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THERMOMECHANICAL SCOPING CALCULATIONS FOR THE WASTE PACKAGE ENVIRONMENT TESTS

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March, 1986

Lawrence
Livermore
National
Laboratory

Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

Price Code	Page Range
A01	Microfiche
Papercopy Prices	
A02	001-050
A03	051-100
A04	101-200
A05	201-300
A06	301-400
A07	401-500
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A09	601

Prepared by Nevada Nuclear Waste Storage Investigations (NNWSI) Project participants as part of the Civilian Radioactive Waste Management Program. The NNWSI Project is managed by the Waste Management Project Office of the U.S. Department of Energy, Nevada Operations Office. NNWSI Project work is sponsored by the Office of Geologic Repositories of the DOE Office of Civilian Radioactive Waste Management.

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ABSTRACT

During the site characterization phase of the Nevada Nuclear Waste Storage Investigation Project, tests are planned to provide field information on the hydrological and thermomechanical environment. These results are needed for assessing performance of stored waste packages emplaced at depth in excavations in a rock mass. Scoping calculations were performed to provide information on displacements and stress levels attained around excavations in the rock mass from imposing a thermal load designed to simulate the heat produced by radioactive decay. In this way, approximate levels of stresses and displacements are available for choosing instrumentation type and sensitivity as well as providing indications for optimizing instrument emplacement during the test.

INTRODUCTION

Waste Package Environment Tests are being planned for the site characterization phase of the Nevada Nuclear Waste Storage Investigation Project. These tests will be conducted in drifts off from the Exploratory Shaft to provide near field information on the hydrological, thermal, and mechanical environment for assessing the expected performance of the waste package subsystem. The tests will also provide an option of testing certain components of the engineered barrier system.

An accelerated thermal cycle used in each test will examine the cooling side of the thermal pulse and provide measurements of parameters as a function of location and time. The parameters of interest include temperature, moisture content, pore water pressure, rock mass deformation, and rock mass stress changes. Temperatures and pore pressures will be used along with measurements of moisture content to determine the spatial distribution of water with time around the heater emplacement hole. Rock mass deformation and stress change measurements will be compared with results from conceptual models of discontinuity stiffness (Goodman, 1980; and Yow, 1985) to indirectly evaluate average fracture aperture changes. Fracture closure is important in that it may affect the amount of fluid migration that occurs in the porous matrix. Selected hydrologic calculations will be used to aid in analyzing different situations where fracture flow is important. Rock core samples will be collected before and after the tests to allow laboratory measurement of porosity, permeability, fracture stiffness, and elastic modulus. Such properties and processes will then be used to integrate the results from the Waste Package Environment Test with results from other Exploratory Shaft tests.

Electrical resistance heaters will be used to simulate the heat produced by radioactive decay. The thermal loading that will be used is higher than that of the reference PWR spent fuel package (O'Neal et al., 1984), and is intended to produce a 100° isotherm about one metre from the heater emplacement hole. A stepped cooldown period of approximately six to nine months will then be used to allow the entire rock volume surrounding the heater to drop below 100°C. Actual heater power levels will be varied in order to achieve desired temperature profiles. This manipulation will be based on pretest calculations and the temperatures observed in the rock mass as each test progresses.

Instruments will be installed in the rock mass around the heaters to measure temperature, moisture content, pore pressure, stress change, and displacement as a function of time and location. High-frequency electromagnetic (HFEM) geotomography measurements and other geophysical probes will be used to estimate the moisture content in the rock before, during, and after thermal cycling.

The reference horizon for a potential repository at Yucca Mountain is the densely welded, devitrified portion of the Topopah Spring Member of the Paintbrush Tuff (Vieth, 1982). The water table at Yucca Mountain is more than 500 m below the central portion of the mountain; as a result, the Topopah Spring Member lies entirely within the unsaturated zone. The matrix porosity of the welded tuff is approximately 13 percent, and the rock has a fracture frequency of 0.8 to 3.9 fractures per metre (Dudley and Erdal, 1982).

The results of the calculations will provide guidance for evaluation and selection of geotechnical field instrumentation that will be used to monitor rock mass stress changes and displacements during the tests. The Waste Package Environment Tests were planned for a depth of about 366 m (1200 ft) at the time these calculations were made. The tests will be separated from one another by at least 12.2 m (40 ft), based on the need to avoid interaction of the individual tests. This planned minimum separation will be refined as scoping and design calculations proceed. The actual test locations within the access drift will be dependent on local geology.

Table I

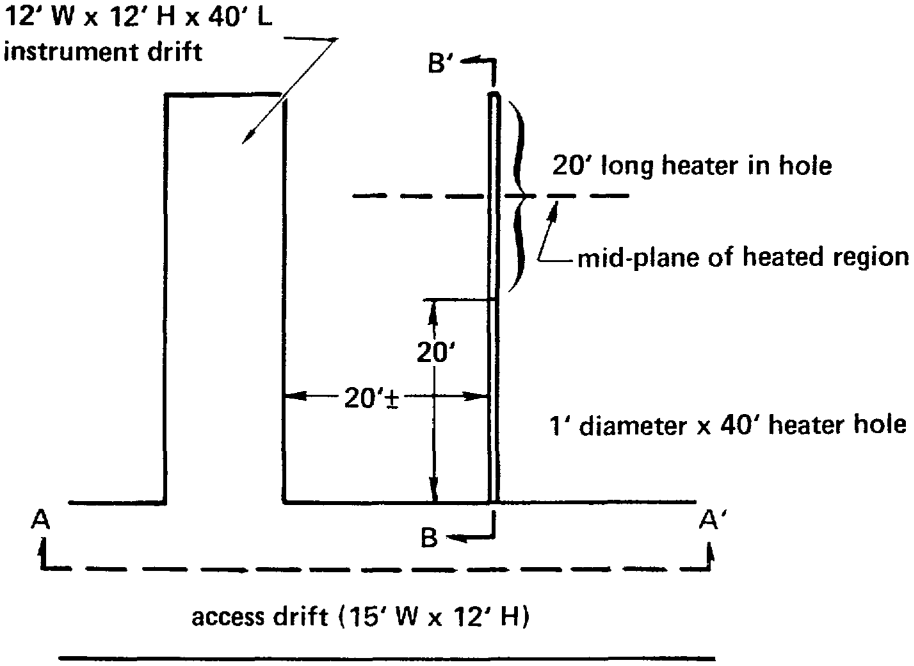
Material Properties Used for Rock In Waste Package Environment Test Scoping Calculations*

Density	2.34 g/cc
Elastic Modulus	15.1 GPa
Poissons Ratio	0.20
Thermal Expansion Coefficient	10.7×10^{-6} /K
Thermal Capacity	2.25 j/cm^3-K
Thermal Conductivity	
(25 - 100°C)	2.07 W/m-K
(100 - 125°C)	1.99
(125°C. +)	1.91

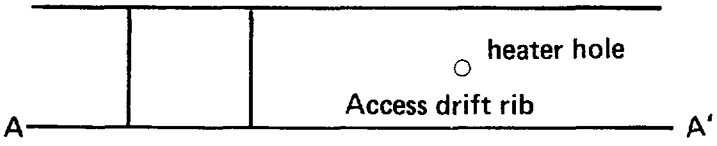
*Sandia National Laboratory (1984)

THERMOMECHANICAL SCOPING CALCULATIONS

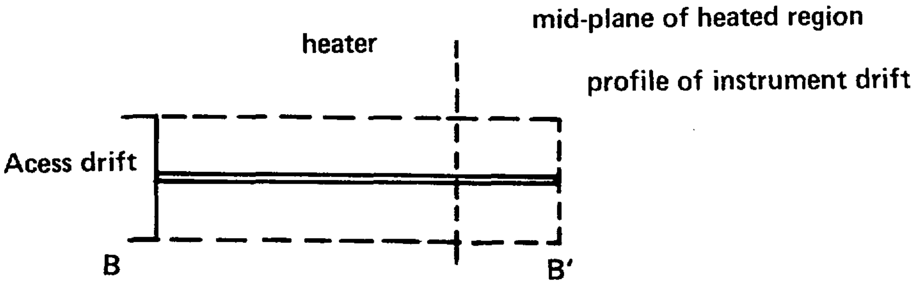
Two thermomechanical calculations were made using the best available thermal and mechanical properties of the rock mass where the test will be conducted. These are shown in Table I. Figure 1 shows the geometry of the problem and Fig. 2 shows the heat input curve used. As can be seen, this geometry would require a three dimensional calculation. However, for scoping



Plan View



Elevation View A-A'



Section View B-B'

Figure 1. Geometry of planned Waste Package Environment Test.

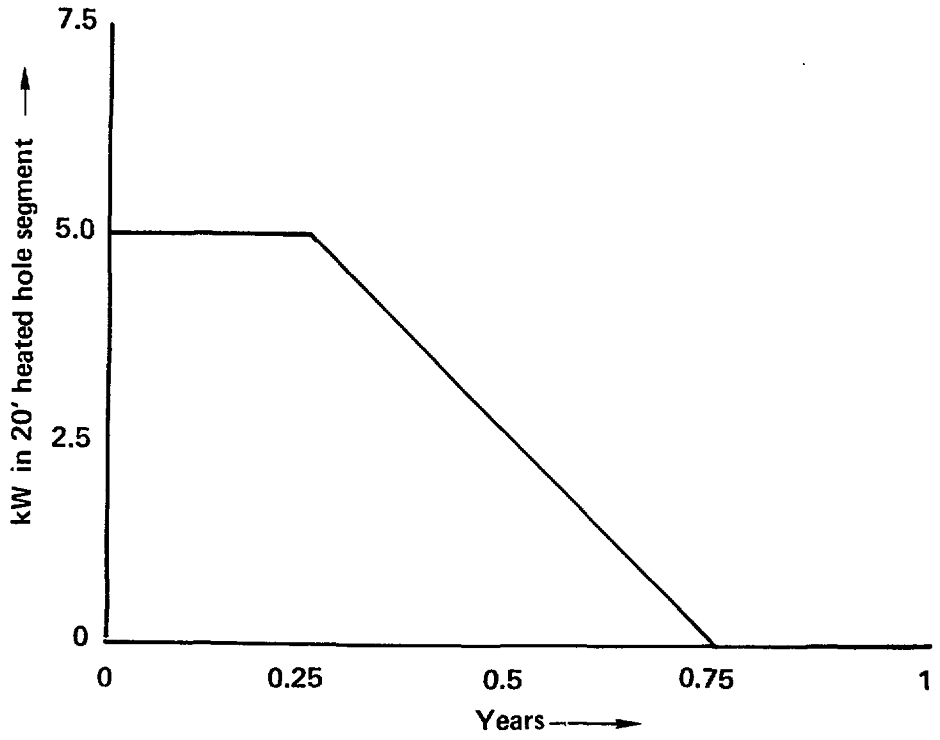


Figure 2. Planned thermal input to Waste Package Environment Test.

purposes it was deemed appropriate to run two 2-D calculations in axial symmetry, one with the instrument drift and the other without.

Two different meshes were constructed, and are shown in Figure 3. The axes of symmetry in both of the meshes run through the heater and are of sufficient dimensions so that the outer boundaries will not influence the heat flow for a period of one year. The meshes represent a cylinder rotated around a line source heater 6.096 m (20 ft.) long, starting at 6.096 m above tne bottom of the mesh which represents the access drift. Grid 1 and Grid 2 are the same except for the 12.192 m (40 ft.) long instrument drift in Grid 2, 6.096 m from the axis of symmetry. The actual effects should be interpreted by comparing the results from both calculations.

ADINAT heat flow calculations were run using the thermal loading curve (Fig. 2). The initial overall nodal point temperatures were taken to be 25°C. Except for the axis of symmetry, all the outer boundary temperatures are fixed at 25°C. Consequently, the boundaries that represent the walls of the access drift and instrument drifts can act as a heat sinks, which is equivalent to ventilation keeping the wall temperatures constant. The other boundaries are too far from the heat source to matter in the time of interest. The calculations were to one year in 52-one week time steps.

An ADINA thermomechanical calculation was made on each of the meshes. The thermal histories for each node calculated with the ADINAT code drove the thermomechanical calculations. The boundary loading assumed a lithostatic overburden stress on the outer boundaries of the meshes of 8.4 MPa.

The results of the calculations are presented graphically. Vector displacements, and temperature, horizontal stress and vertical stress contour plots are shown for 4 , 12, 24, and 52 weeks into the test. Figures 4a-d show the temperature contours at these times respectively for each mesh plotted side by side. Two sets of values are shown. The contour furthest from the axis of symmetry is 26°, followed by 27°, 28°, 29° and 30°C. Working inward from 30° is 35°, 40°, 45°, 50°, 55°, and 60°C. Another way to describe this is that the contour labeled "a" is either 26° or 30°, "b" being either 27° or 35°C, and so on, the outer contour at the lower temperature.

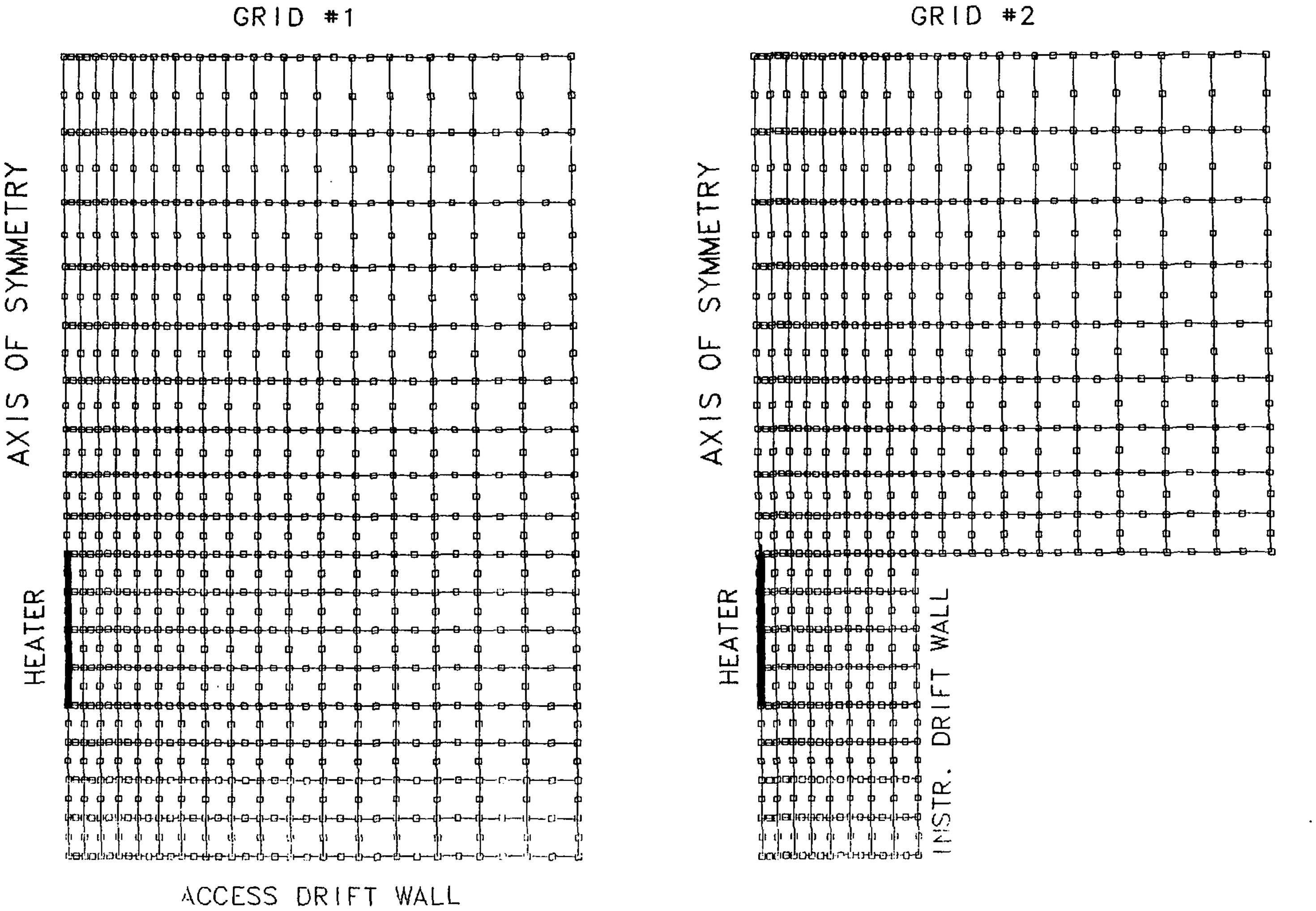


Figure 3. Finite element grids used in thermomechanical calculations.

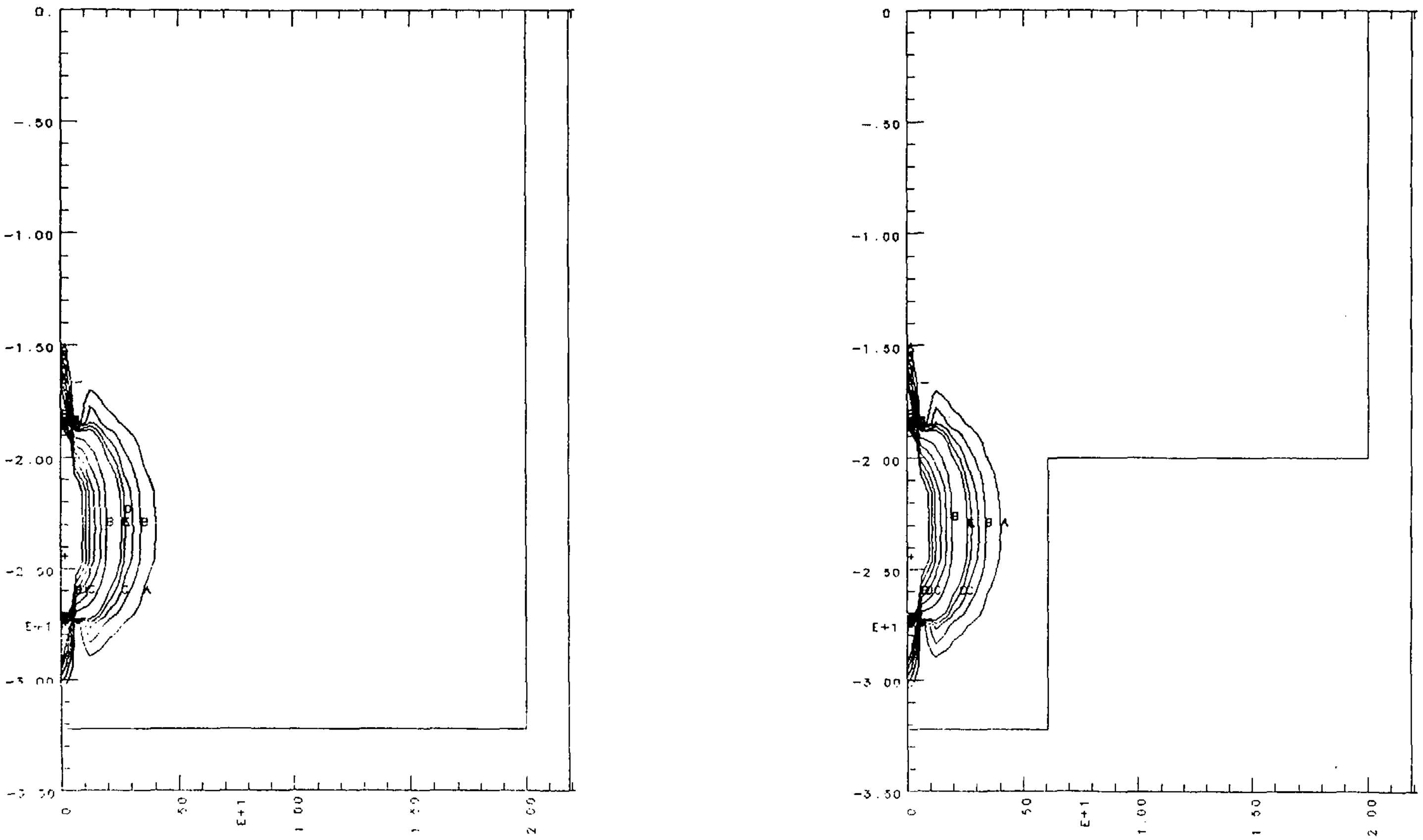


Figure 4A. Temperature contours at 4 weeks into test.

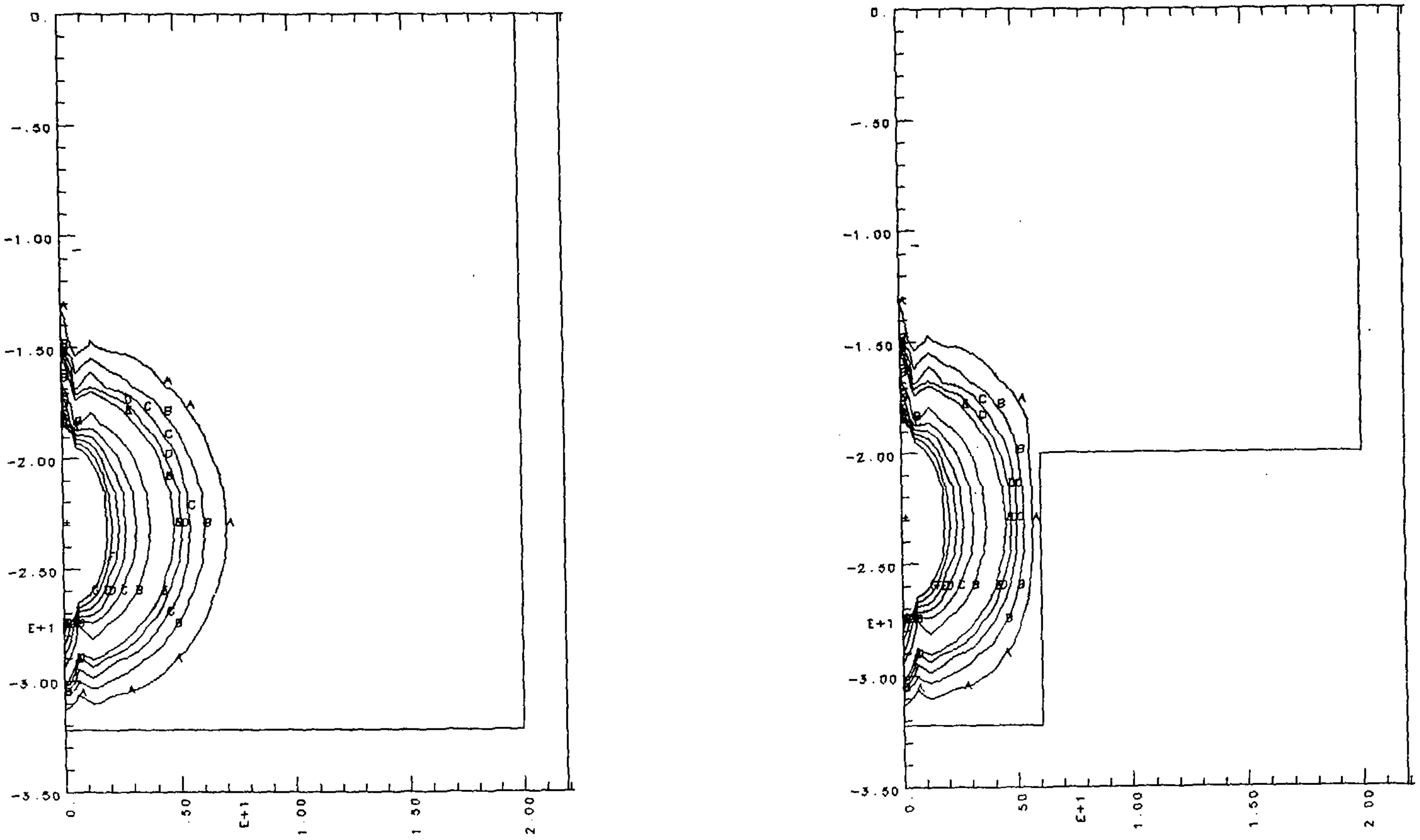


Figure 4B. Temperature contours at 12 weeks into test.

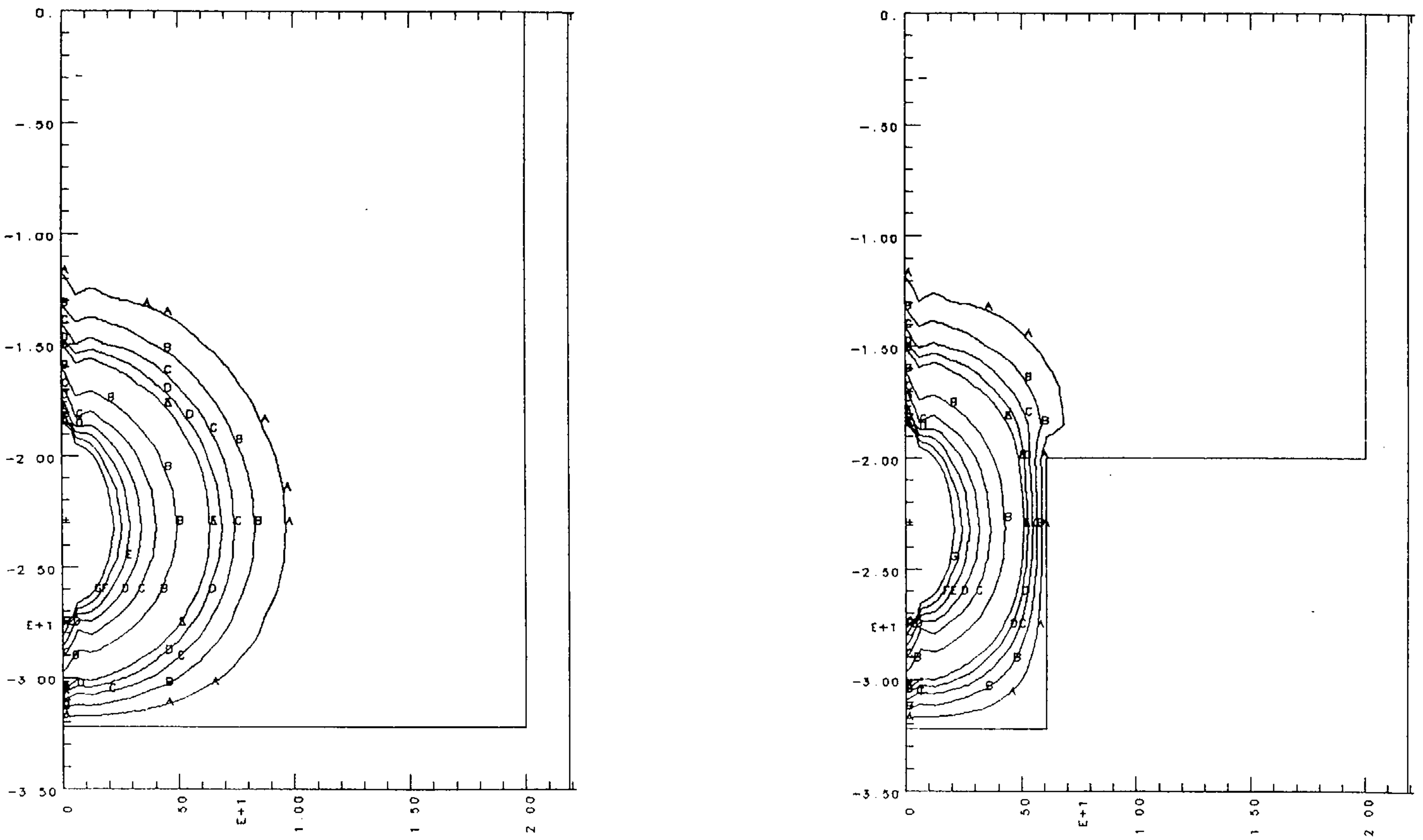


Figure 4C. Temperature contours at 24 weeks into test.

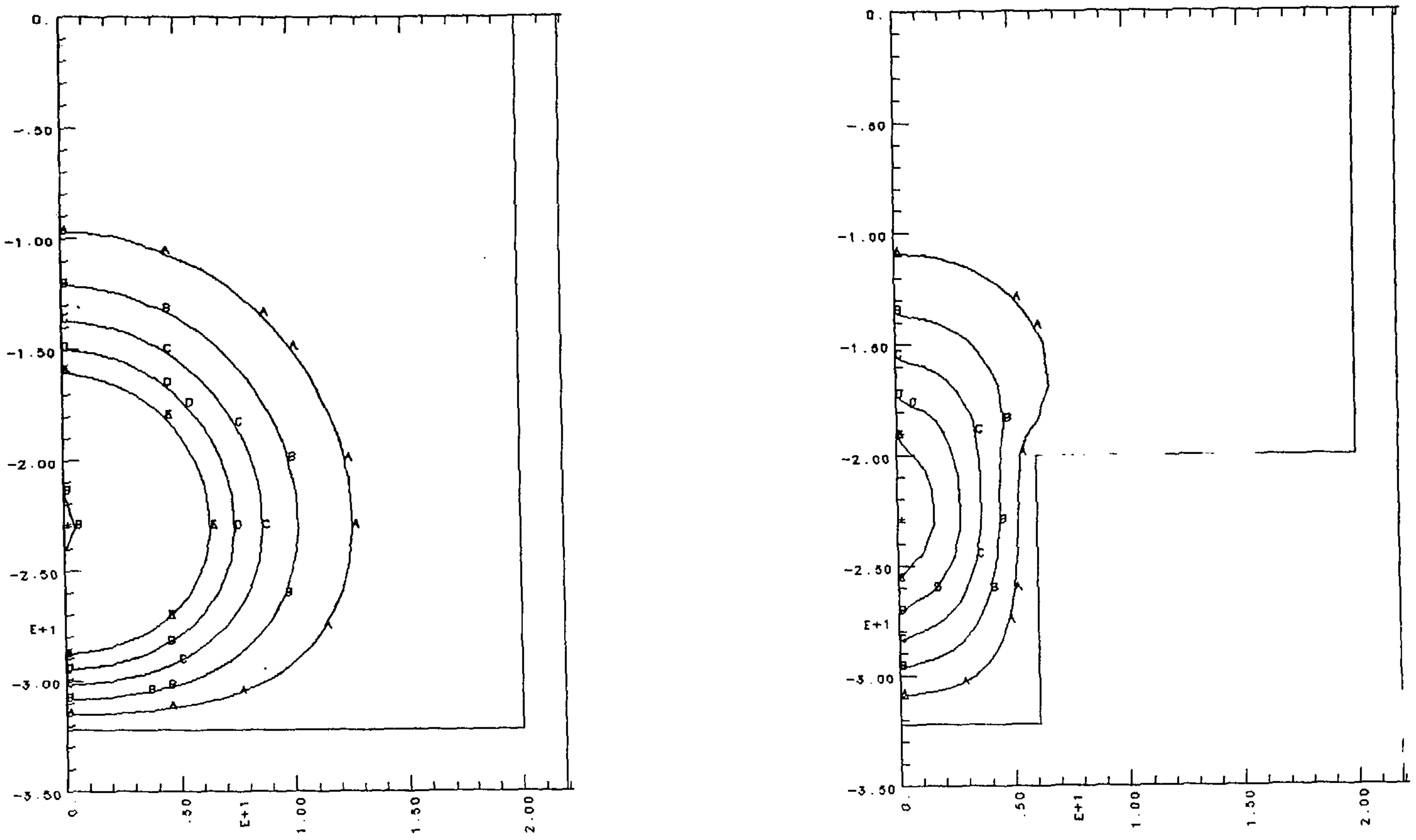


Figure 4D. Temperature contours at 52 weeks into test.

Figures 5a-d show the corresponding displacement vectors. The scale values are in metres, so that a vector with a length corresponding to the length labeled ".001" is a displacement of one millimeter in the direction shown.

Figures 6a-d show the horizontal stress contours. The scale on the right of the figures is in Pascals, so that the stress contours labeled a through f are for 10^6 through 10^7 Pascals. The negative sign denotes compression. Figures 7a-d show the vertical stress contours for the same times. The scale is the same as for the horizontal stress contours shown in Figure 6a-d.

At four weeks, the 5000 Watt heater has been at full power for 4 weeks. Temperature increases of at least 1°C have not yet occured 20 feet away at the access drift or instrument drift walls, although motion of the walls can be sensed due to the thermal expansion of the heated rock around the heater. Both the horizontal and vertical stresses have increased to over 10 MPa immediately around the heater, with the stresses equal to overburden or less everywhere else.

At 12 weeks into the test, the heater has been operating at a constant 5000 Watts for the entire period. The thermal wave has intercepted the instrument drift wall, but has not yet reached the access drift wall. Therefore, about this time, heat is starting to be removed from the calculation where the instrument drift is modeled. Maximum nodal point displacements are approximately one millimeter. The horizontal and vertical stresses have not changed appreciably, except around the regions of the high temperature increase.

The heater is turned down linearly from 5000 Watts to 0 between 13 and 39 weeks into the test. Therefore, at 24 weeks the heater output is about half of the starting value of 5000 Watts. Both the access and instrument drift boundaries have sensed a temperature increase, and are now acting as heat sinks in both calculations. The displacements have increased somewhat since the 12 week plots, although the changes are small compared to the earlier displacements. This is similar to what was observed and calculated during the heating phase of the SPENT FUEL TEST-CLIMAX (Butkovich and Patrick, 1985), where most of the motion occured in the first few weeks of the test. Both the horizontal and vertical stress changes during the period between 12 and 24 weeks appear to be minimal.

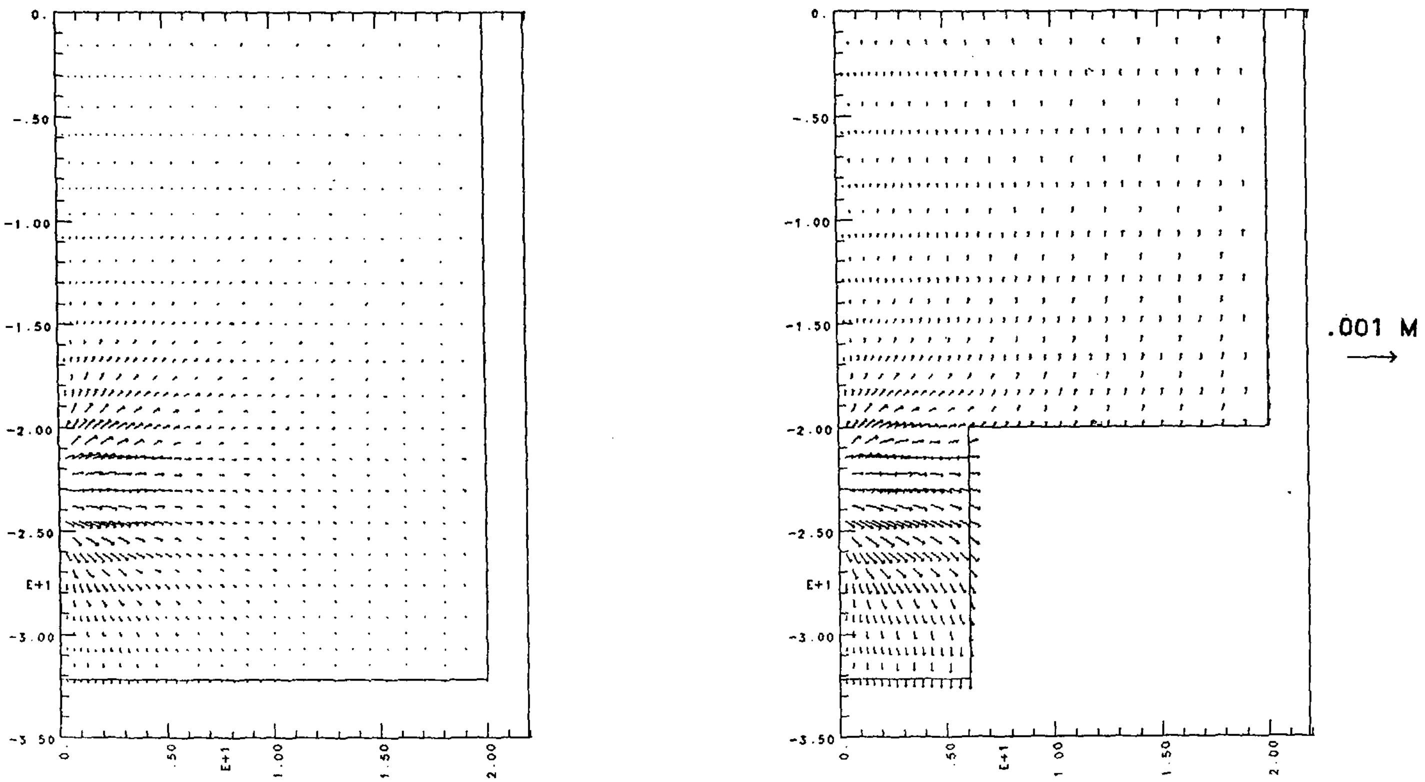


Figure 5A. Displacement vectors at 4 weeks into test.

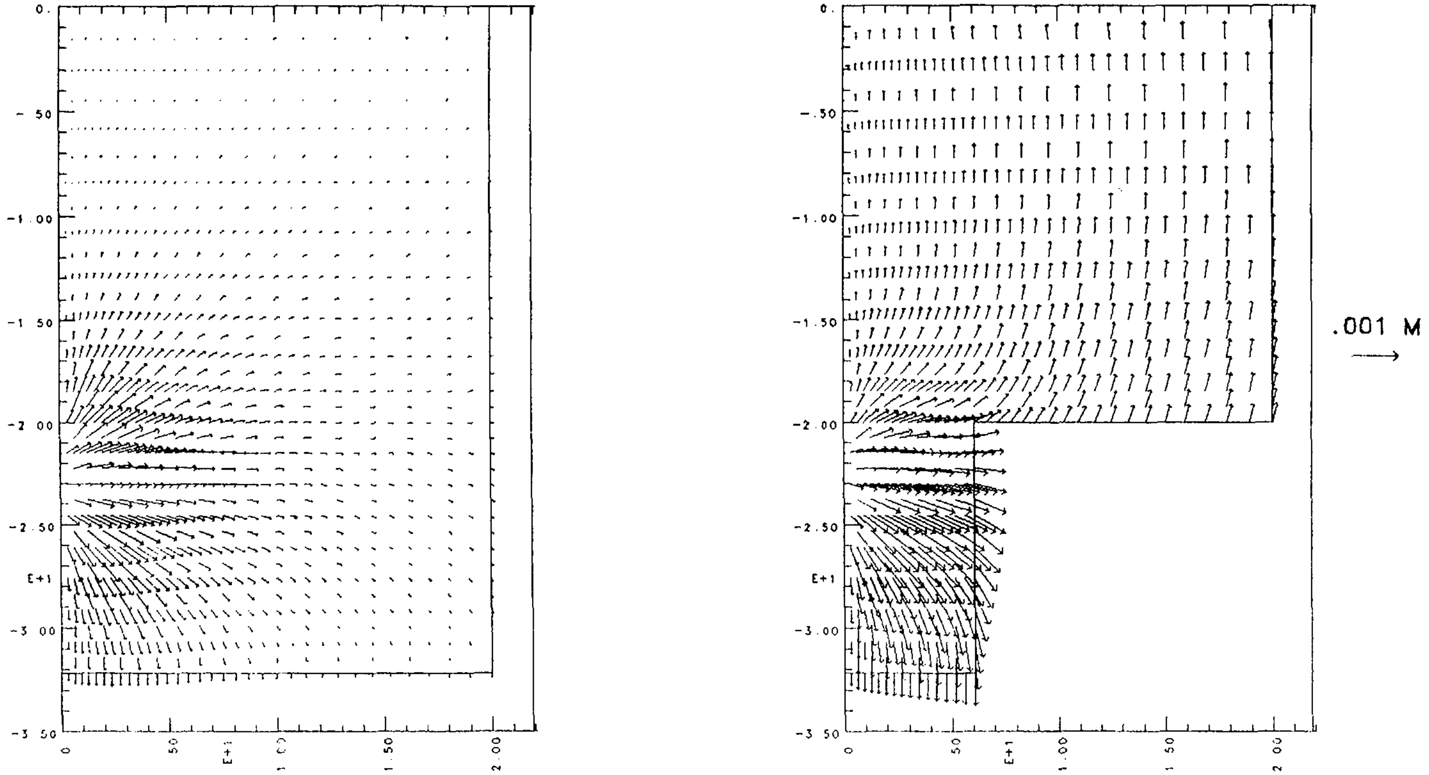


Figure 5B. Displacement vectors at 12 weeks into test.

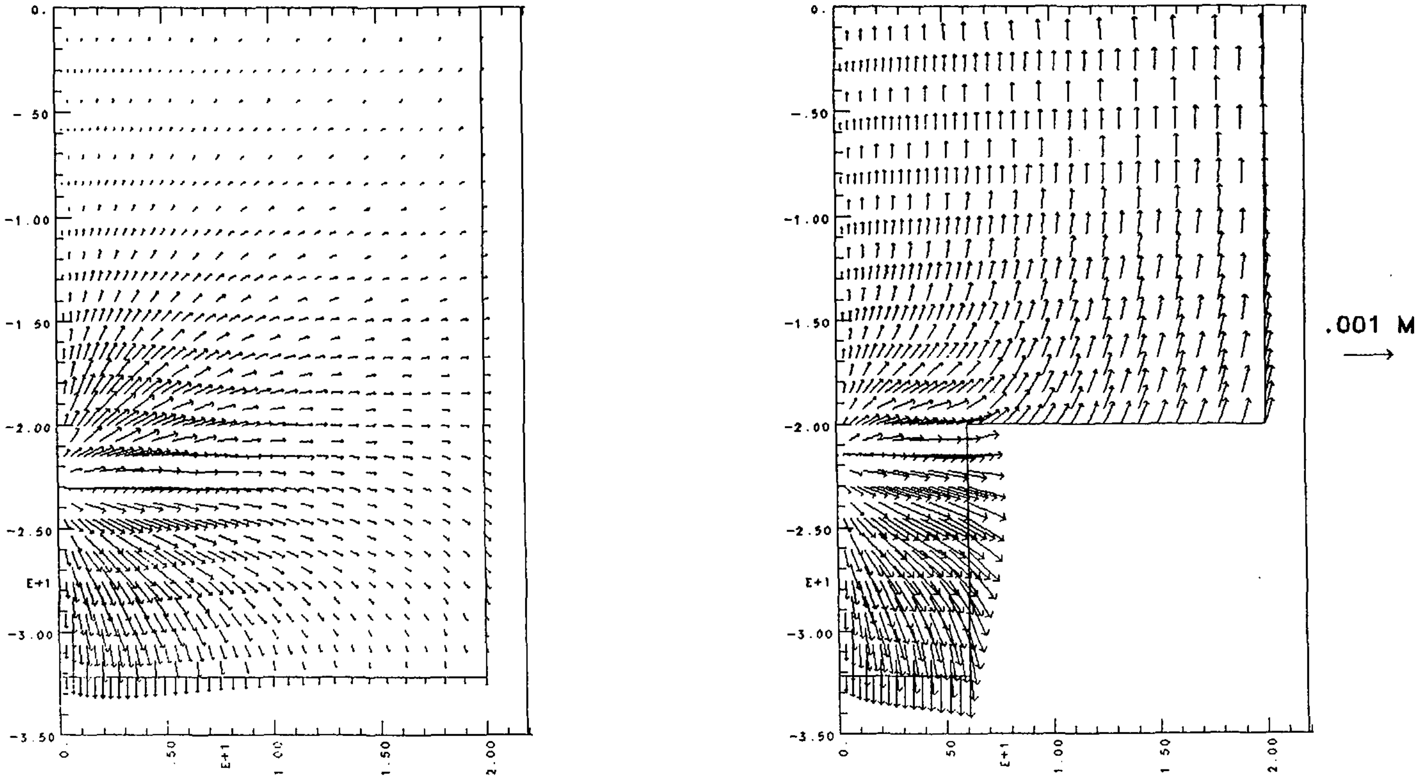


Figure 5C. Displacement vectors at 24 weeks into test.

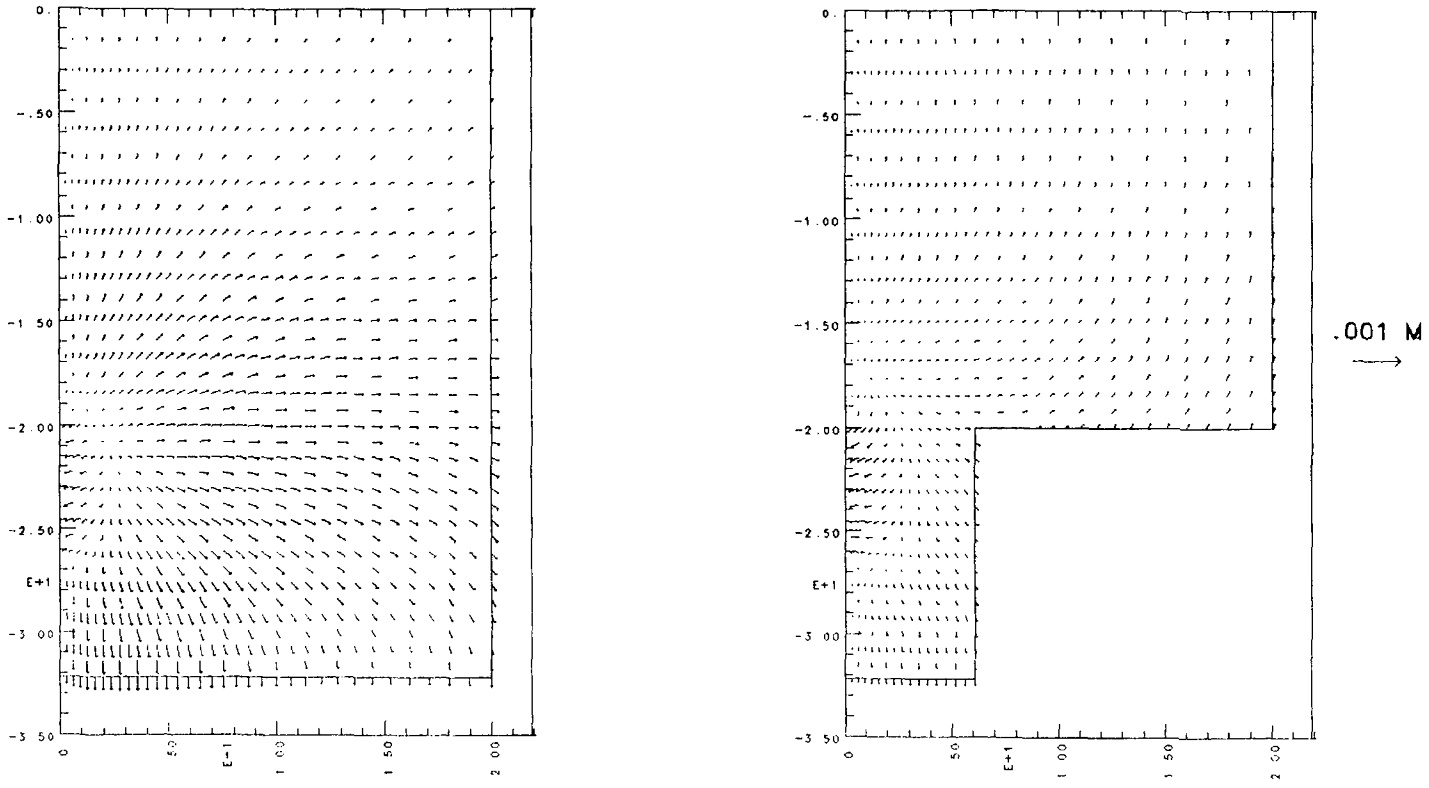


Figure 5D. Displacement vectors at 52 weeks into test.

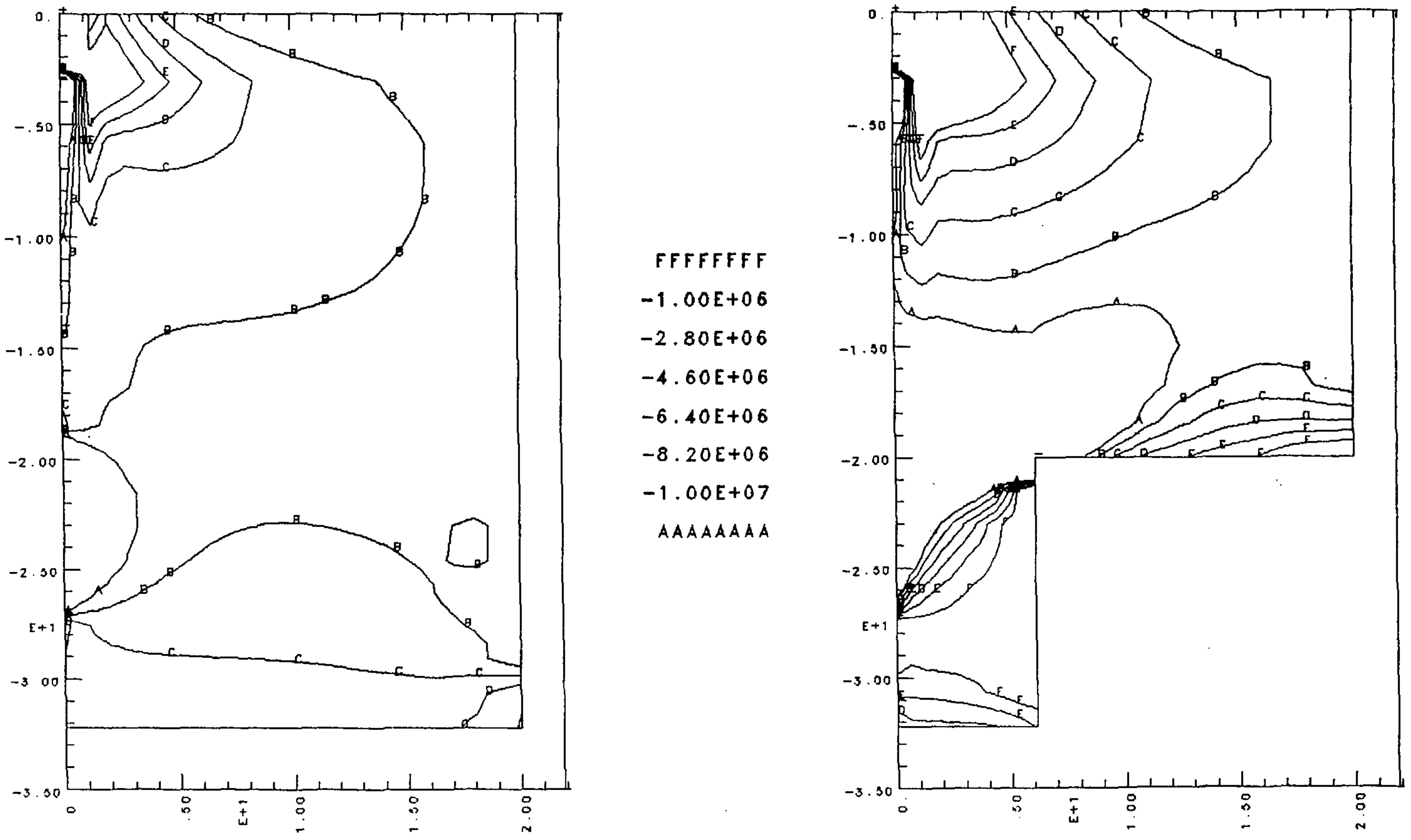


Figure 6A. Horizontal stress contours at 4 weeks into test.

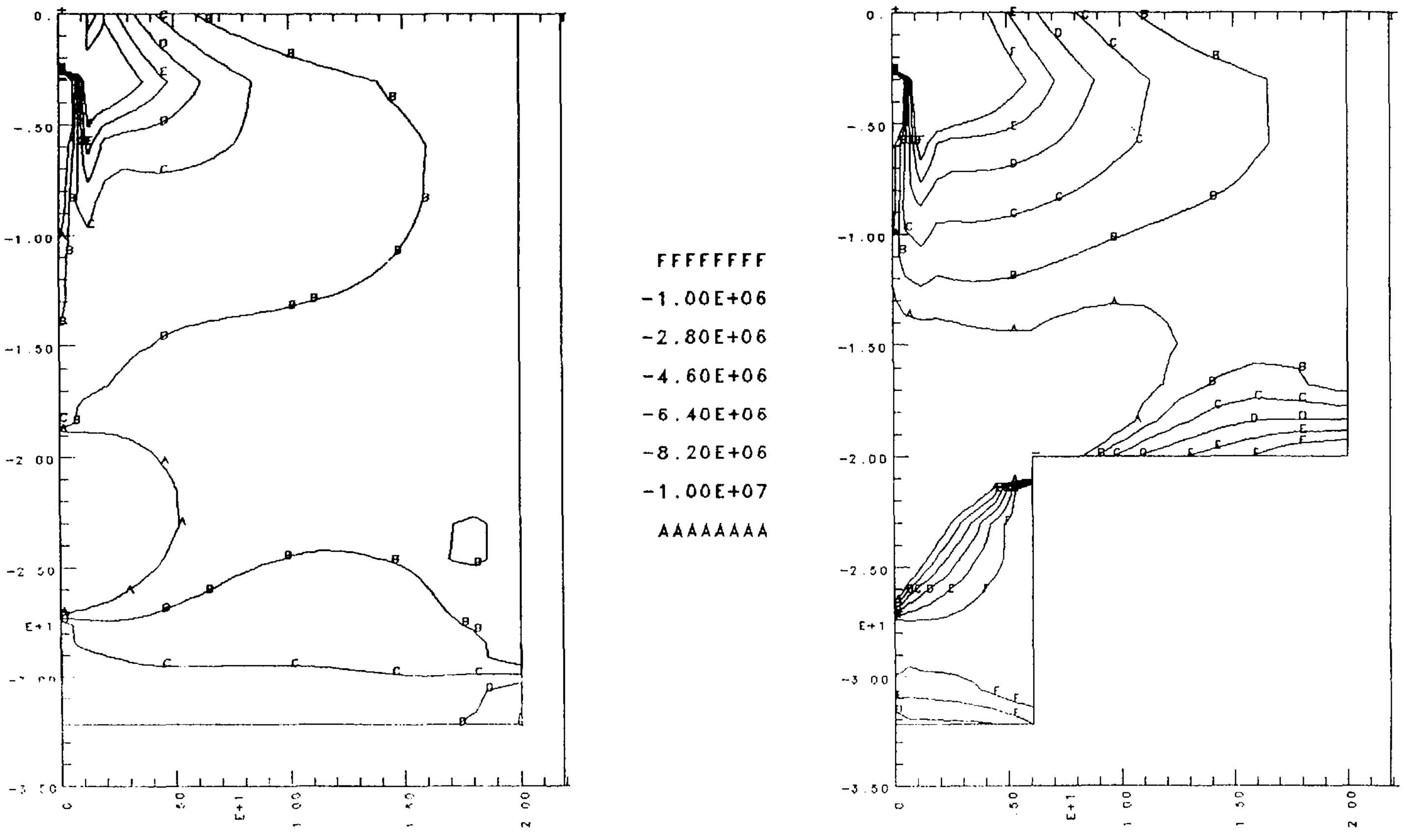


Figure 6B. Horizontal stress contours at 12 weeks into test.

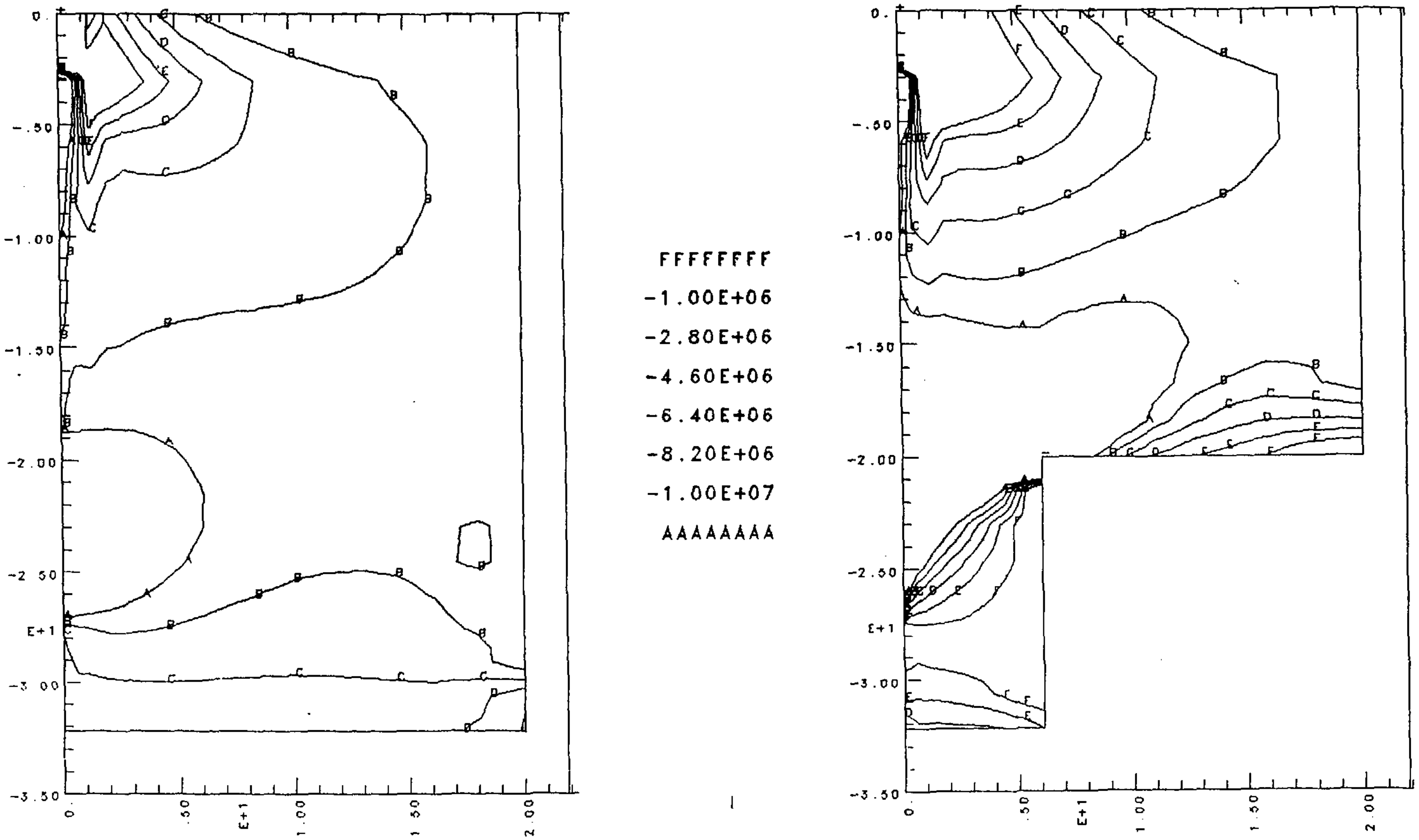


Figure 6C. Horizontal stress contours at 24 weeks into test.

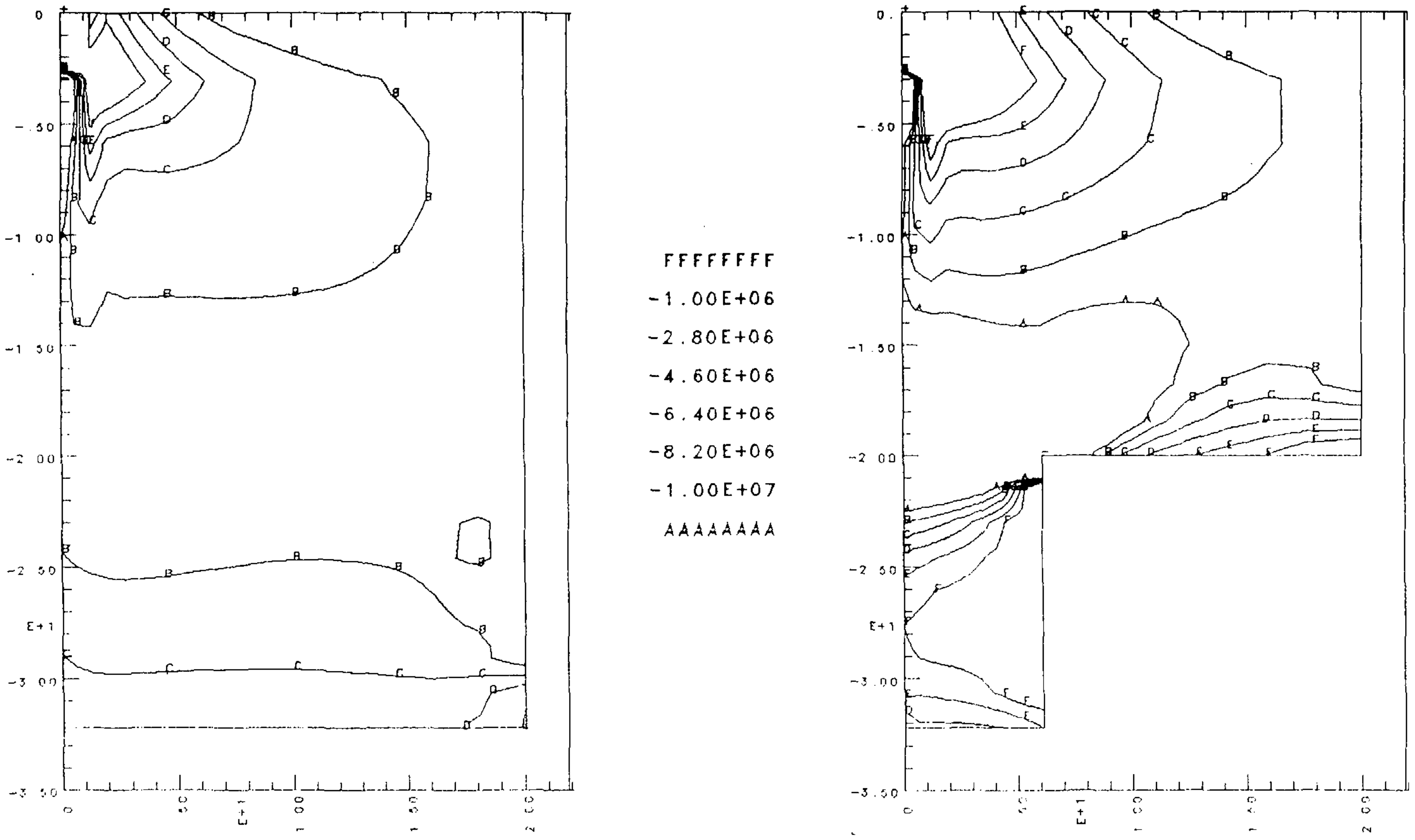


Figure 6D. Horizontal stress contours at 52 weeks into test.

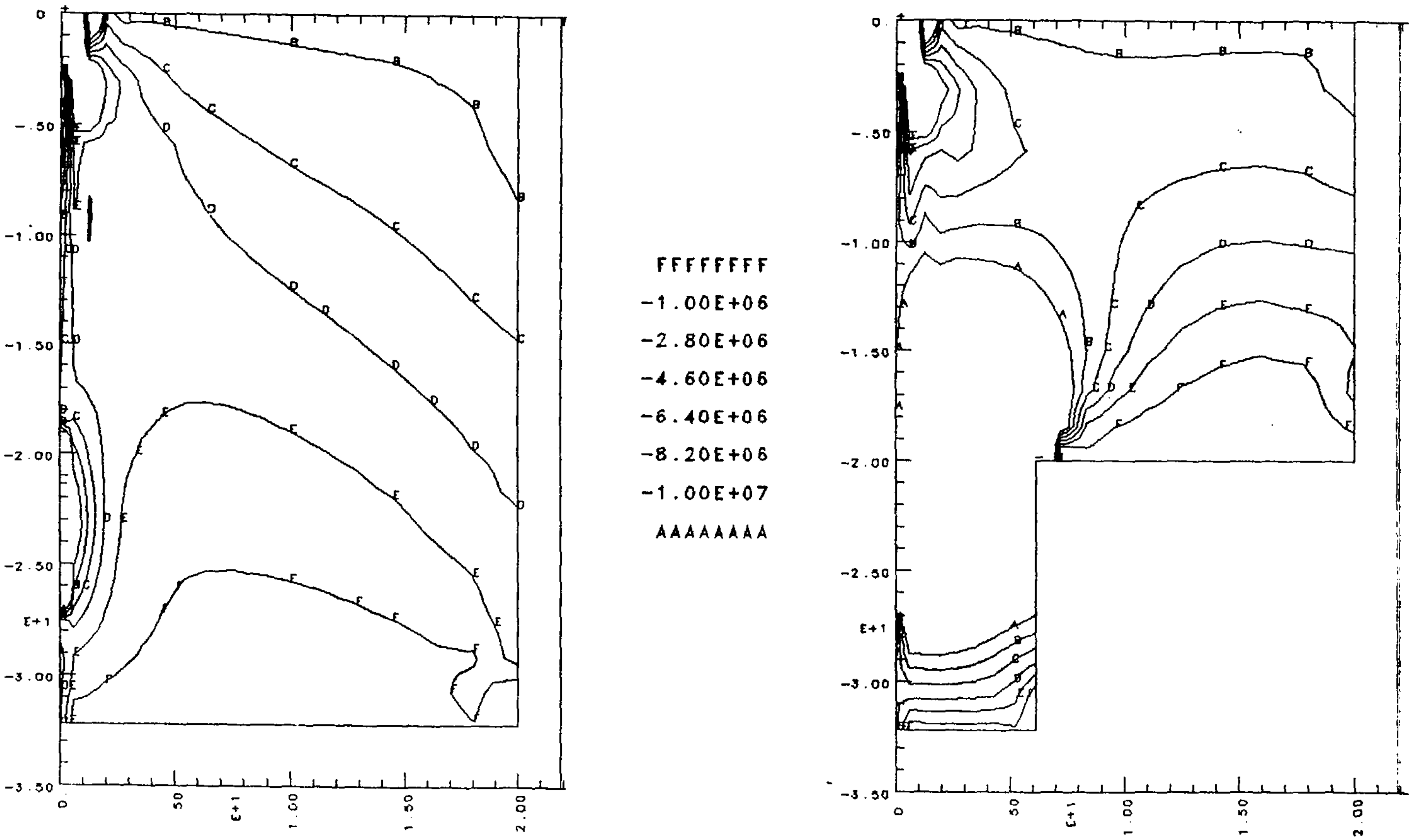


Figure 7A. Vertical stress contours at 4 weeks into test.

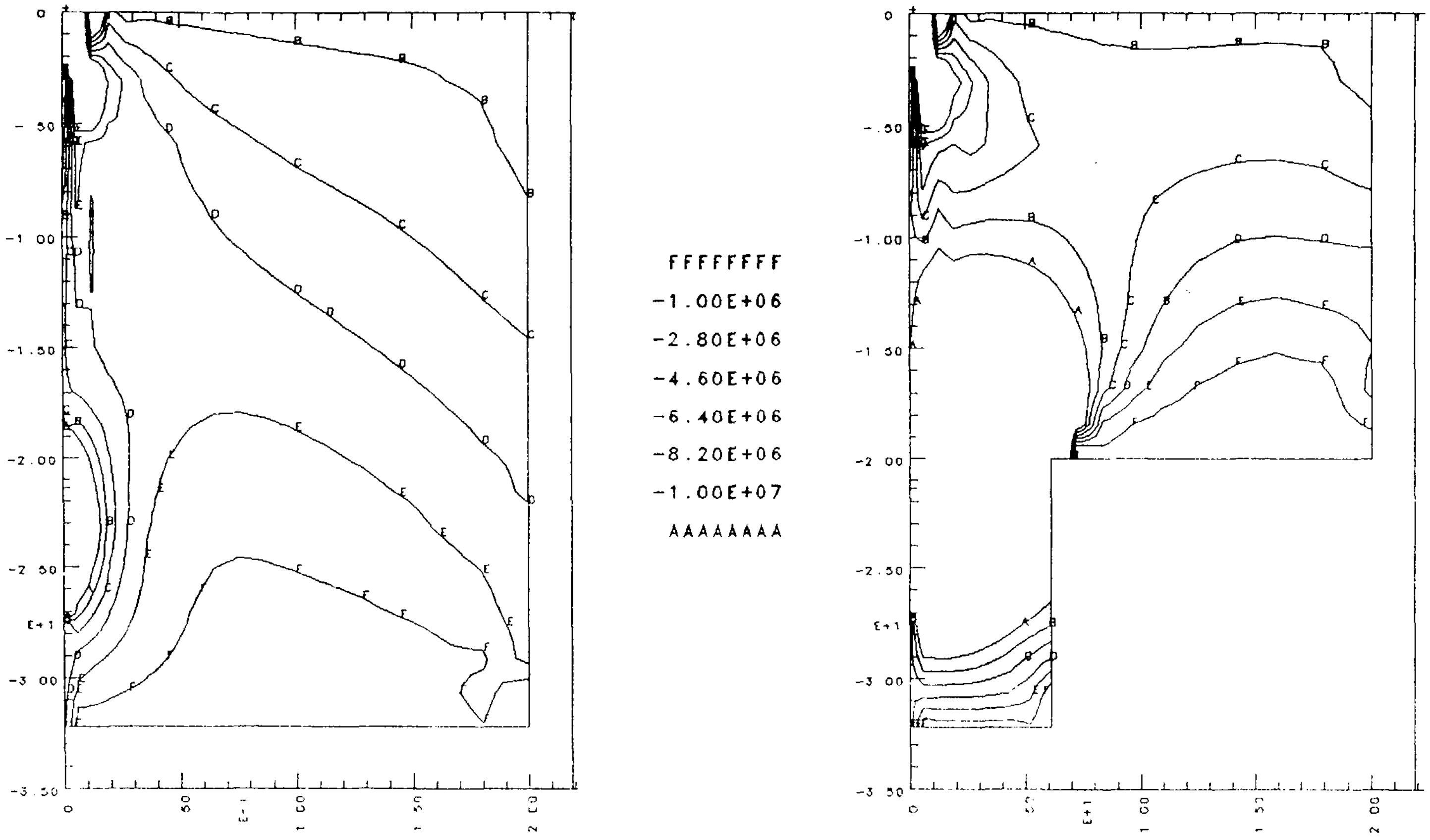


Figure 7B. Vertical stress contours at 12 weeks into test.

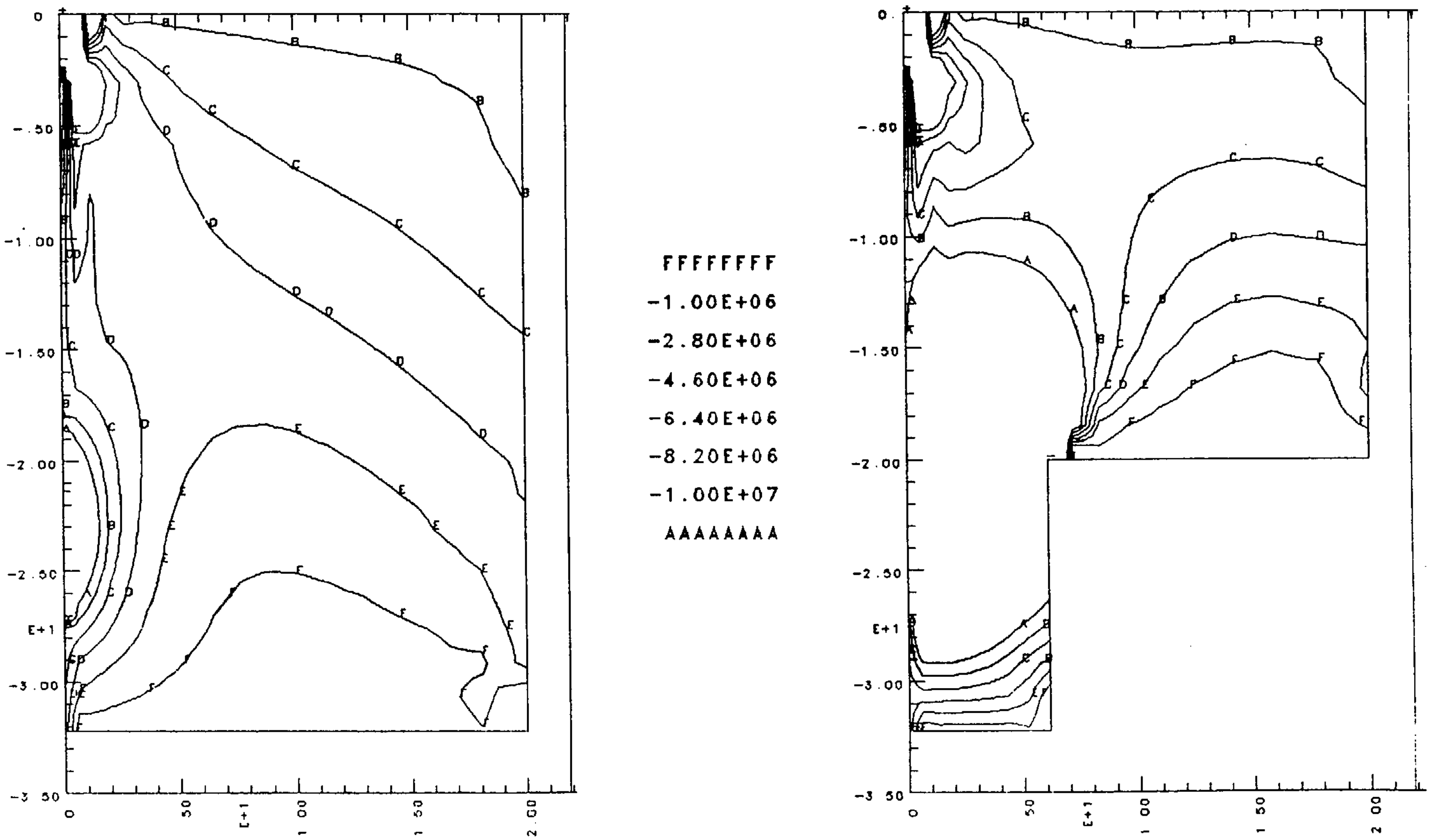


Figure 7C. Vertical stress contours at 24 weeks into test.

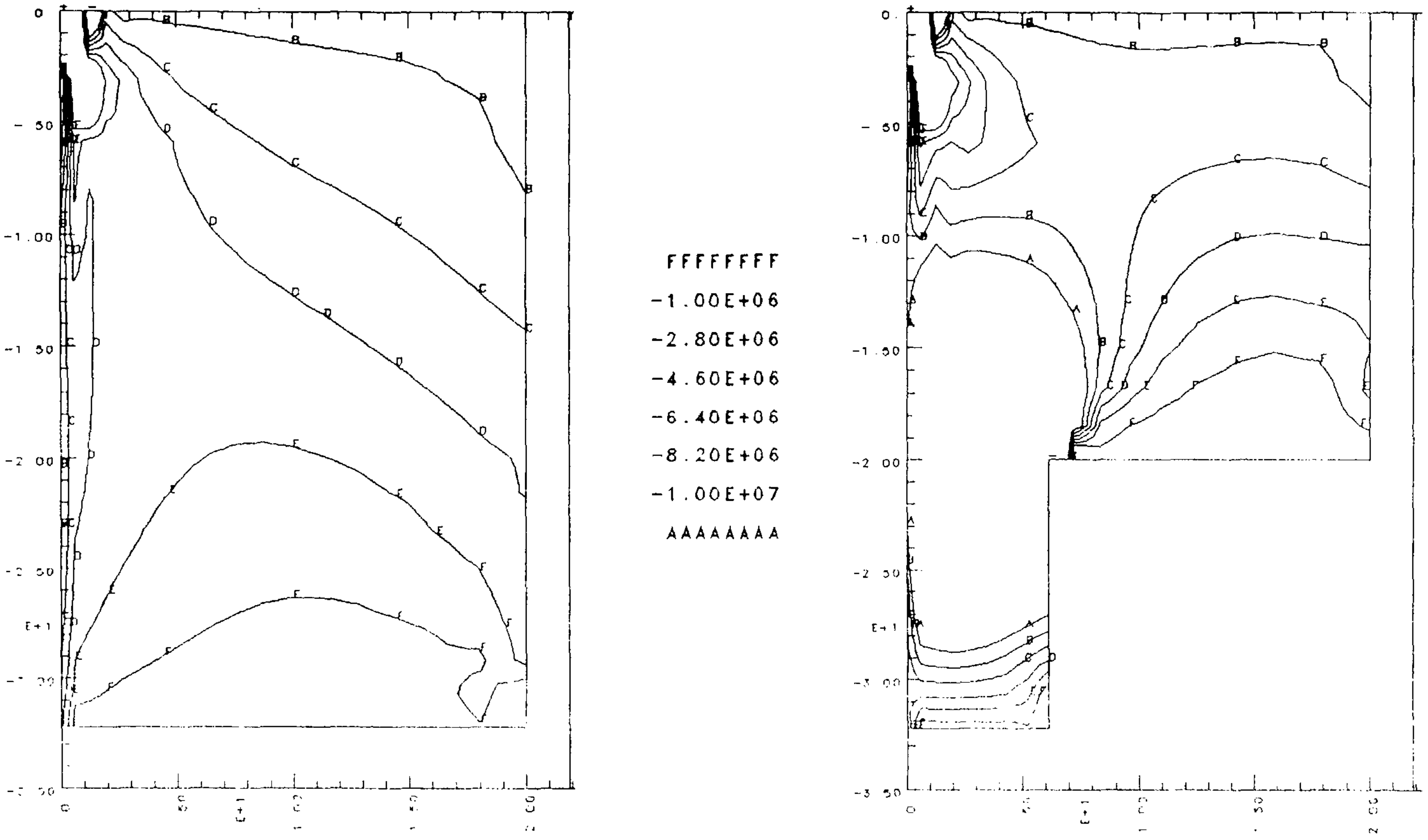


Figure 7D. Vertical stress contours at 52 weeks into test.

At 39 weeks into the test, the heater has been cycled down for a half year. By 52 weeks, most of the heat input during the heating phase has been removed by ventilation, that is, by keeping temperature of the walls of the access and instrument drifts constant. At this time the displacements and the horizontal and vertical stresses have returned to early time values, when the heat was first turned on.

Figures 8a and 8b show the calculated average elemental horizontal and vertical compressive stress as a function of distance from the heater mid points at 4, 12, 24, and 52 weeks into the test for the calculation with the full grid. These show both stresses increasing during the time the heater is turned off at 26 weeks, returning to near pre-heat stresses at 52 weeks.

Figures 9a and 9b show similar results for the calculation with the instrument drift included. It should be noted that in this calculation the horizontal stress on the instrument drift wall is zero, while the full mesh calculation has the overburden stress imposed on its outer vertical boundary.

SUMMARY AND CONCLUSIONS

Stress changes around the excavations planned for the Waste Storage Investigation Project were calculated for an assumed thermal cycle where 5 kW of heat are input over a 20 ft length during the first quarter of the year long test. The heat input was linearly down-cycled to zero during the next 0.5 years. Since the drift walls will be ventilated, heat will start to be removed once the thermal pulse intersects the drift walls. Continual ventilation occurs during the entire year of the test.

The largest stress changes with grid #1 occur at the heater hole wall, rising from 8.4 MPa to over 25 MPa horizontal stress, and from about 5 MPa to 23 MPa vertical stress for the full grid, and decrease asymptotically away from the heater hole wall. Most of the stress changes occurs within the first two metres from this position during the early part of the heat input. For the calculation with the instrument drift wall (grid #2) the magnitude of the changes are similar, except that the vertical stresses at the end of the test are somewhat higher.

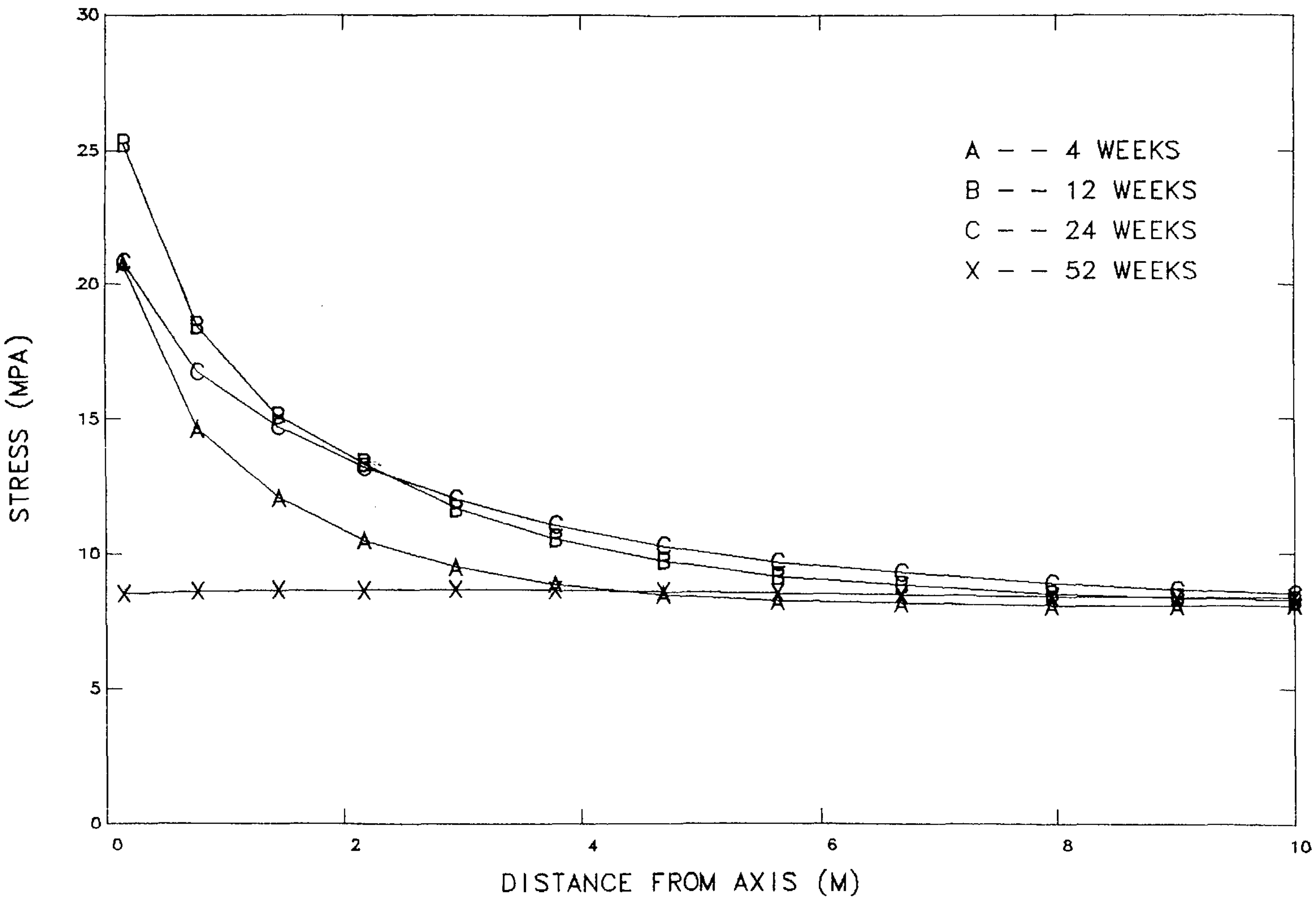


Figure 8A. Horizontal stress vs distance from heater midpoint for full grid (#1).

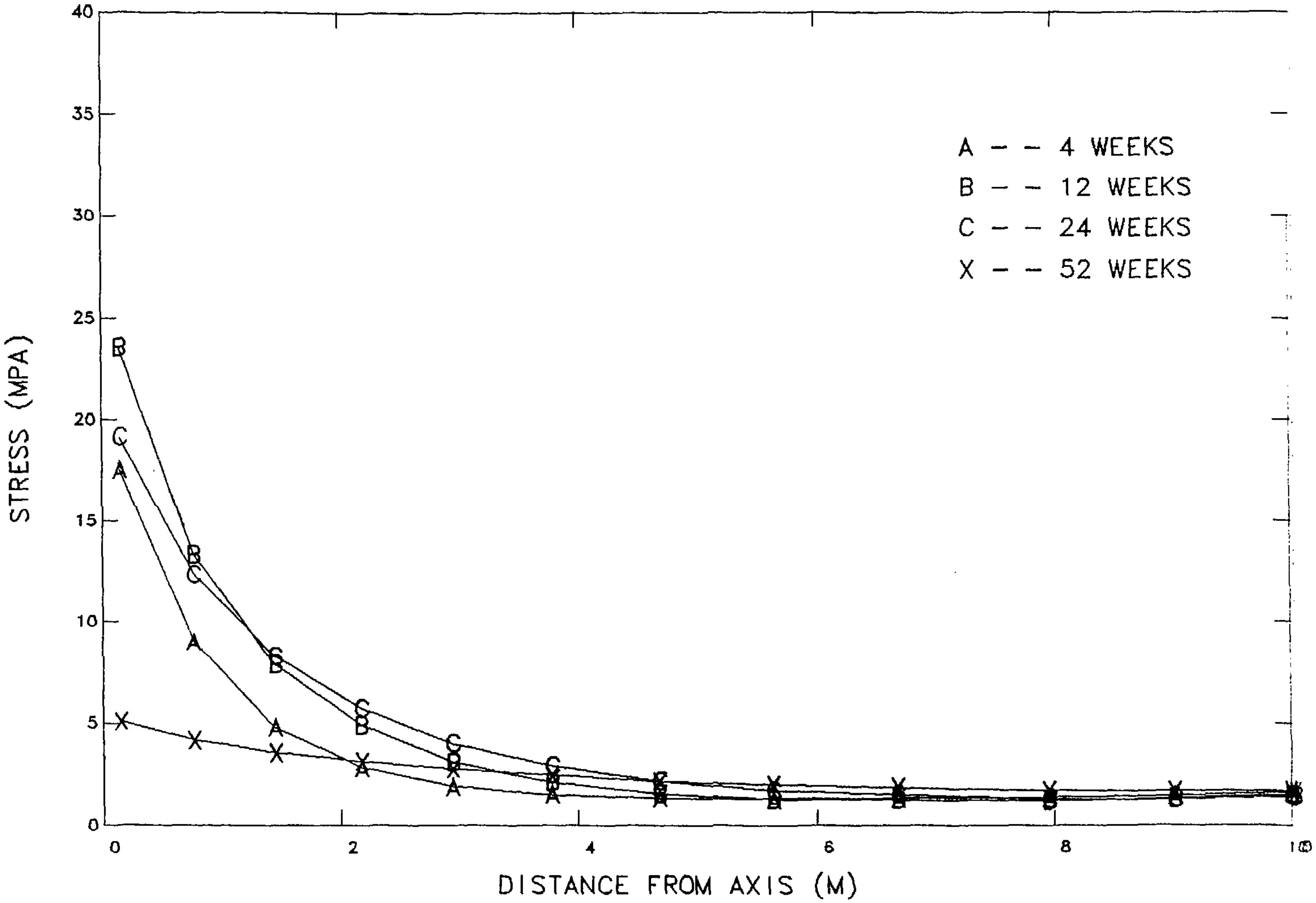


Figure 8B. Vertical stress vs distance from heater midpoint for full grid (#1).

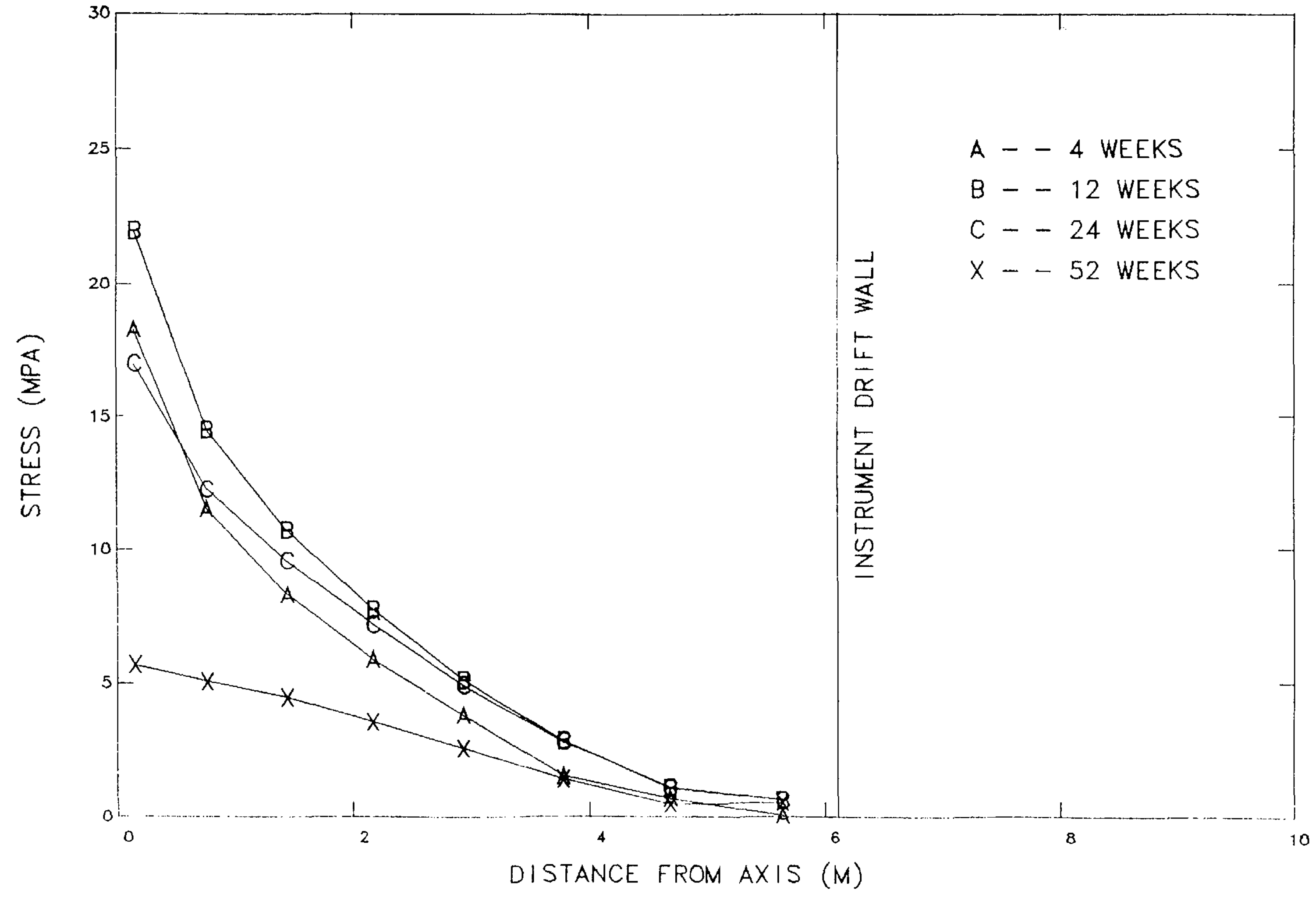


Figure 9A. Horizontal stress vs distance from heater midpoint for calculation with instrument drift.

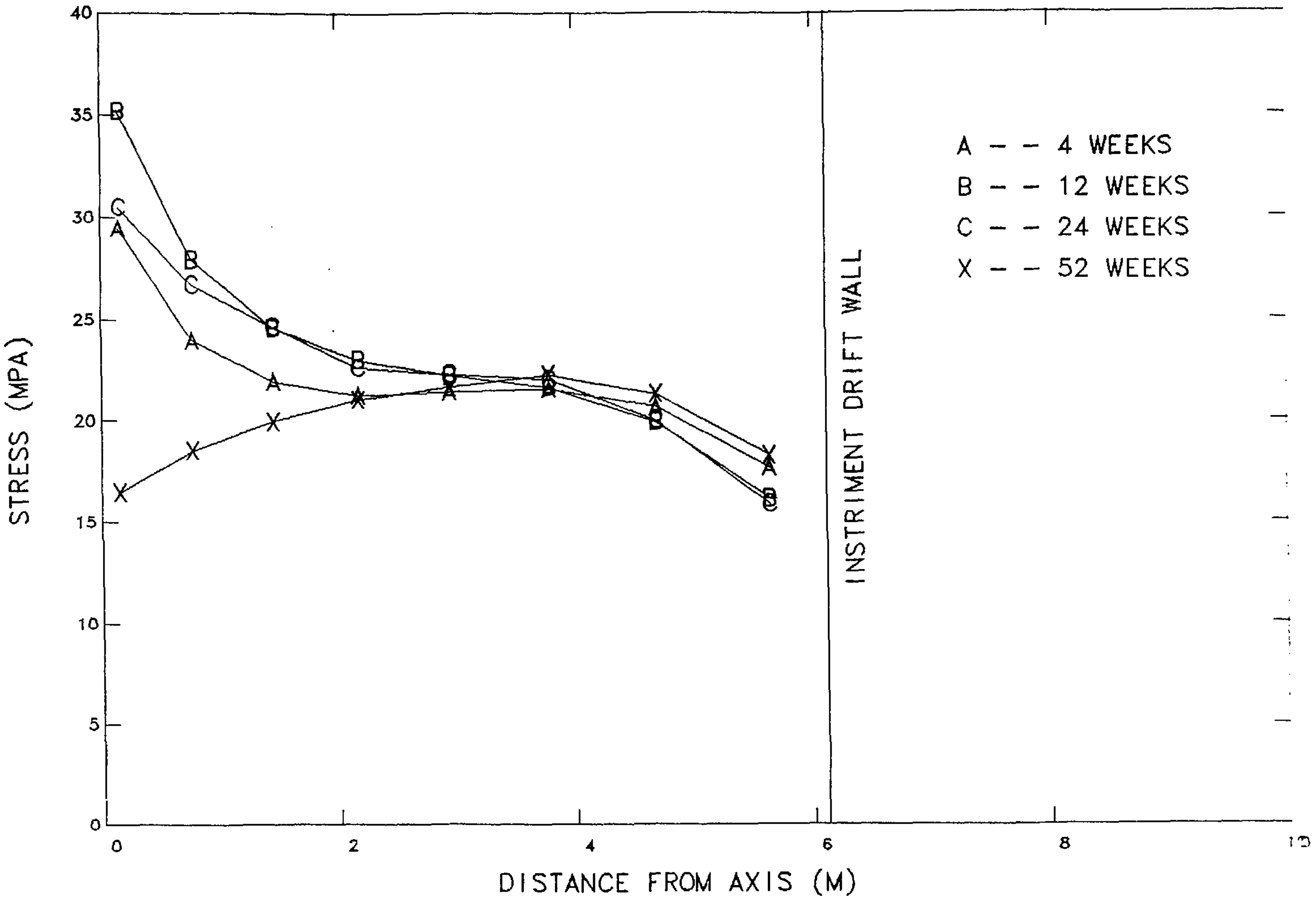


Figure 9B. Vertical stress vs distance from heater midpoint for calculation with instrument drift.

The maximum stress increase of approximately 20 MPa occur at the heater hole wall at the time the temperature just begins to cycle down. Two-thirds of the stress change that occurs is during the first 4 weeks of the test.

These initial calculations will be refined as details of the test plans are developed; test plan development in turn is guided by calculations such as these. Based on these calculational results, it is concluded then that instruments used to monitor stress changes in the near field must possess a working range of at least 10 to 15 MPa, and must be able to withstand the rigors of a high temperature hydrothermal environment. The displacement gauges must be able to accommodate on the order of one to two millimeters of displacement, and must have an accuracy to measure much smaller changes.

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