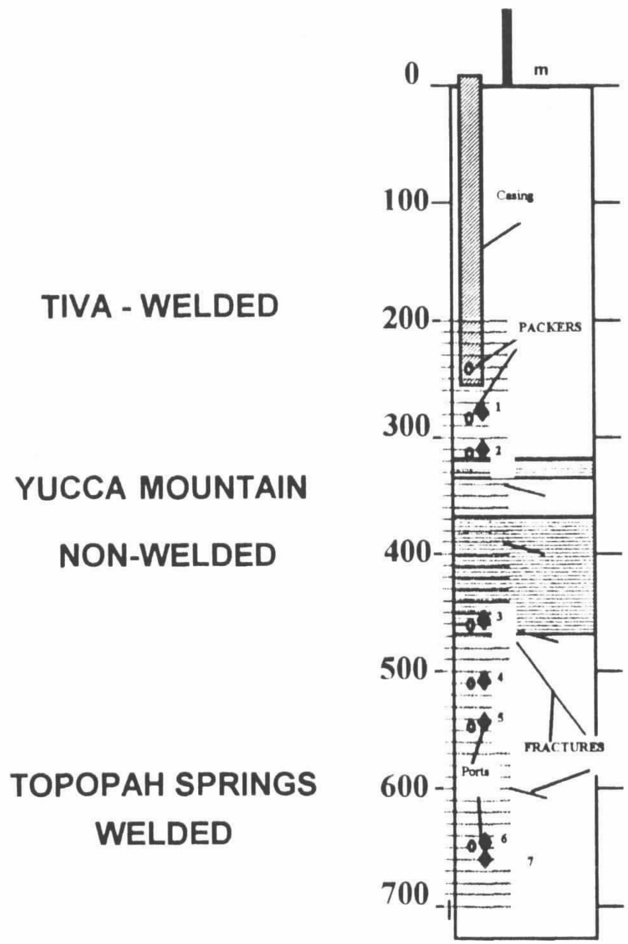


PRESSURE FLUCTUATION WITH TIME IN NRG-4 DURING JUNE 1995



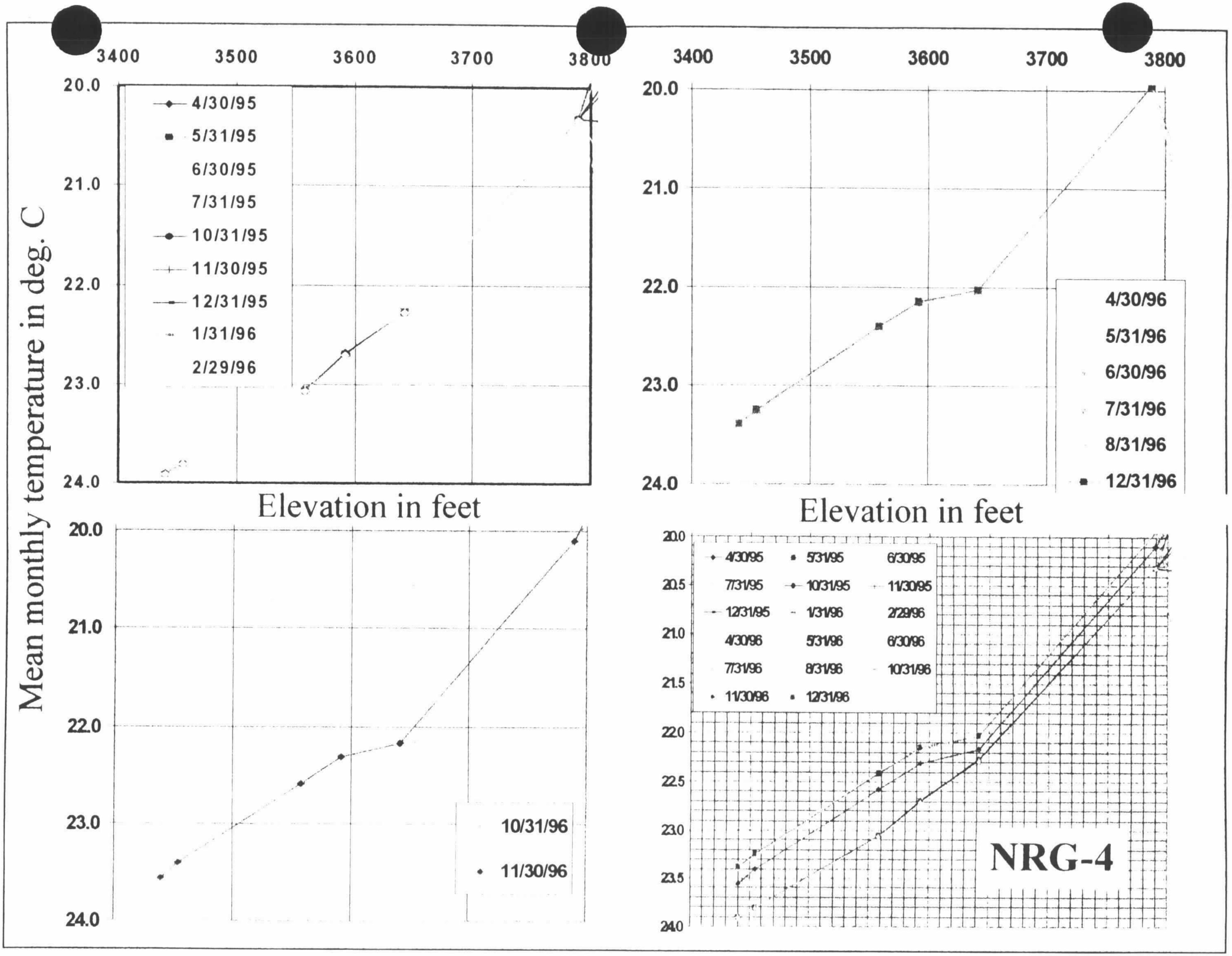
ONE-DIMENSIONAL GRID AND THE RESULTS OF PERMEABILITY CALCULATIONS FOR USW NRG-4

NRG-4 COLUMN



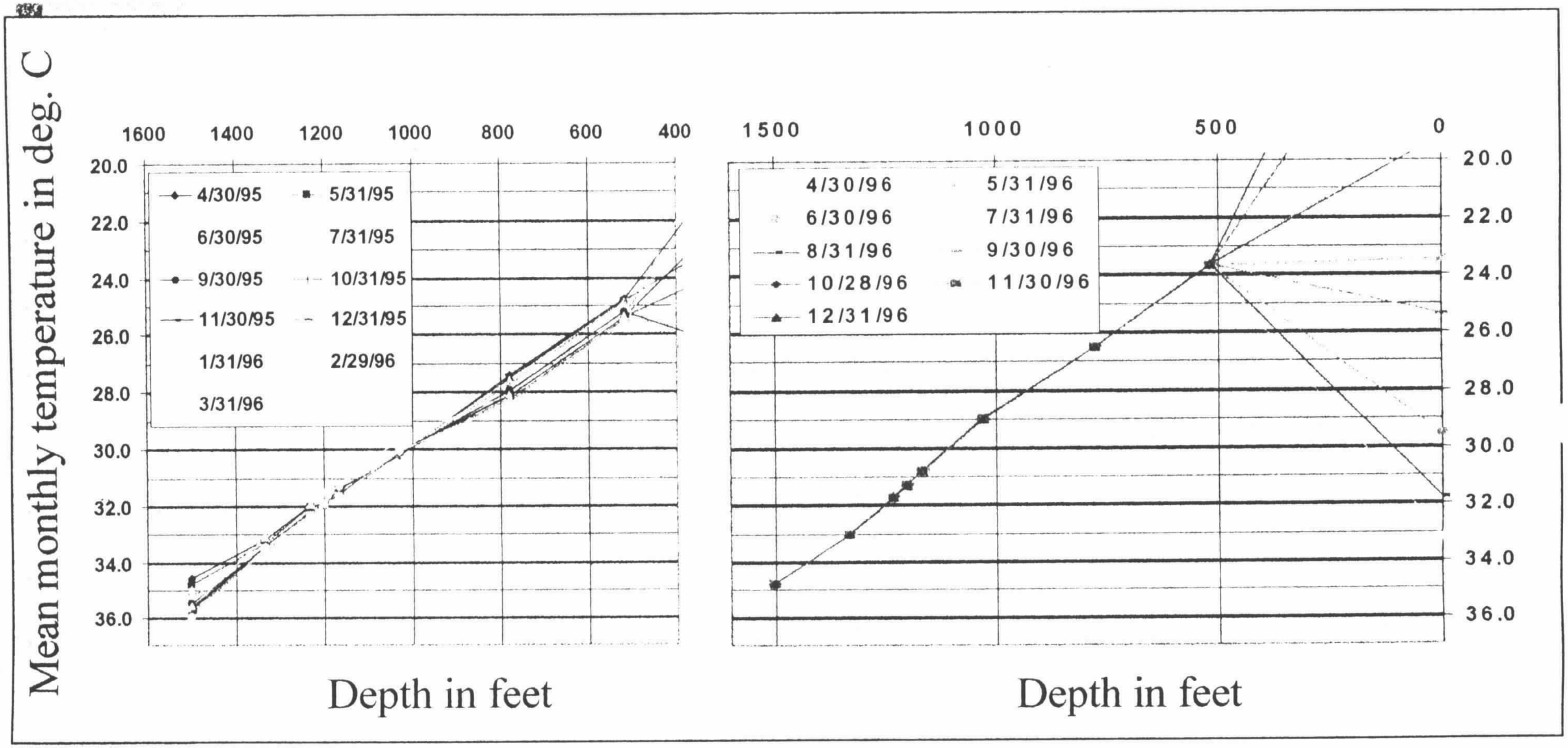
MODELED COLUMN

Material Type	Permeability		Equivalent Conductivity	Equivalent Porosity
[illegible]	m2	Darcy	cm/sec	Fractions
Tiva1	1.00E-10	1.01E+02	9.80E-02	3.42E-01
Tiva2	1.00E-10	1.01E+02	9.80E-02	3.42E-01
Tiva3	1.00E-10	1.01E+02	9.80E-02	3.42E-01
Tiva4	1.00E-10	1.01E+02	9.80E-02	3.42E-01
Ptn	3.50E-12	3.55E+00	3.43E-03	5.00E-01
[illegible]	5.00E-13	5.07E-01	4.90E-04	1.00E-01
[illegible]	5.00E-10	5.07E+02	4.90E-01	1.00E-02
[illegible]	2.30E-08	2.33E+04	2.25E+01	1.00E-02
[illegible]	2.30E-08	2.33E+04	2.25E+01	1.00E-02
[illegible]	2.30E-08	2.33E+04	2.25E+01	1.00E-02



Mean monthly temperature in deg. C
Elevation in feet
3400
3500
3600
3700
3800
20.0
21.0
22.0
23.0
24.0
4/30/95
5/31/95
6/30/95
7/31/95
10/31/95
11/30/95
12/31/95
1/31/96
2/29/96
4/30/96
5/31/96
6/30/96
7/31/96
8/31/96
12/31/96
10/31/96
11/30/96
20.5
21.5
22.5
23.5
NRG-4

MONTHLY MEAN TEMPERATURE IN ONC #1



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Data from boreholes are posted monthly on
NYE COUNTY'S WEB PAGE:

www.nyecounty.com

A LOW-TEMPERATURE AND DRY HIGH-LEVEL RADIOACTIVE WASTE REPOSITORY AT YUCCA MOUNTAIN

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Nick Stellavato and Malachy R. Murphy

Nye County Nuclear Waste Repository Office

Observations and numerical simulations suggest that, with natural ventilation, the host-rock temperature may be kept below 30 degrees Celsius and its moisture conditions kept dry for 10,000 years at the proposed high-level radioactive waste repository at Yucca Mountain, Nevada. Also, from the heat-driven air flow, it may be possible to generate small amounts of electricity for a long period of time.

The U.S. Department of Energy has been conducting research to evaluate the viability of Yucca Mountain as a high level radioactive waste repository. Site characterization and scientific investigations have focused on evaluating various scenarios that would make the repository safe for a period of at least 10,000 years.

Yucca Mountain is a north-south trending ridge in the Basin and Range province, about 150 km northwest of Las Vegas, Nevada (see Figure 1). It consists of alternating layers of interbedded welded and nonwelded tuffacious formations which range from porous, nonwelded ash-flow deposits to massive welded ash-flow and ash-fall deposits. Physical and hydrological characteristics of these formations are highly variable. The annual precipitation is estimated to be about 0.17 m, and the evapotranspiration is considered to be extremely variable but generally high. The hydrological system is characterized by fluid flow through vastly heterogenous fractured and porous layers of volcanic tuffs in the unsaturated zone and major fault zones. The proposed location of the nuclear waste repository is in the unsaturated zone. The unsaturated zone ranges in thickness from 450 to 750 meters. A more detailed description of the site can be found in Montazer and Wilson (1984) and in many references cited in TRW, 1995.

The most important technical issue facing the Yucca Mountain project is isolation of radionuclides. Thermal and moisture conditions of the repository are two of the important processes that influence this containment. These factors affect corrosion of the waste package, which may result in the release of radionuclides. Migration of radionuclides, if released, is primarily controlled by the hydrogeologic and geochemical properties of the rock and processes in the system. Thermal stability of the repository depends on the thermal loading (i.e., density of the waste canisters) and thermo-mechanical properties of the host rock.

To contain the radionuclides, the current concept is to seal (or backfill) the repository with crushed tuff or similar material (TRW, 1995) after approximately 100 years of repository pre-closure performance confirmation period. Although some considerations have been given to designs with no sealing of the repository, the results have not been satisfactory in the past.

The uncertainty in flux through the repository has been one of the most investigated subjects, and probably the least resolved issue in the project. Various mechanisms affect moisture movement in the unsaturated zone and make quantification very difficult. Estimated infiltration and percolation flux have ranged from 0.01 to 4.5 mm/year. Larger values were reported by U.S. Geological Survey scientists in a recent presentation at the Nuclear Waste Technical Review Board meeting (held in Denver, Colorado in July 1996). Climatological variations over 10,000 years add considerable uncertainty to these estimations. Fault zones and preferential pathways have been found and the contrast in hydrogeological characteristics between fractures and the rock matrix in these features has made characterization of flux even more difficult.

The transport of the heat away from the repository, and its effect on radionuclide containment, depend on the hydrogeology, total amount of heat source and specific design options. The current conceptual design of the repository, together with waste emplacement scenarios, is given in the TSPA report (TRW, 1995).

Although a number of thermal loading options have been studied by various investigators, recent studies are based on two thermal loading options termed "low" and "high" (TRW, 1995). The "low" thermal load option is designed to minimize hydrologic disturbance. The "high" thermal load option is assumed to keep the waste packages dry for an extended period of time by evaporating any nearby water (Buscheck and Nitao, 1993). However, in both cases the temperature in the host rock rises to above 100 degree Celsius, and no significant reduction in the near-field saturation is predicted after decay of the heat load.

Natural ventilation and the fractured nature of the tuff are the key features that may be exploited to increase the safety of the Yucca Mountain Site as a potential repository. Recent observations in the Exploratory Studies Facility (ESF) tunnel by the authors, have indicated that ventilation can remove substantial amounts of moisture and heat from the tunnel host rock in a very short period of time. The fractured nature of the rock will facilitate advection of the vapor and heat. Therefore, by naturally ventilating the repository and taking advantage of the thermal drive of the waste package, the repository host rock may be kept dry for over 10,000 years. The amount of moisture removed from the rocks during this time will create a thick low-saturation skin around the emplacement drifts that will require thousands of years to re-saturate. Ventilation can also remove large amounts of heat generated by the waste canisters. In the TSPA's proposed approach, there is very little moisture removal from the system and re-saturation can occur much more rapidly than in the naturally-ventilated case. In an unventilated case (backfilled repository), the moisture will be forced away from the repository. This moisture will be trapped under an umbrella and will eventually return and re-wet the repository.

OBSERVATIONS IN ESF TUNNEL

Continuous monitoring of the temperature, pressure, and humidity in the ESF tunnel has indicated that there is substantial heat and moisture loss from the rock as a result of forced ventilation air. Currently, the tunnel is not connected to any shaft; therefore, the potential for natural ventilation is uncertain. However, large air-flow rates have been observed in some of the relatively large diameter (0.44 m) open holes. Natural air currents have been used historically in mine-ventilation applications.

SIMULATION OF MOISTURE AND HEAT REMOVAL THROUGH NATURAL VENTILATION

Simulations were made to evaluate the effect of ventilation on removal of moisture and heat from the repository host rock. The coupling of the atmospheric processes with the rock was simulated using A-TOUGH (Montazer, 1994), a numerical code which was developed for simulation of coupled atmospheric-soil processes.

A series of simplified simulations were performed using A-TOUGH to calibrate the model with the measured data from the ESF Tunnel. The calibrated model was used to perform predictive simulations. The model is conceptually depicted in Figure 2. These simulations were simplified by assuming an average constant atmospheric temperature, pressure, and humidity outside the tunnel. Effect of higher atmospheric temperature was also evaluated.

The model consisted of a horizontal cylinder 560 meters long with diameter of 600 meters. This cylinder was discretized into 20 concentric cylindrical shells with the tunnel represented by the inner-five concentric shells. The rest of the shells represented the surrounding rock. Each shell was subdivided into 16 grid blocks along the axis of the tunnel. A ventilation shaft, 300 meters high and consisting of 12 grid blocks or nodes, was connected to the main tunnel.

A number of simulations were made using the above described mesh setup to study and to evaluate the sensitivity of the model to changes in heat load, eddy diffusivity, and atmospheric temperature. For this study (as a demonstration simulation), an equivalent heat that would be provided by 52 waste packages was considered (i.e. a total of 445 KW initial heat load). This is less than one percent of the total waste planned to be emplaced at Yucca Mountain. The thermal load, in the model, was applied to 10 grid blocks at the center of the tunnel, stretching over 400 meters distance. The thermal load was assumed to decay according to the predicted heat release rate of a waste package (TRW, 1995). The main driving force for the air movement in the tunnel and along the shaft was the buoyancy caused by the temperature of the waste package and the host rock. The initial pressure conditions were the same as a static atmosphere.

For these simulations, an average ambient atmospheric temperature of 15 °C was used, which was conservatively high compared to the average annual temperature at Yucca Mountain. A lower mean atmospheric air temperature would result in a larger air flow and cooler temperatures in the waste area. The atmospheric air was assumed to have an average relative humidity of 10 percent.

RESULTS OF SIMULATION WITH NATURAL VENTILATION AND HEAT LOAD

The results of the simulation of a case with eddy diffusivity of 0.01 m^2/s are shown in Figures 3 and 4. A small temperature gradient (Figure 3) 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 in a few days. The rock temperature near the tunnel continues to drop below 10 °C until after about 20 years when it rises back to approach 15 °C. The continued decline in the simulated rock temperature is attributed to the continued flow of air (about 1100 cubic meters/min) 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 rises to equilibrate with the atmospheric temperature. This pattern can also be observed in the saturation trends in Figure 4a. Capillary pressure gradients remain directed towards the tunnel at all times as may be inferred from the saturation field (Figure 4b).

IMPLICATIONS OF THE SIMULATIONS FOR REPOSITORY DESIGN

Simulations using measured ventilation data suggest that strong air currents may be produced by natural ventilation. Application of natural ventilation aided by a heat source may provide a cool and dry host rock with a capillary-pressure gradient toward the emplacement tunnels during the first 10,000 years. This means that the primary mechanism for aqueous transport of the radionuclides away from the repository may be eliminated. Also, a denser packing of the waste canisters may be possible and a smaller acreage may be used for waste emplacement.

The results of this study emphasize the need for more accurate representation of the atmosphere-rock interactions in the tunnel. A-TOUGH allows transfer of heat and vapor between rock and the atmosphere to be dependent on the flow velocity using eddy diffusivity as the transfer coefficient. This methodology has not been considered by previous investigators in the application of the tunnel-air interaction with the host rock.

Many shafts will be required to implement a naturally ventilated repository. Considering that a heat-driven total flow rate of over 100,000 m^3/min may be generated, the potential for a small air-driven electrical plant should not be overlooked. Engineering of an open repository could be complicated and would need special study. The emission of the gaseous radionuclides do not seem to be of major concern at this time; however, further investigation is needed to evaluate this issue, and particularly the effectiveness of dilution. At this time, the presentation of the results of these simulations is intended only to generate interest in this potential alternative waste emplacement. The results and analysis are not yet sufficiently mature to be used as any design criteria or for any final decision making for the waste disposal.

The authors recognize that the current statutory and regulatory framework under which the repository program is being conducted contemplate a closed repository. The U.S. Congress is expected to be considering a major rewrite of the Nuclear Waste Policy Act (42 USC 10101 et seq), and both the U.S Department of Energy (DOE) and the U.S. Nuclear Regulatory Commission (NRC) are in the process of amending their siting guidelines and licensing regulations (10 CFR 960 and 10 CFR 60, respectively). In the process of doing so, the Congress, DOE and the NRC are encouraged to consider providing sufficient flexibility in the statue and regulations to allow the concept of an open, naturally ventilated repository design.

5. REFERENCES

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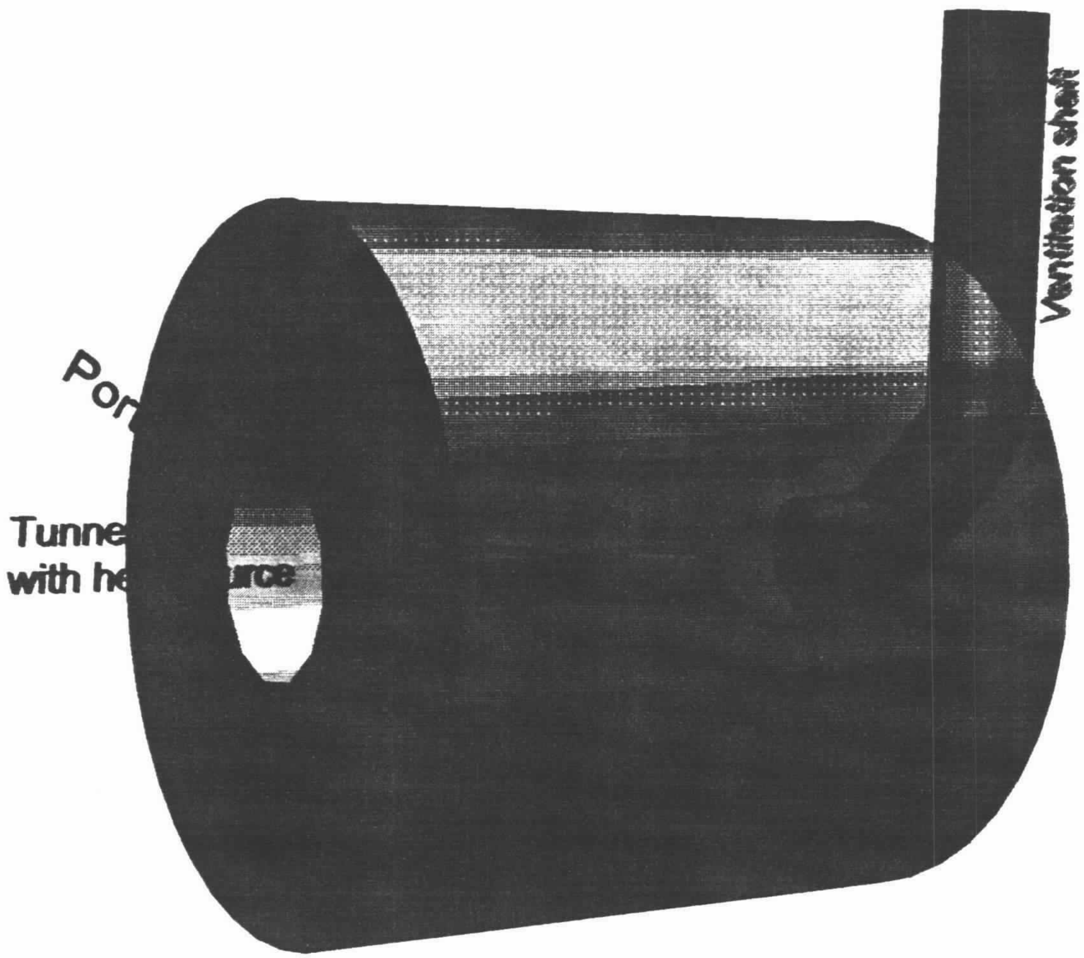


Figure 2 - Conceptual model of the natural ventilation.

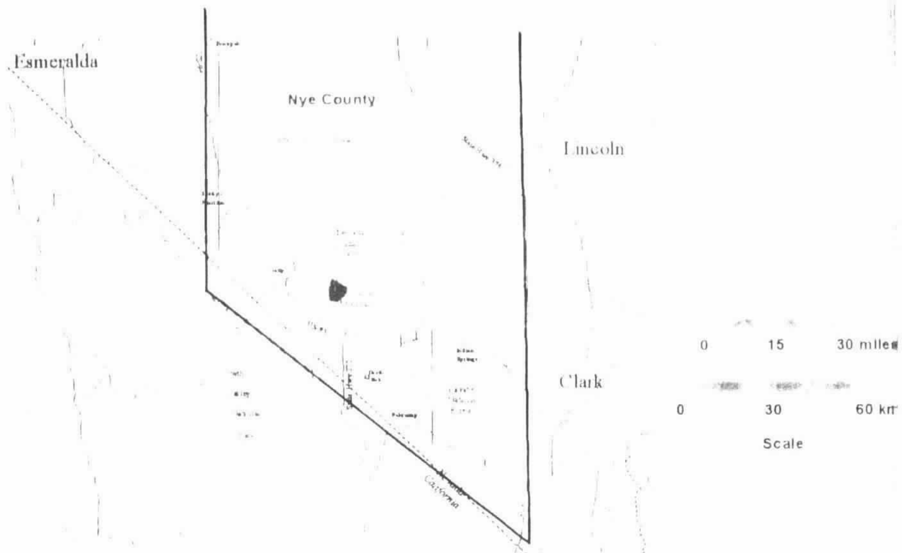


Figure 1 - Location of Yucca Mountain Site in Nye County, Nevada.

Figure 3 - Simulated variation of temperature with time for selected nodes perpendicular to the center of heat load (Eddy Diff = 0.01)

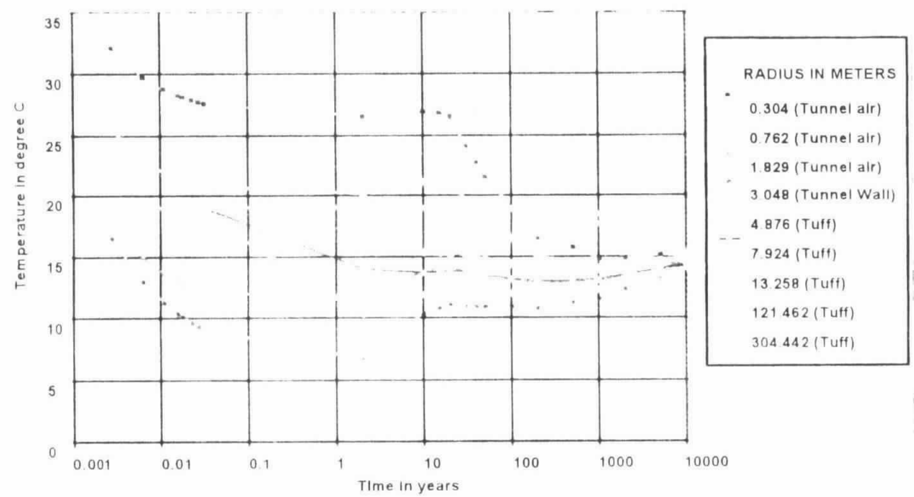
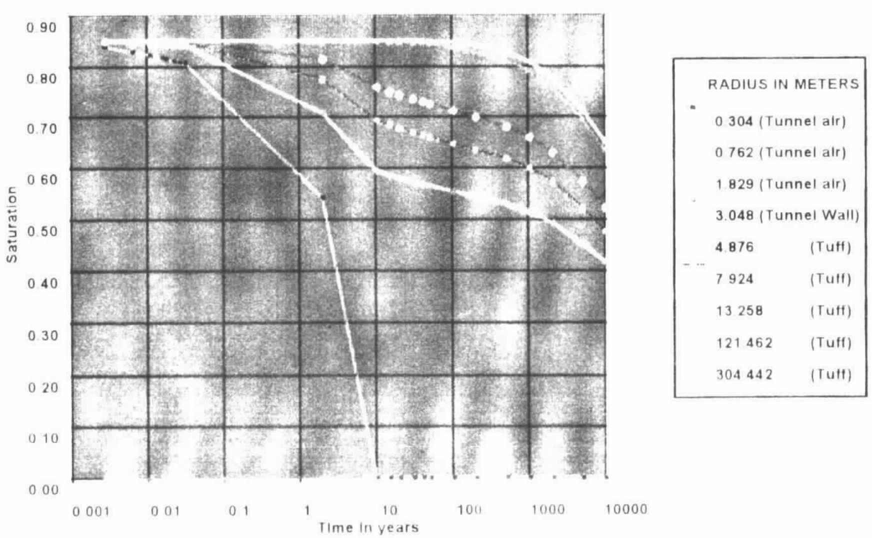


Figure 4a - Simulated variation of saturation with time for selected nodes perpendicular to the center of heat load (Eddy Diff = 0.01 m^2/s)



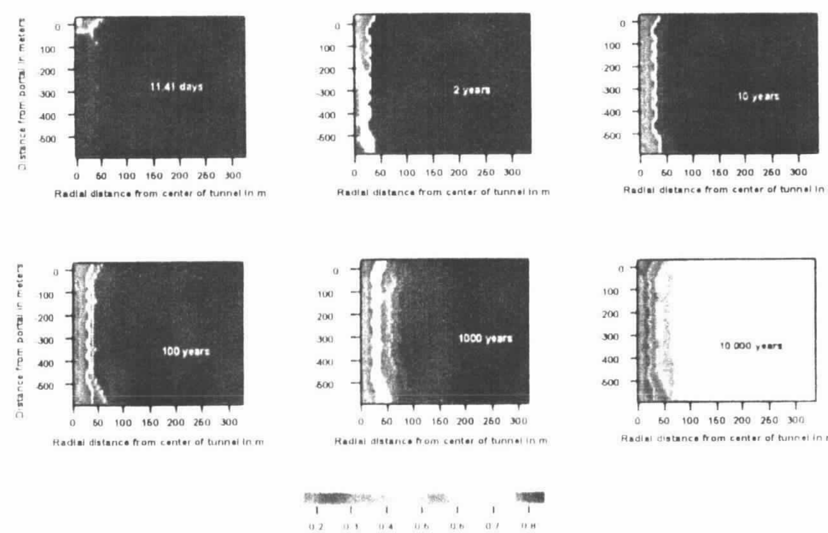


Figure 4b - Simulated saturation around the tunnel for various times. Eddy diffusivity = 0.01, atmosphere temperature = 15 °C